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Editors: S. Galal, J. Boyazoglu and K. Hammond

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Cover page: 17th century engraving by Pieter Jacobsz van Laer of Haarlem, dit Bamboccio, (1599-1642), representing a livestock farm in the Latium region of Italy

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Developing breeding Strategies for Lower Input Animal Production Environments

Editors: S. Galal, J. Boyazoglu & K. Hammond

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Preface

The theme of this Workshop was Developing Breeding Strategies for Lower Input Animal Production Environments, with the objectives to:

1. Consider the 'seminal documents', case studies and other experiences to understand the need for and sustained development of straight- and cross-breeding strategies, for lower input production environments and the main farm animal species, and to draw lessons from a range of successes and failures; and

2. Draw conclusions and develop an integrated set of recommendations for the successful design, implementation and maintenance of animal genetic improvement activities in lower input production systems, emphasizing the <u>policy</u>, <u>technical</u> and <u>operational</u> needs of <u>developing countries</u>.

These conclusions/recommendations are included in the Summary of Workshop Outcome section of these Proceedings.

The Workshop was conducted in a highly structured manner. The meeting was operated by a Workshop Facilitator, Dr Maurice Bichard. There was no presentation of papers at the Workshop. The participants split into working groups. These working groups had each a pre-briefed Leader. The composition of the groups was:

<u>Leaders</u>: Leo Dempfle; **Fernando Madalena**; **Brian Wickham**

<u>Members:</u>

Birgitta Danell	Jumaliev Akylbek	Ahmed Abdelaziz
M'naouar Djemali	Robert Banks	John Gibson
Andreas Georgoudis	El Mostafa Darfaoui	Ab. Groen
Euclides Kepler	Mamadu Diop	Steven Lukefahr
Andreas Mavrogenis	Hans Graser	Gerhard Nitter
Anna Sonesson	Hans Askov Jensen	Jan Philipsson
Andrea Rosati	Theo Meuwissen	Hardi Prasetyo
Kamlesh Trivedi	Jean-Claude Mocquot	Jaime Rodrigañes
John Woolliams	Chanda Nimbkar	Derick Swart
ChiaYapi-Gnoare	Fritz Schneider	N.R. Unnithan

ICAR and FAO staff, Jean Boyazoglu, Salah Galal and Keith Hammond participated in different group sessions without staying with a specific one all the time.

The Workshop theme was divided into a number of topics, which were sequentially treated by Working Group Sessions and a Plenary Session. A separate Rapporteur for each Session by each Working Group enabled quality reporting with drafted documentation presentation at each Plenary Session and the Session Report drafted by the Rapporteurs immediately thereafter.

Workshop participants made use of the substantial working documentation, that is all, included in these Proceedings. This included introductory material, seminal documents and case studies. Seminal papers have been pre-prepared for key areas of breeding strategy development. The authors were requested to emphasize the need for this documentation to support a range of decision-makers in livestock development by assisting them to understand what policy, technical and operational steps are required for sustained breed utilization for food and agriculture production. The broad set of case studies focuses intensely on the experiences of people who have designed, implemented and maintained breeding programmes of various types for a range of species in different production systems and livestock policy frameworks in different regions of the world. The authors of the case studies were asked to follow a set of terms of reference so that the information they provide is focussed and can be easily extracted from their documents. These terms of reference are included at the beginning of the case study section in these Proceedings.

This by-and-large unique seminal and case study documentation plus the knowledge and experience of participants, together with their contributions during the meeting facilitated substantial and quite distinct interactions among participants.

The Workshop focussed on the strategic development within livestock production systems of sustainable genetic improvement between and within breeds, i.e. how to develop and maintain in operation breeding strategies in the (major) production environments for all important farm avian and mammalian species. This covered the establishment of livestock development objectives and breeding goals, choice and sampling of breed populations, decisions on types of breeding programmes to be used, the development of selection programmes within breeds as well as the development and maintenance of livestock development activities dealing with two or more breeds (the array of cross-breeding programmes, including the gene pool formative stages of synthetic or composite development). It also included the structural aspects of the breeding strategy, which must also provide for the dissemination of genetic improvement throughout the livestock sector. Finally, it included the economic evaluation of breeding programmes both for the pre-implementation design and in evaluating the change being realized in breeding programmes underway. A further component of the breeding strategy, the development, use and maintenance of the animal level genetic evaluation systems, will be primarily treated in future work planned by FAO and ICAR for the year 2001. A previous FAO/ICAR workshop

(Anand, India, 1997) dealt with animal recording for production system improvement by both genetic and environmental means.

Whilst the broad bases governing the development of animal breeding strategies are similar in different production systems, more emphasis was placed on the range of medium input and, to the extent possible, low input production systems; these together comprising the so-called lower input production environments. Particular emphasis was given to that major sector of the world where the needs for assistance are greatest, the developing country sector.

Terminology that was encountered during the Workshop discussions is added as Appendix 1. Please note particularly the definition for "lower input production environment". These definitions were developed mainly by the Informal Panel of Experts on Development of the FAO Global Strategy of the Management of Farm Animal Genetic Resources.

FAO is further utilizing this Workshop as one of the important steps required to develop guidelines or decision-aids for countries to use in the development, implementation and maintenance of effective breeding programmes. These guidelines and the Workshop Proceedings will be complementary in assisting country technicians and policy makers to upgrade the sustainable intensification of their livestock production sectors. The guidelines will subsequently be integrated with system guidelines for the development of animal recording and genetic evaluation operations, and with guidelines for other essential elements for the successful management by countries of their farm animal genetic resources.

The Workshop was attended by 34 participants from 22 countries, beside ICAR and FAO staff. They were scientists, research workers, developers and practitioners in the field of animal breeding. Participation was planned to cover developing and developed countries, the most important livestock species and different world regions. Participants included most of the seminal paper authors and many of the case study writers.

The organisers of the Workshop want thank the staff of the Bella Research Station of Italy's *Istituto Sperimentale per la Zootecnia* for hosting the Workshop, for providing their excellent facilities and for their warm hospitality. ICAR and FAO would like to express their great appreciation to the Swiss Agency for Development and Cooperation for its meaningful input to the development of this Workshop and to Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) for the support of the publication of the proceedings. Dr. Cesare Mosconi's effort in the technical editing of these Proceedings is greatly appreciated

The Editors

Summary of workshop outcome

M. Bichard

Introduction

The workshop brought together 37 animal breeding experts from around the world to try to agree on how to create genetic development in the livestock resources used for medium and low-input production systems. The emphasis was on how to make it happen – both to initiate and sustain desirable genetic change. The papers in these Proceedings had all been circulated in advance so that the entire four days could be devoted to group or plenary discussions. Three separate working groups tackled each of seven subjects[1] and we therefore had the benefit of their often different approaches.

The initial focus was on the five seminal documents. These had been carefully commissioned in order to provide syntheses of available knowledge and experience on successive stages in the improvement process:

- Breeding goal definition
- Structures and procedures for straight-breeding
- Structures and procedures for cross-breeding
- Economic evaluation of breeding programmes.

It was inevitable that these documents would deal more with technical aspects than with organisational detail or the policy framework necessary to make improvement happen. This is because authors capable of writing up-to-date technical summaries are unlikely to have been heavily involved in implementation.

Hence it was hoped that the 27 case studies from lower input production environments would permit the discussions to identify the key operational and policy issues which have impacted on past attempts to improve livestock for such production systems. Again, inevitably, there are too few available accounts of such attempts where we have sufficient detail or

[1]FAO is using *inter alia* the output from the Workshop to produce guidelines or decision aids for use at different levels – both policymaker and technician – and eventual incorporation into FAO guidelines for total management of farm animal genetic resources

an adequate number of generations to permit judgements about success or failure. With hindsight, we might usefully have assembled additional case studies from high input systems in developing countries in order to tease out factors controlling their success rates. Nevertheless, the accounts reproduced in these Proceedings, some of them admirably clear and precisely following their terms of reference, served as a valuable back-drop for the discussions – in which many of the authors participated.

No attempt will be made here to summarise the recommended procedures for creating genetic improvement in any detail[2]. In this synthesis the attempt is only to record the results of the workshop discussions where they pointed out gaps in the seminal papers and, more importantly, where they suggested operational issues and approaches relevant to successive parts of the improvement process. However, consulting the seminal papers will be most useful in showing what and how steps must be made. Finally, this Summary Outcome brings together a number of areas of enabling policy that the participants identified as necessary if there is to be a suitably encouraging environment for improvement schemes both to start and to be maintained.

These additional points should therefore be seen as complementary to the material in the seminal documents and based upon the experience drawn both from the case studies and from the experts interacting vigorously in group and plenary discussions.

Technical issues

In general, the seminal papers covered the technical aspects of genetic improvement fairly thoroughly. There was some overlap that resulted from asking five different authors to write about components of the whole. There were also omissions arising in part from their specific briefs, which for example concentrated on straight- and cross-breeding for extensive grazing systems, and in part from their own greater familiarity with ruminant species which have received more attention in developing countries animal breeding initiatives than have the important monogastrics. As a result, the technical issues specific to poultry and pig improvement were under-emphasised.

Specific areas that emerged from the discussions included the following:

1 When proposing improvement goals and goal values in medium and low input systems, it is important to incorporate such

[2]Development Objectives and Breeding Goals; Accessing the Breeds; Straight Breeding; Crossbreeding; Economic Evaluation; Enabling Policy for Genetic Improvement; and Genetic Evaluation

non-monetary values as risk management, social capital, draught usage and aesthetic value. Improvement of product quality may also be as highly valued as increased production efficiency. These goals and their values should be established within a context of a characterised production system

2 It was not thought useful to make a distinction between crossbreeding systems which utilise only local resources and those that rely on breeds brought in from other environments or countries. There are no differences theoretically, but operationally there could be differences in lower input production sytems due to higher degree of fitness of the local genetic resources.

3 While it is now possible to assess the effects of some technologies like artificial isemination, embryo transfer and BLUP, there are others like marker-assisted selection and transgenics for which no firm predictions can yet be made.

4 Genetic improvement utilising straight breeding structures is simultaneously a most appropriate method for the conservation of the genetic resources where farmers are still using the breeds.

5 Aspects of economic evaluation were addressed in several of the seminal papers but none of them illustrated a logical and comprehensive approach (such as Z-Plan). This has resulted in an inadequate presentation on expected investment performance, particularly in terms of times required in the larger species and the distribution of benefits throughout the breeding pyramid. Analysis of the sensitivity of returns, both to parameter errors and price uncertainty, is another area that needs inclusion, as does the subject of competition between programmes and between sectors.

Operational aspects

The workshop discussions frequently concluded that the total amount of information needed to follow optimum procedures is unlikely to be available at the outset in most medium and low input systems. This need not be too serious at the start of a development project. It is important to understand the development objectives and from these to specify the correct breeding goals. When profit functions cannot be formulated from the outset, then other, cruder methods may be utilised to derive goal values, and fitness traits can be handled by independent culling levels. Further sophistication can be based upon information derived from the early stages of the programme – perhaps through a new or enhanced recording scheme. Similarly, the initial number of participating herds or flocks, or the size of an original nucleus may be very modest, but growth can follow later. Decisions on new resource populations will usually have to be made on the basis of data that are **not** sufficiently comprehensive, relevant or reliable. The procedures may therefore need to be employed at more than one level; an initial rough screening followed by a more thorough evaluation among the most likely breeds. Genetic evaluation of individual candidates can also start with ultra-simple methods (visual appraisal), which is how most successful improvement programmes began in developed countries (and some have continued that way). It is thus vital that the operational staff can understand, or can be advised, how to modify optimum procedures in order to make something useful happen.

1 It is essential to consult with the farmers / livestock producers since they will at least be the customers for the improved animals, and often full partners in the improvement process itself. Such consultation is unlikely to be simple, and may well involve explanations of how scientific improvement is created and disseminated. But it should not stop at the producers, since all the downstream buyers may also have valuable inputs (dairy, slaughterhouse, wool buyer, and retailer) as well as other service industries (feed, healthcare).

2 Cost and benefit sharing must be given serious consideration at the outset. Different components of the genetic improvement programme could have different players and stakeholders at different stages. For instance the state may benefit directly from a recording scheme in aspects not necessarily directly related to the programme, so it should pay due share in the recording process. Costing and benefit sharing will develop with the development of the breeding initiative.

3 There is a need to supplement the actual improvement procedures with ‘marketing efforts’ by the private or public sectors – shows, demonstrations, talks, competitions, training schools. Exploit the ‘pyramid of influence’ – identify the key influencers in the community, convince them of the benefits and get them to spread the message.

4 Recording was the subject of the previous FAO / ICAR workshop but it was heavily biased towards milk production. There is a need for more advice on recording all animal species in low input systems, particularly where they are difficult to reach (small scattered or migrant herds or flocks) and on methods of assessing and recording fitness or adaptations.

5 Care is needed in obtaining an appropriate sample of any new population, depending upon its intended use. It may need to be large, random and unrelated, or alternatively a highly selected group from the top tested stratum. Realistically one is often restricted to sampling countries and herds which can comply with the health regulations of one’s own veterinary advisers, and of the importing country’s government officers. It is important that those

regulations are not set so high that valuable improvements are always excluded.

6 The method of dissemination of genetic improvement throughout a livestock industry must also, in practice, be greatly influenced by health considerations.

7 Discontinuous crossbreeding has been widely adopted in high input poultry and pig production systems. It has enabled all routine selection decisions to be concentrated in the hands of specialists. This has led to increased rates of genetic gain and has simplified management at commercial level. Producers then influence the genetic merit of their animal resources through periodic choice between competing sources and, marginally, by their culling decisions. Similar programmes might be possible in lower input systems unless some of the following constraints apply.

7.1 There may not be the necessary specialists who are trusted to make the genetic decisions

7.2 It may be too difficult to organise an efficient dissemination system

7.3 Market signals may not be clear enough to convey the producers' real needs back to the specialists

7.4 There may not be competing sources of stock because the overall business environment is under-developed

7.5 The risk of spreading disease through routine and rapid genetic dissemination may be too great.

8 While rotational crossing appears to be a highly efficient system and was once widely used in the US pig industry, it is very difficult to achieve its theoretical potential except in large, well-recorded and managed units.

9 New methods of genetic improvement should be applied in low input systems in stages, with thorough assessments along the way, and with opportunities to return to the original genotypes if the initial assumptions prove incorrect.

10 Genetic evaluation systems were not a primary subject in this workshop. Nevertheless, it was recognised that they will usually rest upon a data management system which must be customised and kept up to date and will require adequate resources.

11 Routine assessments of progress against plan should be made for those components of the genetic development system which are under the control of the technical staff. In selection programmes these are mainly the realised selection differential (for individual traits or an index), the realised generation interval and their ratio. Other measures can be devised to monitor the efficiency of immigration or crossbreeding or dissemination.

12 Because of initial uncertainty about the importance of genetic-by-environment (G x E) interactions in a specific programme, it must be advisable to estimate breeding values from performance measured in a relevant environment.

13 No genetic improvement programme should be established in isolation from a broader attempt to ameliorate other aspects of the production and marketing system. Such changes may allow the direct responses to be expressed and could help to compensate for any negative correlated responses.

Policy issues

The successive steps in developing enabling policies were seen as:

- Description of the current situation
- Definition of the development objectives
- Strategy to manage animal genetic resources
- Implementation, monitoring and evaluation.

It was recognised that the different areas of international, national or local policy may help or hinder the development of successful genetic improvement programmes. The following areas are provided as a checklist.

1 **Education.** There is a need for both highly trained specialists and skilled technicians, but also for livestock producers to be aware of what genetic change can achieve and how this can occur. If the best specialists with good local knowledge are to be retained in developing countries, it may be essential to establish meaningful collaboration with overseas organisations, perhaps where they were trained. Education is of course necessary in all aspects of animal production and veterinary sciences and not just in genetic improvement.

2 **Zootechnical.** In developed countries there has been a long evolution of policy instruments controlling herd-books, licensing of breeding males, importation of breeds and artificial breeding centres. Most of this was imposed by government, but livestock breeders themselves evolved systems to guard the purity of their breeds (although these have sometimes hampered genetic development). It may not be necessary to copy all these rules or

institutions. The requirement is for organisations which ensure farmers' participation and which can provide the necessary services to support genetic progress.

While it is mainly the countries responsibility FAO or some other agency may assist to consolidate the available information on the performance of indigenous and other livestock in specified environments and make it widely available.

3 **Veterinary.** Policies regulating livestock importations, movement within countries, diagnostic laboratories, drug usage, notifiable diseases, and inspection down the food chain are all necessary components for modern livestock industries.

4 **Research.** There will always be a need for problem-solving within production systems, including reproduction, biotechnology, and veterinary research. In the early stages it may also be necessary to have demonstration projects showing producers what can be achieved – even if the answers are already well known in other areas or countries.

5 **Finance.** Local banks or credit institutions may need to provide finance in the early stages of livestock improvment programmes – since costs normally precede returns, often by several years. Inducements may also be needed to help persuade producers to avail themselves of improved genotypes.

6 **Market.** Schemes to promote the grading, classification and labelling of produce can help to generate increased prices for higher quality, so that the market itself begins to finance the costs of the programme. Unprotected markets can suffer from dumping of imported products that may stifle any initiatives to improve the local output.

7 **Environmental.** Policies must be in place to prevent pollution and ensure sustainability of improved production systems.

8 **Welfare.** The welfare of both livestock and workers needs protection on the farms, during transport, at markets and abattoirs.

9. The Workshop naturally left many questions unresolved. One of these concerns the likely roles in developing countries of international agencies, government, co-operatives and the private sector – either local or foreign. Today, though many successful improvement programmes in developed countries are firmly in the private sector, they have evolved from earlier arrangements that relied heavily on public investment that continues at least in education and research. It may not be necessary to repeat such a

long evolutionary process in other countries. FAO should be working closely with co-operative and private breeding organisations to see where their businesses, or at least their methods, could hasten the development of new programmes: to make it happen!

There is also the issue of what will be the structure of livestock industries in ten, twenty or thirty years' time; not long in terms of animal generations. And will they still be working within the same environmental constraints? There is today a reaction against many past attempts to introduce high input high output breeds into unsuitable environments and a commendable interest in seeing whether indigenous breeds can be improved without losing their valuable adaptation.

Nevertheless, it seems likely that the number of livestock-owning households and small-scale farmers will decrease as humankind continues to shift towards urban life. Similarly, serious pests, diseases and deficiencies will gradually be conquered as they already have been in developed regions. The result, as in the more developed world, will be increased scale and more specialised livestock enterprises that may in turn demand different breeds and crosses. Genetic improvement efforts must constantly bear these possibilities in mind and not concentrate solely on breeding objectives constrained by today's problems. It is important that the many breeding programmes operating around the world produce genotypes adapted to the variety of economic, disease and climatic environments that will exist in the future. Otherwise the inevitable time-scale of improvement may mean that the solutions (new and improved strains) are already out of date for the new conditions.

10. The third output from the Workshop was surely an improved understanding among the privileged participants. It is inevitable that this will be expressed in their future work whether this is teaching, extension, writing or planning and supervising projects. While the direct experience of interacting with many of the authors had to be limited to a fairly small group, it is hoped that countless others will benefit from reading the Proceedings.

This volume contains a unique collection of papers combining up-to-date summaries of animal breeding theory with concise accounts of attempts to improve livestock in difficult situations. While the reviews require some specialist training to utilise them fully, the case studies should be required reading for anyone contemplating new projects.

Dr Maurice Bichard
Workship Facilitator

Developing breeding strategies for lower input animal production environments. An Introduction

K. Hammond & S. Galal

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Livestock currently account for over 30% of the total value of food and agriculture; where the term 'agriculture' includes such important products as draught for cultivation, irrigation, harvesting and transport; fibre for clothing and for meeting various other material needs; manure for cooking, heating and for use as fertilizer; employment generation throughout the year; risk management, where livestock frequently serve as 'the bank' and add resilience to the farming system; and the generation of foreign exchange through international marketing of livestock products in demand. Livestock also support many cultural needs of human communities; and particular products with special qualities often contribute importantly to the unique nature of local cuisines and of other local material goods, a role for within-product diversity in food and agriculture production.

Animal genetic variation

Globally, the genetic variation in inputs required and outputs produced by farm animals is very large, with differences often involving orders of magnitude. This diversity is available for farmers to use in meeting their needs, as well as those of the communities the farmers supply. Because of the comparatively permanent nature of this genetic variation, once it is deployed its benefits and liabilities are recouped year-in and year-out, making the use of genetic diversity an important consideration in livestock develop. There are three primary levels of this domestic animal diversity with each level contributing a portion of the total diversity available to farmers to utilise:

1. *Diversity amongst farm animal species* - as species evolved over time they developed unique adaptive and production characteristics, and were domesticated for these genetic qualities; thereby offering farmers choices amongst species and of combinations of species, depending upon the inputs available and the outputs required of the production environment.

2. *Diversity amongst the breeds of each species* - as breeds have developed they have become highly adapted to their particular production environment, in response to the environment's set of complex selection pressures operating repetitively over many generations of development. These production environments frequently differ markedly in the overall nature of the set of selection pressures imposed. So, it is not surprising to find 50 percent or more of the quantitative genetic variation for characteristics of a species being unique to the breed level, making decisions about breed selection also very imporatant to the sustainable intensification of livestock production.

3. *Diversity amongst the individual animals of each breed* - with coefficients of variation for input and output characteristics of interest in the breeding livestock populations of developing country production environments commonly being 30 percent or more, there are likely to be very large differences amongst farmers' animals of the same breed in ability to utilize feed and other inputs and to produce outputs.

Consequently, the utilisation of this species, breed and individual animal diversity should be an important element in livestock development within- and between-human communities. In fact its natural partition into the 3 levels is a further asset assisting farmers to manage the benefits it offers; where management covers understanding, accessing, use, development, and conservation of these genetic resources.

As animal reproduction does not permit the ready exchange of genetic diversity amongst species, once decisions are made on the animal species to be included in a production system, farmers' consideration of genetic development of their livestock can focus on:

1. Which breed or breeds?
2. When more than one breed is chosen: How to use these breeds? and
3. How to further develop the breed(s), i.e. which animals and how to use these to maximum benefit?

Importance of genetics in livestock development

One in six people in the world are in food poverty and in the developing country sector, some 88 percent and increasing of the world community, the demand for animal products is now substantially outpacing that for plant products. With population numbers in this sector set to continue to rise over at least the next half-century the pressures on inputs to produce food and other needs from agricultural will continue to intensify.

The drive by FAO, other international organisations and the developing countries themselves, is for food security and for sustainable rural development, ‘the imperatives’.

More than 70 percent of the land used for food and agriculture production, approximately 80 percent of the world’s livestock, and around 70 percent of all breeds of farm livestock currently reside in the 140+ developing countries, occupying a very broad spectrum of primarily lower input production environments. Few effective genetic improvement programmes have been initiated during the past half-century and of these very few are being sustained amongst the 4000 or so livestock breeds throughout these developing countries – ponder the various reasons why! Breed importation, generally involving high input, short lifecycle breeds and often combined with poorly planned crossing with local breeds, has been common during the past decades. However, at least in the lower input production environments where long lifecycle genetics is generally critical, these importation and crossing activities have frequently not resulted in sustained increases in food and agriculture production. Further, and perhaps even more importantly, it seems that these activities have frequently substantially reduced lifecycle productivity of the species in the production system. On the other hand well thought out genetic improvement once made is recouped one generation after another.

Unless effective animal genetic improvement activity for meaningful breeding goals is introduced to these major lower input production environments and sustained, many developing country communities will experience even greater difficulty over the next half-century meeting their food and agriculture imperatives. Further, the majority of the 4 000 or so locally adapted breeds of these lower input production environments will (rightly or wrongly) be considered to be falling further behind the high input, high output, short lifecycle breeds which have been developed to supply most of the developed world community.

Requirements for genetic improvement

Sustainable genetic improvement programmes need to be planned, implemented and maintained for each of the livestock populations which farmers are still utilising, covering most of the medium to low input production environments of the developing world.

A primary issue is: What is required in the decision-making process for countries to begin realisation of this need?

Responding to the need is indeed a challenge for this large sector of the world community. In these countries, capacity and financial resources are severely limited. Further, those genetic improvement programmes which have succeeded over the past 5 decades in the developed countries are generally complex operationally and their development has enjoyed substantial human and technological capacity. They were developed under comparatively sophisticated and stable policy environments, and commonly aided with various forms of financial support throughout their prolonged development periods. For the developing countries, pragmatic and sustained approaches to policy development and technical opearations are necessary.

Knowledge base required for developing country decision makers to ensure successThe decision making process will generally not be commencing from nothing! Stable, basic policy environments are developing in many countries. Livestock production systems in the country will already be operational. Each production system will involve one or more animal species and there will be one or more breeds of each species to consider, i.e. the decision-makers will be operating in real time!

In these situations, and irrespective of species or production system type, the following information must be available to decision-makers who will plan and those who will implement and maintain a 'sustainable genetic improvement programme':

1. For existing livestock production activity:

- What is the current Development Objective of the relevant livestock sector (in a comprehensive sense of course, all inputs and outputs)?
- How is the livestock population structured, over a lifecycle of production; accounting for all aspects of structure?
- What policies are operating at the farm and higher levels, both socio-cultural driven and legislative based policies?
- What likely genetic gain is occurring for the possible spectrum of traits involved in this livestock production activity?

2. For the future livestock production activity:

- What should be the Development Objective and the Breeding Goals?
- What different technologies and different arrangements are required to realise effective and sustained selection, culling and mating practices?
- What opportunities are there to better utilise existing livestock population structural aspects to better realise genetic gain and, if the gain is realised first only in a sub-population, to disseminate the gain throughout the livestock population as a whole?
- Are there some changes required to the livestock population structure – again considering all structural aspects - to both realise the genetic gain being sought and, if the gain is made first only in a sub-population, to disseminate the gain throughout the livestock population as a whole?
- What opportunities are there to better utilise existing policy at the farm and higher levels, concerning the livestock, again considering both socio-cultural driven and legislative based policies?

- What changes of policy at the farm and higher levels, concerning the livestock, are necessary in the beginning and at later stages, again considering both socio-cultural driven and legislative based policies?
- What likely rates of genetic gain could be realised for the breeding goal, and for the possible spectrum of traits involved in this livestock production activity?
- What other support services and activities will be required to ensure that this genetic improvement activity is effective and sustained?
- How should this genetic improvement activity be funded initially and as it develops?
- What are the economics of the whole operation, and of different options?

Of course **each** of the above general questions involves many specific questions and decisions.

How to begin, and how to continue developing, over time?

An iterative approach to developing the breeding strategy, applied over time, must be considered – "optimising" in a technical sense may not even be considered in the first 10-15 years of an initiative being implemented.

Decision-makers must be encouraged to ask, in reasonably logical sequence, the fundamental questions concerning the development of sustainable breeding strategies for particular production environments, rather than to *de novo* identify the preferred approach. In addition, there will be advantages and disadvantages, about most decision points associated with utilising particular strategies in particular environments. It is important that the decision-makers are aware of pitfalls as well as strengths – this will also aid their appreciation of the folly of always utilising a particular strategy as the best. In this respect, the identification by leading experts of particular approaches, for example, open nucleus breeding schemes, or of MOET schemes, as being superior may be interpreted quite inappropriately by others with decision making roles. There may be lack of understanding of just how complicated technically and logistically a MOET programme can be, particularly for developing country use when capacity is seriously constrained.

Decision making structure for genetic development

As for other walks of life, recognising the decision-making structure for genetic development is crucial for effecting such development and ensuring its sustenance. Some levels of these structures are:

- **National structures.** It is necessary to account for several levels of in-country decision-making being involved in developing breeding strategies: as yet we have not finalised upon a suitable breakdown.

It will be important to effectively involve the high-level decision-makers, whether they be in government or the private sector (including farmer bodies). These will not be involved with the many technical, operational and even policy decisions of detail.

Often individual farmers or local farmer groups will not have the capacity nor inclination to work through decisions requiring technical detail; although they must of course be able to obtain practical interpretations associated with particular decision options.

Consider utilising just 2 decision levels in guiding the planning, implementation and maintenance of sustainable genetic improvement programmes. For example, these levels could be:

- Decision-Level 1: *Operations and Management Decision-Making*
- Decision-Level 2: *Executive Decision-Making*

Decisions-Level 1 could be broad and include most of the decisions required in planning, implementing and maintaining the operation – decisions by individual small farmers to local farming groups, by operations planners and managers including the applied technicians involved, by extension agents, and even by researchers, educators and trainers associated with maintaining the necessary ongoing amount of training and research to enable capacity building and the development of subsequent stages of the programme.

Decision-Level 2 could provide for the major enabling decisions within, and across, genetic improvement activity within and across species, production systems and for the country as a whole. By definition, these will involve critical but broad policy decisions. Of course at least part of the basis for these will also be technical in nature.

- **Structures for decisions within particular breeding strategies.** It will be necessary to encourage the development of decision structures which fully involve the key stakeholders from the outset, to generate ownership. Very important stakeholder groups are:

  - *Farmers* - who generally own and have the responsibility for day-to-day decisions concerning the animals of the herds and flocks responsible for producing most or all of the food and agriculture from livestock
  - *Policy and planning developers* – create an enabling environment in responding to consuming and farming needs.
  - *Collaborators* – a number of important sub-groups with potential to provide additional human operational and management resources and additional funding resources. The latter in particular will generally be required for the early stages of development of a genetic improvement initiative, including capacity building.

- **Farm community structures.** Finally, the food and agriculture production structure of communities can be a significant structural consideration itself when one is addressing the design of genetic improvement. Broad design structures induced by the food and agriculture production structure of communities or by government or community socio-economic policies may benefit by structuring the genetic improvement initiative to:

1. Involve only 1 or a few herds/flocks with some form of reliable system to be developed for dissemination of the improvement over time – sustaining dissemination of improvement in developing countries must be very carefully considered; or

2. Form a first tier as responsible for the genetic improvement comprising a good number of farmers who are more developed or have good geographic access to each other; this approach also requiring a reliable system for dissemination of the improvement over time to all farmers;

3. Involve all farmers in the production system in the breeding activity, as a flat structure.

This food and agriculture production structure of communities, induced by government or community socio-economic policies, can differ greatly amongst communities. Existing characteristics of these structures may be used to enable increased genetic improvement. In other situations the community may be willing to alter some of its structural characteristics to introduce a more effective breeding programme. In still other communities particular structural aspects may be so important to the socio-cultural environment that there will be unwillingness to alter them to introduce a more effective breeding operation or to permit use of a particular strategy.

Some beginning examples of farm community activity with implications for policy, operational and technical decisions in the development of breeding strategies:

- The scavenger livestock component of many production systems, particularly common with poultry species and goat, e.g. chickens providing eggs and meat for the small farming family and also some cash (generally in the form of chicks/birds sold) in times of need;
- Roving transhumant groups of herds or flocks that are run separately or together for all or part of the year;
- Many small herds being maintained by individual farmers in local communities but using males in common with all/some number of the farmers being involved in the selection of the common males, as part of community's socio-cultural activity - service may be provided naturally or through artificial insemination;

- Landless, peri-urban production systems where virtually all replacements and feed, etc is introduced and product is sold commonly for a domestic (city) market, or sometimes for export (often requiring higher production plus standards);
- Individual animals of larger species in particular may, in some production systems, be permanently tethered / controlled, with all feed and other inputs brought to the animals (perhaps simple measures of intake are possible in these situations); whilst in other systems
- Animals roam freely, whilst
- Fertile males may be retained separate, run with the herd / flock for part of the year, e.g. in spring and summer, or the total herd / flock run together permanently; or
- All fertile males may be left entire, or the majority may be castrated for cultural reasons or because some communities prefer castrates for particular uses such as draught.

Seminal papers

Seminal Papers

Breeding goal definition

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Introduction

Sections 1 and 2 introduce the users to the area of genetic improvement in general and in particular to the role breeding goal definition has in the management of animal genetic resources. The process guiding the user through the decision-making when defining breeding goals (see 2.3.) starts with Section 3.

- Users for which these guidelines provide a first entrance in the area of breeding goal definition are advised to go through Section 1 and 2 in detail (including Annexes), to get the basic principles of genetic improvement and breeding goal definition.
- Users of these guidelines familiar with genetic improvement and breeding goal definition may wish to go to Section 3 directly; these people are advised to read the (double framed) boxes from Sections 1 and 2, as these boxes include the headlines of the sections.

Section 1. Why genetic improvement in managing farm animal genetic resources?

1.1 Helping to achieve the development objective

Genetic improvement aims for an active use of the genetic variation available, both within breeds and between breeds[1] of livestock. The animal genetic variation can be used to accommodate interests and wishes of farmers to make livestock even more efficient in using available resources to produce human food and other agricultural products. Genetic improvement focuses at a directional improvement in genetics of animals in coming generations such that they will produce the desired products more efficiently under the (expected) future economic, social and ecological production environment. This direction of the improvement is formalised in a 'breeding goal'. The breeding goal is to serve the farmers and the community in a broader sense in establishing the development objective for agricultural production in their country. The development objective will (traditionally) include economic variables, but it should be extended to also accommodate aspects like ethics and other social aspects of human welfare and well being.

[1]All words underlined refer to terms used in these guidelines for which a description is given in Annex VII.

Genetic improvement helps to achieve the development objective

• Defines what is the 'best' animal	- Breeding goal
• Identifies the best animals by recording	- Breeding value
• Uses the best animals	- Breeding structure

1) Breeding goal definition is the first step to be made in designing genetic improvement strategies. The breeding goal identifies the animal traits that farmers would like to be improved. To be able to identify the animal traits, the development objective of agricultural production in the country is to be defined and the animal production system is to be characterised.

2) Then, a second step is to implement a structure of gathering information, a recording system, to identify those animals that have the highest breeding value for traits in the breeding goal. This step of identifying high genetic merit animals is called 'breeding value prediction'.

3) A third step is to make a well-organized structure for:
   - the use of animals with highest predicted breeding value; and
   - the dissemination of superior genes through the population, a quick and widespread use of selected animals.

It is apparent that the second and third steps involve a lot of costs, especially the second step of recording. Investments will have to be recovered by the genetic improvement giving increased sustainability of production in future generations. Development of breeding strategies that will be effective is of great importance for the management of animal genetic resources.

Breeding goals focus on
- saving inputs of resources
- achieving sustainability
- dynamic genetic improvements
- accommodating local production environments

Saving inputs of resources

Animal production is a means to producing human food, other agricultural products for human consumption (like fur or coats, or biogas) and intermediates to be used as inputs for plant production (dung as fertiliser, draft). Animal production also serves human interest in different other ways, like banking and social status. Animal production is a means to creating human welfare and well being by converting lower valued resources (production factors, labour, land and capital) to higher valued products.

Genetic improvement involves a technological development to improve output and quality of animal production. Genetic improvement aims at saving input of resources per unit of output and a change towards the use of cheaper resources. These two statements imply:

- firstly, that genetic improvement should be based upon farmers' perceptions and wishes; this will enhance acceptability and implementation of developed technology;
- secondly, that the value of genetic improvement is in the alternative use of saved resources.

Farmers want to save on resources because there are additional opportunities to use these resources, either to expand the production of the animal activity or to use them in another (animal) activity.

Sustainability

Development objectives should consider sustainable development of agricultural production. Sustainable agricultural production permits conversion of available resources to human food and other agricultural products without diminishing the future availability of those resources or causing environmental degradation. Livestock is a critical part of sustainable agricultural production because of unique abilities to utilise a spectrum of renewable resources. Genetic improvement is an important tool in achieving sustainability when used to improve these unique abilities of livestock.

Dynamic genetic improvement

Genetic improvement is not aiming at an optimum; genetic improvement is dynamically searching for improvements. Given animal genetic variation (within or between breeds), there is always a means of improvement. In fact, this approach of farmers is originating from the historical and continued natural processes of re-establishing genetic variation (i.e. mutations). This genetic improvement approach is also an incentive to conserve genetic variation during the process of selection.

Breeding goal definition is an important area of decision-making; genetic change is lasting and therefore valuable. The state of the future generation will depend partly on the state of the current generation and so on. For this reason, genetic improvement is an important tool in the realisation of the development objective

A third dimension to the dynamics of breeding goals is the uncertainty about the future. Breeding goals ought not to change according to seasonal or cyclic variation of circumstances. As soon as structural and lasting changes are observed, breeding goals should be adjusted in order to avoid losses. Breeding goal definitions should be robust, but also continuously requiring reconsideration of economic and social developments.

Accommodating local production environments

There is not 'a worldwide standard' or even 'a country standard' breeding goal. Differences in economic, social and ecological production environment give rise to different approaches and desires in what human welfare and well being is. These differences give rise to different development objectives. A diversification of breeding goals is important to serve farmers facing different local situations. A diversification of breeding goals according to local production environments will help to conserve the diversity in genetic resources. A diversification of breeding goals according to local production environments will support genetic improvement towards locally adapted breeds.

Wise use is the best form of *in situ* conservation

About these guidelines

Breeding goal definition involves a decision-making process. To provide a helpful tool, the decision-making process in breeding goal definition is broken down in sequential steps and users will be guided step-by-step, following logical flow charts. For each step or decision:

- examples are used to illustrate the step;
- background information is given as why this step is important;
- it is indicated how to find data to make a sound decision; and
- drawbacks of not making the decision or of making a poor decision are denoted.

After some decision-making steps, an incentive is given to go back some steps to reconsider decisions made earlier.

Forms are provided to fill in to help systematically putting the information together. A list of terms used is given in Annex VII.

1.2. Links to other guidelines for development of farm animal genetic resource management plans

The purpose of the FAO guidelines is to assist countries to develop Farm Animal Genetic Resource (AnGR) Management Plans that will become both components of the Diversity Plan and a basis for developing livestock breeding policies. In the FAO guidelines, management of AnGR includes identification and description of AnGR, the active utilisation of AnGR to increase food production (including animal productivity and product quality) and other agricultural production, the conservation of endangered livestock breeds for possible future use, access to AnGR and the monitoring and reporting.

These guidelines help policy-makers, field technicians and farmers to define breeding goals for genetic improvement to manage animal genetic resources. These guidelines account for a broad range in country capacity and are applicable to all important animal species and production environments.

For domestic species, issues of utilisation and conservation cannot be separated; both are critical components of management of AnGR. Most AnGR reside in developing countries where the need to increase food production and to reduce poverty are greatest. The breeds that farmers use today are different from those used in the past and from those that will be used in the future.

Management of livestock AnGR seeks to ensure that appropriate genetic material is used and developed and will be available to meet future challenges of changing environments and human preferences. The most important use of these guidelines is for setting priorities for the design and implementation of AnGR management activities thereby better targeting country needs and for establishing and maintaining cost-effective activities. In addition, the guidelines will assist in describing the countries' AnGR to the global community.

Section 2. What is genetic improvement?

Farmers always like the animals to perform better in order for:
- dairy cows to give more milk and live longer;
- young stock to grow faster;
- the suckler cows to reproduce regularly and to give birth more easily;
- sheep to produce more meat and wool with a better quality;
- chickens to lay more eggs without a loss in egg weight.

2.1. What is a breeding goal?

Each farmer will come up with several traits. The breeding goal lists these traits and gives each of these traits a value. By giving each trait of the breeding goal a value, a weighed analysis of traits is made, an aggregate genotype to be improved.

An example. Goal traits in genetic improvement of chickens
- General
  - Disease resistance
  - Adaptation to heat stress
  - Utilisation of poor quality feeds
- Breeding stock
  - Productive life
  - Fecundity
  - Quality of eggs (fertilisation, hatchability)
- Growers
  - Growth rate
  - Feed conversion
  - Carcass quality

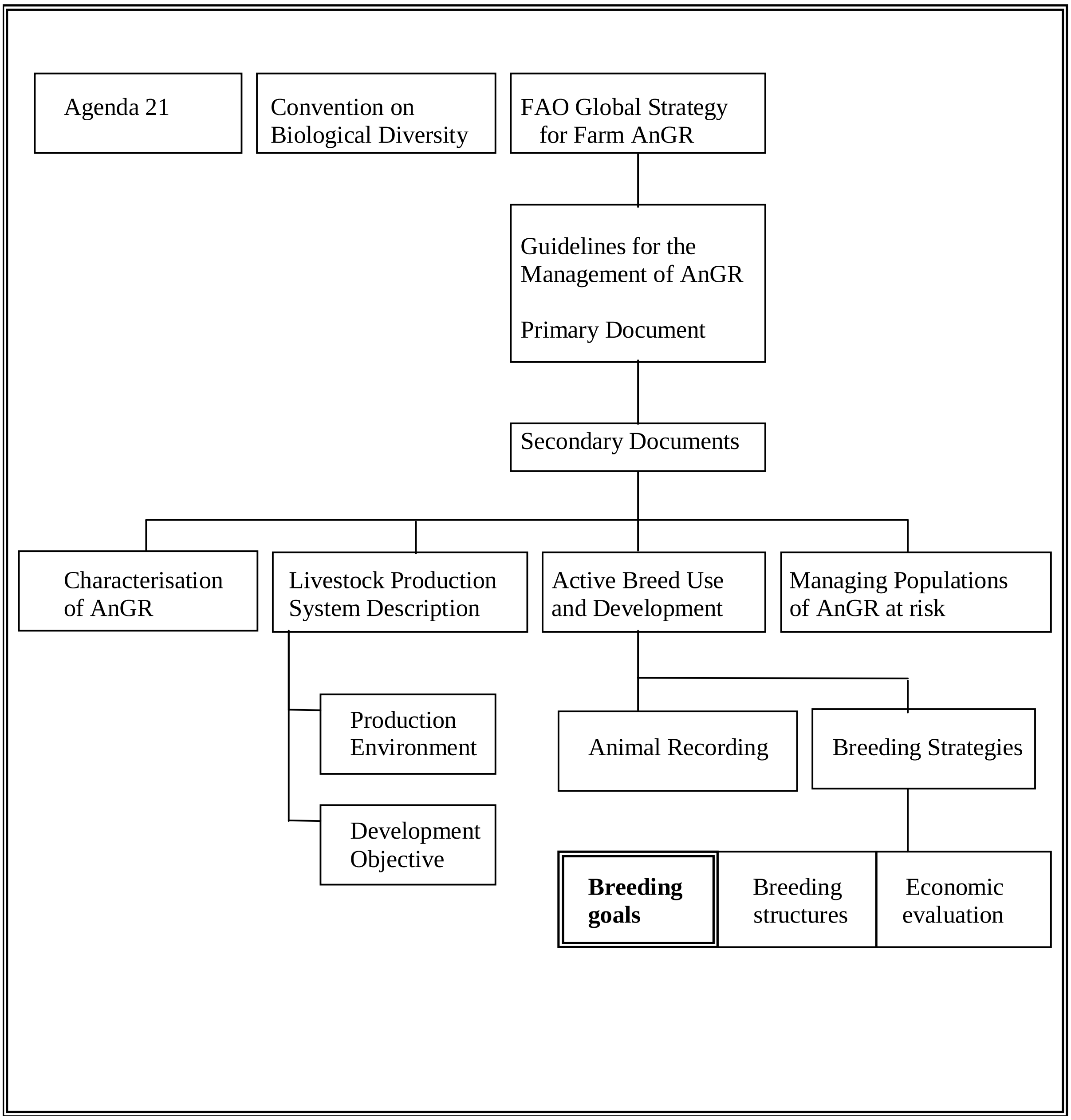


Figure 1.1. Breeding goal guidelines in the context of Farm Animal Genetic Resource (AnGR) Management Plans.

The choice of the list of traits is to be based on the development objective of agricultural production and the characterisation of the animal production system. The values used for making the calculation are generally called 'economic values' or 'economic weights'. In these guidelines they will be called 'goal values for genetic improvement' or simply 'goal values'. The term 'goal values' emphasises that these values fit the overall development of the agricultural production in a country, accommodating not only economic environment, but also the social and ecological environment. The goal value of a trait denotes the contribution of its improvement to the realisation of the development objective. The list of breeding goal traits and their goal values will be used for within-breed selection, but also help to choose between breeds to be used in the animal production system.

Breeding goal

- the breeding goal is a list of traits the farmer would like to be improved genetically;
- this list is based on the development objective of agricultural production and the characterisation of the animal production system;
- each trait in the breeding goal is given a 'goal value', indicating the contribution of the improvement of the trait to the realisation of the development objective.

The breeding goal is not the final criterion or tool used in selection. The tool used in deciding on which males and females will become parents of the next generation is the 'selection index'. The selection index is a summary of observations, information on measurements and scores. In the selection index weighing is performed by co-efficients. These index co-efficients also account for:

- the genetic possibilities of improvement (by considering the genetic and phenotypic parameters in the population, such as (co)variances and correlations); and
- the number of observations on the animal and its relatives.

As breeding goal traits differ in genetic possibilities of improvement and in ease of recording (directly or indirectly) and as observations generally do not give complete information, index co-efficients are generally not equal to goal values and they differ markedly.

This selection index approach is described in Annex I: the breeding goal is the aggregate genotype to aim for and the tool to reach the goal is the selection index. The good thing about this approach is that the tool is optimised given the goal. Index co-efficients are calculated in such a way

An example. Goal traits in genetic improvement of yak

- milk yield;
- beef yield – big body;
- wool yield – rich, thick hair;
- draught – body strength, good feet and legs;
- tame and gentle;
- fertile;
- disease resistance;
- grazing, feed intake from pasture.

Selection index

- the selection index is a tool that lists all the observations for making the selection decisions;
- in the selection index observations are weighed by their index co-efficients;
- these index co-efficients are calculated to maximise the correlation between the breeding goal and the selection index.

An example. Using the selection index approach

A farmer wishes to select male goats for improved milk production and carcass quality. Of course, he cannot measure milk production on the male and he will not slaughter the (potential) breeding males. Therefore, he uses milk production records on the dam and full sisters of the male and carcass quality information on slaughtered full brothers.

Breeding goal = goal value milk * genotype value milk + goal value carcass quality * genotype carcass quality
(where genotype is the unknown true breeding value)

Selection index male =
index co-efficient milk dam * milk performance dam
+ index co-efficient milk full sisters * milk performance full sisters
+ index co-efficient carcass quality full brothers * carcass quality full brothers

Alternatively – a simplification generally used in practice (see Annex I):

*Selection index male = goal value milk * PBV milk*
*+ goal value carcass quality * PBV carcass value*

where PBV milk is the predicted breeding value for the male based on corrected and weighed performance of the dam and full sisters; and PBV carcass value idem performance full brothers to maximise the correlation between goal and tool. This maximisation considers the assigned goal values, the genetic and phenotypic population parameters and the observations available. The selection index approach simultaneously gives optimal co-efficients to observations on different groups of animals and on different traits. In fact, the aggregate genotype is the true breeding value to improve; the selection index is the predicted breeding value. The calculation of the index co-efficients is detailed in Annex I.

The correlation between goal and tool is also called the 'reliability' of the predicted breeding value. The more observations included in the selection index, the higher the reliability of the predicted breeding value. Notice that the observations included in the selection index are to be measured in the setting of the breeding structure. Of course, these can be measurements that are also used for other management decisions, like feeding strategy.

Nowadays, breeding value prediction uses sophisticated statistical techniques, all based upon Best Linear Unbiased Prediction (BLUP) applying mixed model methodology, as developed for livestock selection by Henderson in the 1960s. This mixed model methodology uses exactly the same optimal index co-efficients to weigh observations from different sources (i.e. individual itself, or a relative) and to observations on different traits. In fact, mixed model equations are used to calculate selection indexes.

Two advantages of using mixed models methodology in genetic improvement are:

- it is much more flexible: mixed models simultaneously consider calculation of index co-efficients when potential selection candidates have different numbers of observations available for breeding value prediction; and
- it directly corrects for the (disturbing) environmental contributions to observations: mixed models use the available performance data to simultaneously give an estimate of the environmental contribution to observations (while the selection index assumes that these environmental effects are known without error from external sources).

The mixed model prediction of breeding values disentangles the genetic and environmental contributions to observations. More details on mixed model methodology are in Annex II.

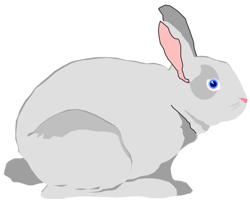
2.2. What genetic changes are addressed?

Before starting to take action, the user has to get an idea what the result of the genetic improvement strategy might be. What is meant by improving genetics?

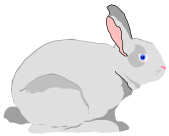
The observed performance of an animal, its phenotype (P), is a result of genetic (G) and environmental (E) contributions. The DNA of the animal forms the genetic contribution; the environmental contribution is formed

An example

Why is a rabbit growing fast? Is it due to housing, feeding or genetics?



= lots of feed + excellent genotype + good housing



= little feed + excellent genotype + bad housing

by husbandry: feeding, health care, climatic influences and so on. The genetic and environmental contributions are often considered to act independently (additive). However, there can also be a G*E interaction meaning that particular genotypes of animals will not be best in all husbandry practices. All contributions give rise to deviations from the (overall) mean performance

$$P = meanP + G + E + G*E.$$

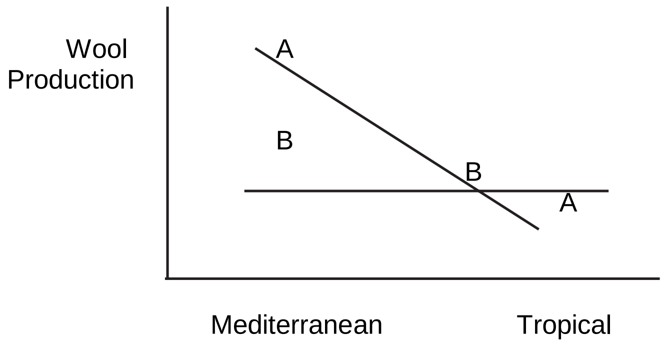
The farmer aims to improve the genetic contribution; G is in the breeding goal. The selection index is built up by phenotypic observations. What selection index and mixed model methodology in fact do is to disentangle G and E in order to predict G from P.

Differences in phenotypic observations among animals result from differences in genetic contributions G, differences in environmental contributions E and differences in interactions G*E. In addition, higher or lower variances in phenotypes may occur because of co-variances between components. For example, a decrease in phenotypic variation is observed when higher genetic merit animals are kept in better environments.

The genetic material, DNA, of an individual is a very complex structure. Part of the DNA codes the genes for production of enzymes. Enzymes act within the metabolism of the animal. Livestock species have thousands of genes. All important domestic livestock species are diploid, so they have two (homologous) copies of each gene, one inherited from the sire and one inherited from the dam. Genes may have variants, called alleles. All

An example. Genotype*Environment interactions

Performance levels in terms of wool production by daughter groups of two different rams A and B



Under Mediterranean environments the daughters of ram A outperform the daughters of ram B. Under tropical environments production levels for both daughter groups are lower but less for B than for A; now the daughters of ram B perform better than the daughters of ram A.

alleles of a given gene code form an enzyme with the same function, but the alleles may differ in the speed of processing the enzyme, or may give slightly different enzymes that, for example, give rise to other blood plasma levels of the enzyme. When considering the effect of an allele on a single metabolic process:

- the allele may act independently of the others (additivity; A);
- the allele may interact with the other allele at the homologous gene (dominance; D);
- the allele may interact with any other allele of any other gene (epistasis or interaction effect, I).

$$G = \text{mean}G + A + D + I.$$

Within breed improvement of quantitative traits is generally focussing on improvement of additive genetic effects. Cross-breeding is especially trying to exploit dominance effects. Adaptive fitness is a complex of G*E and I effects. Adaptive fitness is merely thought to evolve from keeping animals over many generations in the same environment; the animals with the favourable G*E and I effects will have a higher fitness, which literally means have a higher genetic contribution to the next generation (i.e. more offspring). Performance testing in recording in the local environment will enhance adaptive fitness and so will the definition of a complete breeding oal, including trait definition according to local environment.

An example. Differences in layer performance

full sib hens I x x x x x x x xx x

full sib hens II x xxx x xx xx x → performance

Observations on two full sib groups of layer hens were plotted. Differences within each full sib group are found and also differences between full sib groups. Each full sib group was housed in one back yard pen, but the pens were in two different villages. The differences within each full sib group will be due to genetic differences between the hens. It is unclear whether the differences between groups I and II are due to genetic differences or due to the different feeding in the different pens.

Identification of higher genetic merit animals requires disentangling the environmental contribution from the phenotypic observation – this is accomplished by the **breeding value prediction** using mixed model methodology.

Selecting the animals with better genotypes means selecting animals that have the favourable variants or alleles. A generally adapted model is that when selecting on (predicted) G or A of quantitative traits and combinations as a whole, the number of genes involved is very large, the so called ‘infinitesimal’ model. Due to this very large number of genes involved, allele frequencies of individual genes in the population will hardly change. Selecting for individually identifiable alleles at specific loci (e.g. polledness or milk protein variants) does give a directional change in allele frequencies. Please notice these selection procedures according to type of observations used do not change the breeding goal, but they do change the selection index.

2.3. Strategies for genetic improvement– steps and stages involved

The ultimate goal of genetic improvement strategies is to get improved genotypes for the traits of importance in order to help to achieve the development objective of agricultural production. There is a direct relationship between the chosen definition of the breeding goal and the future realisation of genetic gain of traits of importance.

Setting up strategies for genetic improvement involves breeding goal definition, designing recording systems for routinely observing animal performances for breeding value prediction and optimising a structure for using the best animals (see Section 1.1.). Figure 2.1 gives a more detailed, overall picture of this plan process for genetic improvement strategies.

Adaptive fitness
A nation's locally adapted livestock breeds are a result of the selective forces imposed by the production environment(s) and management systems of the nation and by the preferences of the nation's farmers and consumers. As nations change, their livestock breeds likewise evolve in response to changing conditions and demands. Historically, these changes have been gradual, permitting genetic changes within the nation's breeds to keep pace with the changing needs of the people. The result has been an array of slowly evolving livestock breeds that are generally well adapted to the specific production conditions, management systems and markets of the nation.

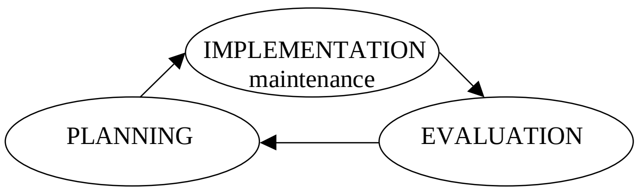
This overall picture highlights the position of the definition of breeding goals.

These guidelines will help the user to perform the subsequent steps to set up a breeding strategy with special reference on the breeding goal definition. Subsequent steps are to:
Section 3
- define the development objective of the agricultural production in the country;
- characterise the animal production system for the animal species of interest;
- identify breeds to be (possibly) used and improved by selection;
- identify a list of breeding goal traits; and

Section 4.
- derive goal values for each of the breeding goal traits.

The characterisation of breeding structure and the choice of breeds involved, the estimation of population genetic parameters, the choice of information sources for breeding value prediction and the evaluation of the (economic) efficacy of breeding strategies are subject to other AnGR breeding strategy documentation. Selection index calculations, resulting in index co-efficients and genetic gain, are described in Annex I. Calculation of geneflow for future expression of genetic superiority in offspring of selected parents (dissemination of superior genes) is described in Annex III.

Genetic improvement, as any other management area, involves planning, implementation and evaluation



Planning, implementation and evaluation is a continuous process. Evaluation is necessary to identify drawbacks and bottlenecks of the strategy and to find new opportunities that give rise to new planning and implementation. New planning and implementation with regard to breeding goals is especially of importance when (long-term) changes in production environments are to be encountered. Users of these guidelines may be in the position of:

1. having to define a breeding goal in a population as part of setting up a whole new breeding strategy; or
2. having to re-think and possibly revise the current breeding goal in a running breeding strategy.

The users in the first position need to pay specific attention to the fact that their breeding goal is embedded in the development objective of agricultural production in the country. As an example; there is no need for increasing milk production output of the system, when there is no demand for more milk. Recording of traits to implement selection is to be embedded in a broader structure of trying to improve husbandry practices as well. When planning and implementing the breeding goal and breeding strategy, the users will have to involve farmers in making the decisions.

Developing breeding strategies is a process of continuous refining; after initial planning and implementation of the strategy (breeding goal, breeding value prediction and breeding structure), evaluations will pinpoint opportunities for improvement giving rise to renewed planning and implementation.

Also during the initial planning, the user will realise that when starting from 'scratch' it is better first to use well-defined but simple breeding goals and selection indexes (e.g. only two to three traits) rather than to complicate these on fore hand. As an example, in these guidelines the breeding goal will first be split up into several sub-goals for different groups of traits. This helps to find solutions and provides a way of obtaining results more quickly. Subjective assignment of values to different (groups) of traits is adopted, which is especially useful in the case of missing information. In other words, even before implementing a first strategy, the use will have to go through several 'iterations', when appropriate, this will also be indicated in the guidelines.

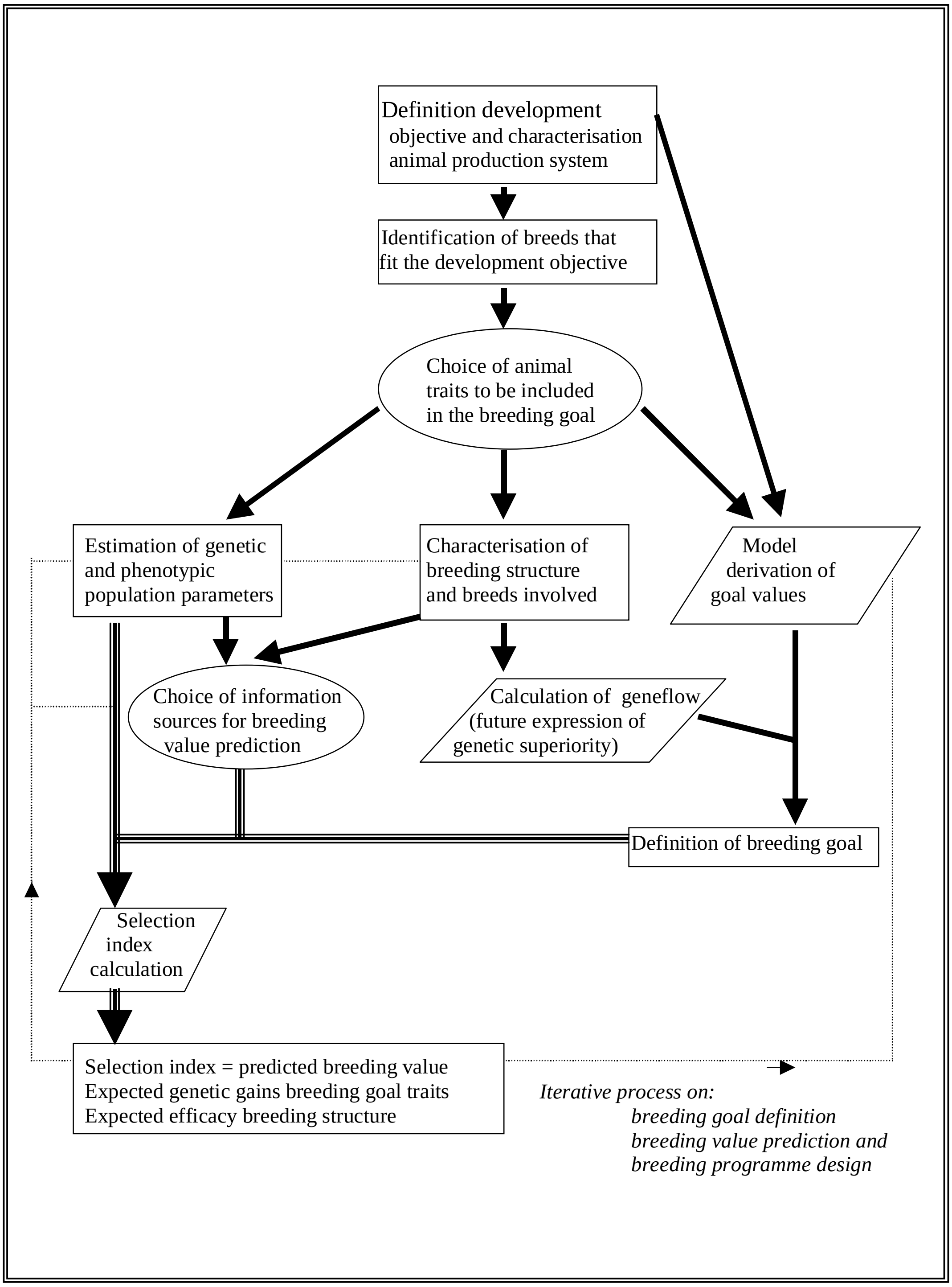


Figure 2.1. Planning genetic improvement strategies.

User guidance

Section 3 helps the user to identify the breeds and the breeding goal traits that fit the animal production system and the development objective of the farmers and the community in a broader sense.

- *Users not familiar with genetic improvement strategies and breeding goal definition* are instructed first to get an impression of the end terms of this chapter (by superficial reading) and then to carefully read the whole chapter following the different steps one by one. By going through the chapter several times, the users can iteratively refine their model of the production system before starting with Section 4.
- *Users familiar with breeding goal definition who want to refine or renew the breeding goals currently applied* should first document the model of the production system used for the current breeding goal and then use this as a starting point when going through Section 3.
- *Users already having made a definite choice on the breed and breeding goal traits and who are interested in the objective derivation of goal values* had best roughly identify the main ideas from Section 3 by studying the flow charts and then go to Section 4.3 directly. When working step by step from section 4.3 on, these users need information that others gather during Section 3.

Section 3. Development objective in agricultural production and characterisation of the animal production system

The aim of this chapter is to provide guidelines for the definition of a complete list of animal traits of interest to farmers to improve efficiency of production. The definition of this list of animal traits is to be based on:

- definition of the development objective of agricultural production in the country;
- characterisation of the animal production system for which the breeding goal is defined;
- choice of relevant breeds for the animal production system.

The list of animal traits serves as an entrance to the choice of breeding goal traits. This list of breeding goal traits should be complete, comprehensive and mutually exclusive. In this section focus is on making a complete list. A lot of the information gathered in this section is used again in deriving goal values (Section 4).

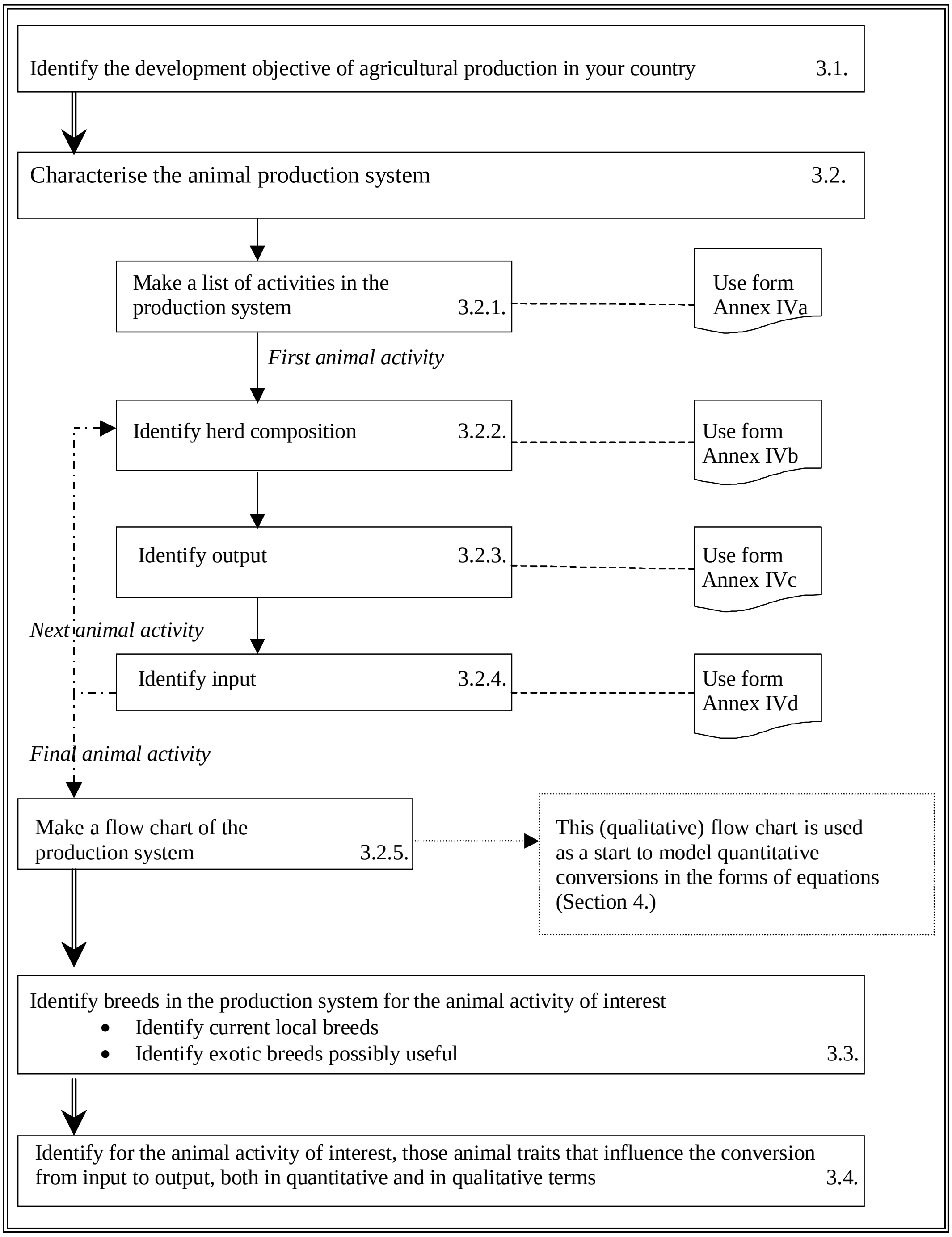


Figure 3.1. Stepwise characterisation of the animal production system and the development objective for agricultural production in the country.

User guidance
In these guidelines first the definition of the development objective in agricultural production in your country is established and next the characterisation of the animal production system (as a part of agricultural production in your country).

- First read this section on the development objective and then the section on the characterisation of the animal production.
- Then more carefully read this section and define a 'draft' development objective.
- Then more carefully read the next section and characterise the animal production system.
- Finally reconsider the 'draft' development objective and proceed with the choice of breeds.

A thoughtful definition of the breeding goal may require several 'iterations' (re-thinking to combine new ideas) on the underlying starting points like the development objective in agricultural production and the characterisation of the animal production system.

3.1 Defining the development objective in agricultural production

Genetic improvement is an important tool to achieve the broader development objective of agricultural production. This means that in order to make genetic improvement a suitable tool, we need to define the development objective as a starting point.

In Chapter 1, it was generally stated that the development objective focuses on sustainable agricultural production: conversion of available resources to human food and agricultural products without diminishing the future availability of those resources or causing environmental degradation. Genetic improvement can add to saving of resources (per unit of production) offering opportunities to alternative use of these resources. Now according to local environments the breeding goal should emphasise saving of one or more of these resources. For example, when pasture is very expensive or only available in a limited amount, emphasis is on reducing pasture required per animal. Again according to local environments, the saved resources are used to either expand production (in case of need for more human food), or are used for other purposes, not agricultural production (for example, saved labour is used by having a family member work in a local factory).

To conclude: to decide upon the breeding goal (traits included and goal value per trait), the user first needs to establish in what direction the agricultural production in the country is to change, the development objective of agricultural production. Before doing so, two important dimensions of decision-making in agricultural production ‘level’ and ‘time horizon’ are discussed.

Decision-making level
When you ask a national policy-maker in what direction agricultural production should change, you will get a different answer than when you ask an individual farmer. It certainly is not true that one of the answers will be wrong, but it simply is the case that the national policy-maker and the individual farmer take other points of view. Logically, the national policy-maker will be concerned with the availability of food for all inhabitants and national economics. On the other hand, the individual farmer will be more concerned with the interest of his own family and the profit of his own farm. To conclude: the interest in decision-making will depend upon whom you ask and the **level** or the scope that this person will take.

Decision-making time horizon
Suppose a veterinarian goes to a farm and asks the farmer what can be done for the farmer that day. The farmer will probably say that there is an ill animal that needs direct treatment because a bacterium is causing a clinic infection. When the veterinarian finished the treatment, the farmer is offered veterinary help for the next month and the farmer may choose what is to be done. Then the farmer will probably say that the animals in the herd are regularly suffering from the bacterium, endemically present in the herd and the farmer wants the veterinarian to have a look at all animals to determine which animals suffer sub-clinically from this bacteria. The next month the veterinarian does so and together with the farmer, the veterinarian sets up a scheme for preventing the bacterium to cause clinical infections again. At the end, the veterinarian asks the farmer what the farmer would like to do in the future to prevent the bacterium from causing damage again. The probable answer of the farmer to this last question will be to breed resistant animals. To conclude: the interest in decision-making will depend upon the **time horizon** taken for solving the problem.

Development objective:
- in what direction should agricultural production change?
- what opportunity is used when having available (saved) land, labour and capital?

The interest in decision-making will depend upon whom you ask and the **level** or the scope that this person will take.

The interest in decision-making will depend upon the **time horizon** taken for solving the problem.

Consider the long-term and a broad, national level in decision-making: what is the function of agricultural production? What purpose serves agricultural production in your country? Food production is certainly number one. But what else? What role does agricultural production serve in rural development, maybe in the tourist sector or nature conservation, or maybe it is an important sector in employment of people?

Given this role, would policy-makers in your country have preferences for the development of agricultural production in a certain direction? For example, in The Netherlands, policy-makers would like agricultural production to become more environmentally healthy and the Dutch Government gives subsidies to farmers when they take management measures to preserve nature and when they start activities in the tourist sector. In addition to political points of view, what do you think citizens in your country consider important for agricultural production? Consider not only economic factors, but also social and ethical factors.

When you are not sure about the long-term function of agricultural production in your country, or about the political issues, you should ask around and talk with policy-makers and citizens. Have a look at recent subsidies for agricultural production.

The **development objective** for your country:

Development objective of ....:
Future functions of agricultural production:
....
....
....
Changes in agricultural production looked for:
....
....
....

Discuss the development objective with many people, policy-makers, citizens and farmers. Try to find out if there is consistent thinking on this development objective, e.g. do policy-makers and farmers agree on the development objective. One way to check this is as follows. It was mentioned that genetic improvement can add to saving of resources (per unit of production) offering opportunities to alternative use of these resources. Ask a policy-maker what he would like farmers to do when there is land available (or labour or capital) and also what would the farmers do.

Putting things the other way around, the wish to develop a country in a certain direction will lead to market demand for production factors and to (relative) prices for the production factors that express their (relative) need for (alternative) opportunities. **Look up long-term price developments and check if the defined development objective is consistent with current developments in your country.**

Decision-maker

There is one more thing to find out with respect to breeding goal definition in relation to the development objective: who is the decision-maker in genetic improvement? In the selection process, who is making the final choice in deciding which sire is to be mated to which dam? Is it the farmer (owner of the animal) or other family members, is it a supplier of genetic material (e.g. commercial farmer) or is it some regional or governmental institution? It may be that the farmer is deciding within a limited list of alternatives offered by the commercial farmer, then it is still the farmer who decides. It may also be that the actual mating of a sire with a dam is not under direct control because several sires are within a group (flock or herd or whatever); then there is still someone who decides which sires are allowed in the group.

The decision-maker in genetic improvement:

Decision	Person
……………………	………………………..
……………………	………………………..
……………………	………………………..
……………………	………………………..
……………………	………………………..
……………………	………………………..
……………………	………………………..

Warning: this can be a very delicate point in the context of social structure! This question relates to the social status and influence of people. Make sure that you make a correct choice. Do not only ask the landlord who is making the decisions, but also the farmers. Do not only ask the head of the family, but also ask the women and herdsmen in the field.

3.2. Characterising the animal production system

This paragraph will guide the user to make the decisions on the first five steps of the characterisation of the animal production system.

1) The user's interest for these guidelines may have been to set up a breeding structure with breeding goal for a specific species. However, it is important to consider that farming systems will commonly involve more than one species. For example, farming systems in Ethiopia involve grazing cattle, sheep and goats. In China small farming systems have chickens, cows and pigs. Generally, the husbandries of these different species compete with each other, e.g. for feed or labour. Consider a separate activity for each animal species in the production system. Decide upon the relevance of taking many details for all species or only species of interest.

2) In developing countries, agricultural production is commonly in mixed farming systems. Plant and animal activities interact to make production as a whole more efficient. Also a mix of animal activities is used to enhance the efficient use of resources. For example, cows graze in longer grass and only eat the grass, while the goats eat the shorter grass and eat a lot of herbs; together they make better use of the pasture and the pasture will produce more feed. Although, the interest is in setting up a system structure for animal species, the whole of the production system in which the animals are kept is considered.

3) In characterising the production system, a lot of information is needed. Make sure that information from all kinds of sources is acquired: have a look at descriptive books and database statistics available, talk with specialists (people from extension services and researchers) or go out and have a look at the practical system and talk with farmers.

3.2.1. Activities

1) The first step in characterising the animal production system is to identify the different activities within the system; to break down the system into separate, but dependent, interacting entities. Use the form in Annex IVa to list the activities and have a look at the supplied example.

2) The identification should not be limited to animal activities only, but it should also include manufacturing of agricultural products and activities to acquire resources.

Be precise. Identification of the different activities is important because it is a first step to identifying the flow of products and resources and their use in the system. Especially the identification of activities that use resources is important when assigning values and cost, as are the activities that use (final or intermediate) products. Ignoring activities means ignoring flows of products and resources, which in turn lead to ignoring animal traits that are meaningful for the efficiency of the animal production system. This may lead to erroneously not including these animal traits in the breeding goal.

An example	Plant production	Market
	Biogas production	Cattle
Chickens	Household	Milk manufacturing

3.2.2. Herd composition

For the identification of product output and resource input in animal activities, closely examine the composition of the herd or flock. When multiple species are involved in the animal production system, consider herd composition for each of them.

What can be the sources of information for the figures on herd composition? Refer to statistics on number of animals within a certain region for example from a private or national recording institute. If these are not available, make an inquiry for farmers and gather the information in the field. Ask enough farmers (ten to 20) to make sure that a reliable and representative figure is obtained.

1) Animals enter the herd within the production system either by birth within the system or when bought; leaving the herd is by death or selling. Death of an animal may be the decision taken by the farmer (slaughtering or sold for production with another farmer) or may be involuntary by illness or high age. The life span of animals will depend on their sex and their use within the herd. Specific categories can be reproducing female, breeding male and slaughtering male. When looking at the herd composition, one could start with drawing the life span of an individual animal within a certain category and with defining the age structure in the herd at a given moment.

2) When drawing the life span of an individual animal, consider an average animal. Consider all important events for this individual animal, starting with birth and ending with death, referring to both production and reproduction. Use Annex IVb and consider the examples below. Make a life span drawing for each category of animals, reproducing females and males, slaughter males and females.

3) There may be an apparent difference between what you would like an average animal to do and what an average animal actually does under

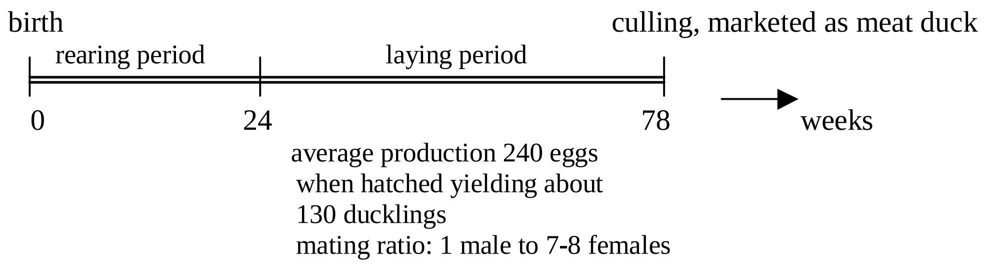
practical husbandry practices. At this stage consider an average animal under practical husbandry.

4) Consider average herd composition. Make categories of animals, for example, young animals in rearing, pregnant young animals, animals in first production cycle and so on. Do this for each animal category.

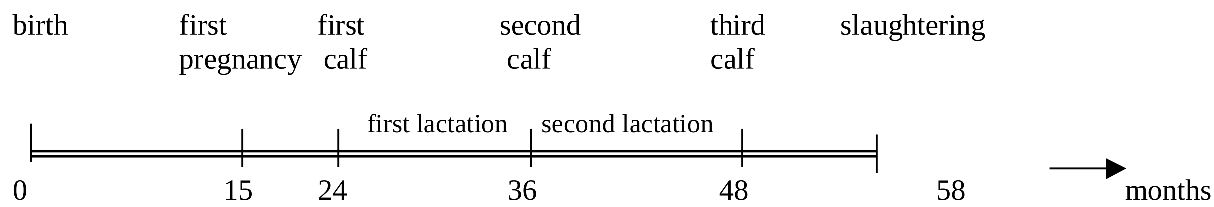
5) It is important to check consistency in the figures for life span and herd composition.
   - Calculate average age at leaving the herd from your average herd composition; this should be equal to the average age at slaughter / death in your life span drawing.
   - The number of animals born in the herd on a yearly basis should be equal to the number of animals leaving the herd on a yearly basis, at least in a herd of constant size.

Be precise. It is important to make a precise life span of the animals, with all important events included. These events relate to major requirements for inputs and major product outputs from the production system. These events also help to define efficiency of production over the life span of the animals. Ignoring events might lead to erroneously not including animal traits that influence efficiency of production in the list of important traits to be improved by selection.

An example - a typical Chinese duck: Jianchang Duck – dual purpose (meat, table eggs)



An example - an average buffalo cow in Egypt



An example – a buffalo herd in Egypt				
Animal category		Age period (in months)	Number in the herd on average per year	Specification
Young stock for replacement and reproducing females				
	Rearing period year 1	0 – 12	20	
	Rearing period year 2	12-24	18	
	First lactation	24-36	15	
	Second lactation	36-48	10	
	Third lactation	48-60	8	
	Fourth > lactation	60 >	17	
Total			50	
Breeding males				
	Rearing period	0-12	3	This assumes natural mating
	Adult bulls	12-24	2	
Total			5	
Slaughter animals				
	Female veal calf	0-10	5	When considering the dairy herd, these animals are generally sold at an age of two weeks
	Male veal calf	0-10	22	
	Beef bull	0-16	0	
Total			27	

An example – a buffalo herd in Egypt

Average age of slaughtering.

- 15 – 10 = 5 animals slaughtered during first lactation at average age of 30 months
- 10 – 8 = 2 animals slaughtered during second lactation at average age of 42 months
- other animals (43) at average age of 62 months
- ⇨ average age of animals at slaughter [5*30 + 2*42 + 43*62]/[5+2+43]=58 months of age
- ⇨ this is consistent with the age of the average dairy cow in the life span

Number of animals sold or involuntary leaving the farm per year:

- 5+22 female and male slaughter animals
- 1+2 young and adult breeding bulls
- 2+3 young female stock during rearing period
- 5+2+8 dairy cows during first, second and later lactation

This makes 25 female animals and 25 male animals yearly leaving the herd, which is equal to 20 young female stock + 3 young breeding bulls and 27 slaughter animals entering the herd on a yearly basis.

3.2.3. Output animal production activities

1) Domestic animals provide a whole range of human foods and other agricultural products, like power and fertiliser (see box). Identify for your production system, per species, the output of the animal activities. Do not leave out any output or contribution of the animals. Use the box below and the assumed herd categories and age groups for screening if your list is complete. Also re-consider the listed activities in your system for screening; include all flows of products from animal activities to other activities in the system. Use the form in Annex IVc.

Domestic animals provide

Food	Fertiliser	Income
Fibre	Fuel	Security
Power	Transportation	

Also Include in Annex IVc the following information:

2) Which activity uses the outputs (household, within farming system, market)?

3) Where a shortage of the product output is compensated (taken from another activity in the household or farming system, or bought at the market); identify (market) values; identify limitations in buying products.
4) Where a surplus of the product output is used (kept in household as savings, expanding household or farming system, sold at market); identify (market) values, identify limitations in selling products.
5) Identify quality differentiation in the products; for example, egg size or colour, fat content milk, beef marbling.

Be precise. It is important to list outputs of the animal activities carefully. Common outputs of the activities are directly related to animal traits that influence efficiency of production (especially traits measuring productivity of animals). Ignoring outputs might lead to erroneously not including animal traits that influence efficiency of production in the list of important traits to be improved by selection.

3.2.4. Inputs animal production activities

1) Domestic animals consume resources or inputs to produce their outputs. Identify for the production system, per species, the inputs to the animal activities. Use the box below and the assumed herd categories and age groups to check if the list is complete. Also re-consider the listed activities in the system for screening; include all flows of products from all activities to animal activities in the system. Use the form in Annex IVd.

An example – a list of output of a chicken farm

Animal activity	Output	To activity	In case of surplus to activity	In case of shortage from activity	Use for	Price differentiation[i]
Chickens	Eggs	Household	Market	Market	Food	Yes
	Feathers	Household	-	-	Pillows	-
	Meat	Household	Market		Food	Yes
	Young poultry	Market	Household		Replacement stock	Yes
	Dung	Plant production Household	Market	-		

[I] Is there any payment for quality of the product? If yes, how much?

Also include in Annex IVd the following information:

2) Who provides the inputs, who is the owner of inputs (household, local community, veterinarian, bank, etc.)?

3) How would a shortage of input be compensated (taken from another activity in the household or farming system, or bought at the market) - identify (market) values; identify limitations in buying inputs?

4) How would a surplus of input be used (kept in household as savings, expanding household or farming system, sold at market) - identify (market) values, identify limitations in marketing inputs/production factors?

5) How is quality appraised for inputs and outputs - is their price differentiation in quality?

Domestic animals need

Labour:	family labour, hired labour
Land:	crop production, grazing, other feeds, water
Capital:	housing, veterinary care, equipment, etc.

Be precise. It is important to list inputs of the animal activities carefully. Common inputs of the activities are directly related to animal traits that influence efficiency of production. Ignoring inputs might lead to erroneously not including animal traits that influence efficiency of production in the list of important traits to be improved by selection.

An example – a list of input of a chicken farm

Animal activity	Input	From activity	In case of shortage input	In case of surplus input	Owner	Price differentiation[I]
Chickens	Corn	Crop production	No buying	Market	Farmer	Yes
	'Waste'	Household, crop production, other animal activities	No buying	Pigs	Farmer	No
	Labour	Household	Other family	Help other family	Farmer	Yes

[I]Is there any payment for quality of the product? If yes, how much?

3.2.5. Flow chart of the production system

1) Now all the information on inputs and outputs of animal activities in the production system is to be summarised. From the information gathered a flow chart is made. A flow chart systematically shows all the 'flows' of products and resources between the activities within the production system. When making the flow chart, use the information from Annexes IVa, IVc and IVd.

2) In doing so, the user might conclude that the annexes are not complete; just complete them when making the flow chart. Use the example in the following box as a guideline for making the flow chart.

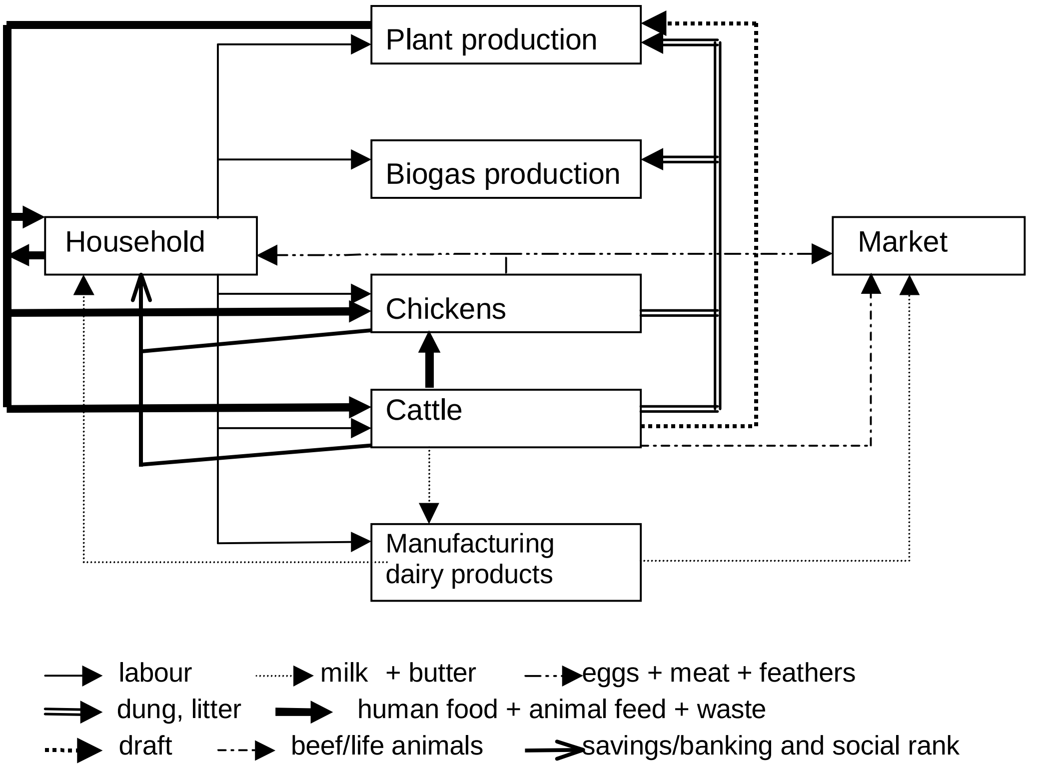
User guidance

The structure of the production system is assigned, a major step in the decision-making process. This structure is a starting point to:

- identify breeds that fit the development objective;
- choose animal traits to be included in the breeding goal; and
- identify the development objective of the production system.

This structure is also used for building a (mathematical) model to derive economic values (see Figure 2.1; Chapter 4.)
A lot of information on the animal production system is put together, the user might like to reconsider the definition of the development of agricultural production in the country.

An example – a mixed farming system



Interactions between activities in the production system

The approach taken is to decompose the production system in activities. Relationships between activities are considered by the flow of inputs and outputs. This approach is very helpful in understanding the production system; the variables and their relationships (mathematical functions) represent the activities and the flow of products and resources. It is however, important to realise that this approach is a simplification of the complex nature of life. It may be assumed that changing the genetic merit of the animals will not influence grass growth, dung composition or product quality, but in reality this will not always hold. It has always to be realised that the results of modelling are a direct consequence of the assumptions made.

3.3. Deciding on the breeds to use

Looking at livestock species, tremendous differences between individual animals are observed. A group of individuals 'more alike' (within the group) than others (outside the group) is called a 'breed'. The trait on which likeness is based can be anything from morphological trait (e.g. coat colour or hair type), to region of birth, to known breeding history (e.g. pedigree) or to production traits (e.g. suitability for pulling or meat yield). In general, breed definition is a composite of many likeness criteria.

When breeding, variation between individuals is exploited and in essence that part of the variation that has a genetic origin. In fact, generally a two-step procedure is followed:

1) choice of breeds used (this may be one breed, or multiple breeds in case of cross-breeding systems),
2) within-breed selection.

It is obvious that choices in both steps will deal largely with the same group of traits. In other words, when considering the choices that users have made in the past or would make in the near future, information is obtained on the traits to consider for within-breed selection. Therefore, this paragraph deals with the first step and in the next paragraph the traits for within-breed selection are considered.

① Identify the breeds of your current stock, use the box below. Also identify any other local breed used by other local farmers. List on what traits you define breeds and reveal the reasons why you keep the breeds you currently have.

Breed identification

Breeds of your current stock ………………..…………….
Other local breeds ………………..…………….
………………..…………….

Characteristics used for breed definition ……………… …………….
……………… …………….
……………… …………….

Why do you have the breed you currently have?
……………………………………………………………………………….
……………………………………………………………………………….
……………………………………………………………………………….

For information of the breeds and breed definition, ask the farmers. It is helpful to look at information provided by DAD-is.

② Look for any information available on local breeds, like mean production levels, disease resistance, product characteristics, etc. Some countries will have very good information on the breeds, other countries only poor information. Any information is welcome! Specify those characteristics, also based on the reasons given above, that make the local breeds especially adaptable to the local production environments and markets. Use the following box to characterise the local breeds, specifying per characteristic (if relevant) the level (e.g. growth, length calving interval, laying period, kg milk per lactation or hatchability of eggs).

Characterisation local breeds

Trait	Local breed				
	……				
……					

③ Put in the above box for each breed and characteristic a score: ++, +, 0, - or - -.

④ Make a choice on your two favourable local breeds.

⑤ A choice of breeds should start from the local breeds available, but should not be limited to those breeds only. Try to identify the weak points of the local breeds given the structure of the animal production system and the development objective of agricultural production. Look in the DAD-is system for other interesting exotic breeds that might be useful for you. Choose five breeds that might be useful and list the traits that complement your current local breeds and list the characteristics of the exotic breeds that are unfavourable relative to your current local breeds. From this list, decide upon whether or not you want to explore the possibility of using exotic breeds in improving your local breeds.

3.4. Listing animal traits

Make a list of animal traits for which genetic improvement might be important in order to realise the development objective of agricultural production in your country. Try to be complete. List anything important that comes into your mind when considering:

Characterisation exotic breeds

Exotic breed	Favourable traits	Unfavourable traits
……	……	……
…….		
…….		
…….		
…….		

- animal activities of the production system;
- inputs and outputs and the internal flows of commodities of the production system;
- development objective of agricultural production of the country;
- what the decision-maker in selection decisions will consider to be important;
- special characteristics of the local breeds and exotic breeds.

User guidance

After assigning the structure of the production system, we have now also defined the development objective of agricultural production and have identified breeds and traits we would like to be improved by selection to contribute to the development objective. Again a major step accomplished; we have gathered all the information we need for the more specific decision-making on the breeding goal. This is what we will do in the next chapter.

To make a start in breeding goal definition it is appropriate to start with a relatively simple situation. The user should be very careful with the implementation of results of (too) simplistic models.

- A sensitivity analysis is very useful: search for the major factors that determine the results of the modelling. Depending upon the outcome you might reconsider the assumptions for these major factors, or define a breeding goal that is relatively robust to the assumptions for the major factors.
- A sensitivity analysis can only be performed for modelling elements, not for factors that are not considered in the model. Therefore, reconsider the results of modelling from a broader perspective before applying results. Only when doing so, a relatively simple approach is a suitable and useful step in deciding on breeding goals. The more broad approach should include interactions between system activities and ecological effects of the production system on the society and world as a whole.
- It is advised, to apply an iterative approach: starting with a relatively simple, model and then stepwise expanding to a more complicated model.

A broader ecosystem

In this section, the entity of an animal production system was considered. The main objective was to assign outputs and inputs of the system that correspond to market commodities. This is an initial step, but it certainly cannot be the only step to be performed when defining breeding goals for sustainable production systems. It does not matter if the aim is for sustainable production by resource sufficiency or functional integrity, there is also a need to consider important criteria like nutrient leakage, gas production (NH_3, CH_4 and CO_2) and resource depletion rates. In other words, the broader ecosystem 'surrounding' the agricultural production system is to be considered.

User guidance

Section 4 helps the user to make a choice on the breeding goal traits and to assign goal values to each breeding goal trait.

- Users not familiar with genetic improvement strategies and breeding goal definition are instructed first to get an impression of the end terms of this chapter (by superficial reading) and then to read carefully the whole chapter following the different steps one by one. By going through the chapter several times, the users can iteratively refine the derivation of goal values.
- Users already having made a definite choice on the breed and breeding goal traits and who are interested in the objective derivation of goal values had best go to Section 4.3 directly. When working step by step from section 4.3 on, these users need information that others gather during Section 3.

Section 4. Breeding goal: defining goal traits and assigning goal values

This section guides the user in defining the breeding goal.

1) First a complete, comprehensive and mutually exclusive list of breeding goal traits is made.
2) The next step is to weigh the breeding goal traits, to give each goal trait a relative value expressing to what extent genetic improvement for the goal trait is needed: a goal value.

- The goal value of a trait determines the emphasis a trait will get in selection decisions. A higher goal value for a trait (relative to goal values of other traits) means that animals with a high predicted breeding value for the trait are generally more selected. Thus, with a higher goal value, the trait will be more genetically improved in the offspring.

- In other words, the (relative) goal values are very important because they determine the levels of genetic improvement of the traits in the breeding goal. These levels of genetic improvement should fit the development objective in agricultural production.

- In order to make breeding goals effective, the decision-maker in decision selection should indeed use the goal values to weigh the predicted breeding values. To enhance the practical implementation of breeding goals it is important to obtain a certain degree of commitment on the goal values with the farmers.

Goal values can be assigned in a subjective way or by an objective derivation based on normative modelling. When first defining the breeding goal, a subjective assignment is a meaningful step, because it forces the user to carefully think about the close relation between the development objective in agricultural production and the desired genetic improvement of traits. The objective derivation of goal values is a more advanced way of establishing the breeding goal based on concrete knowledge on the technical and socio-economic production environment.

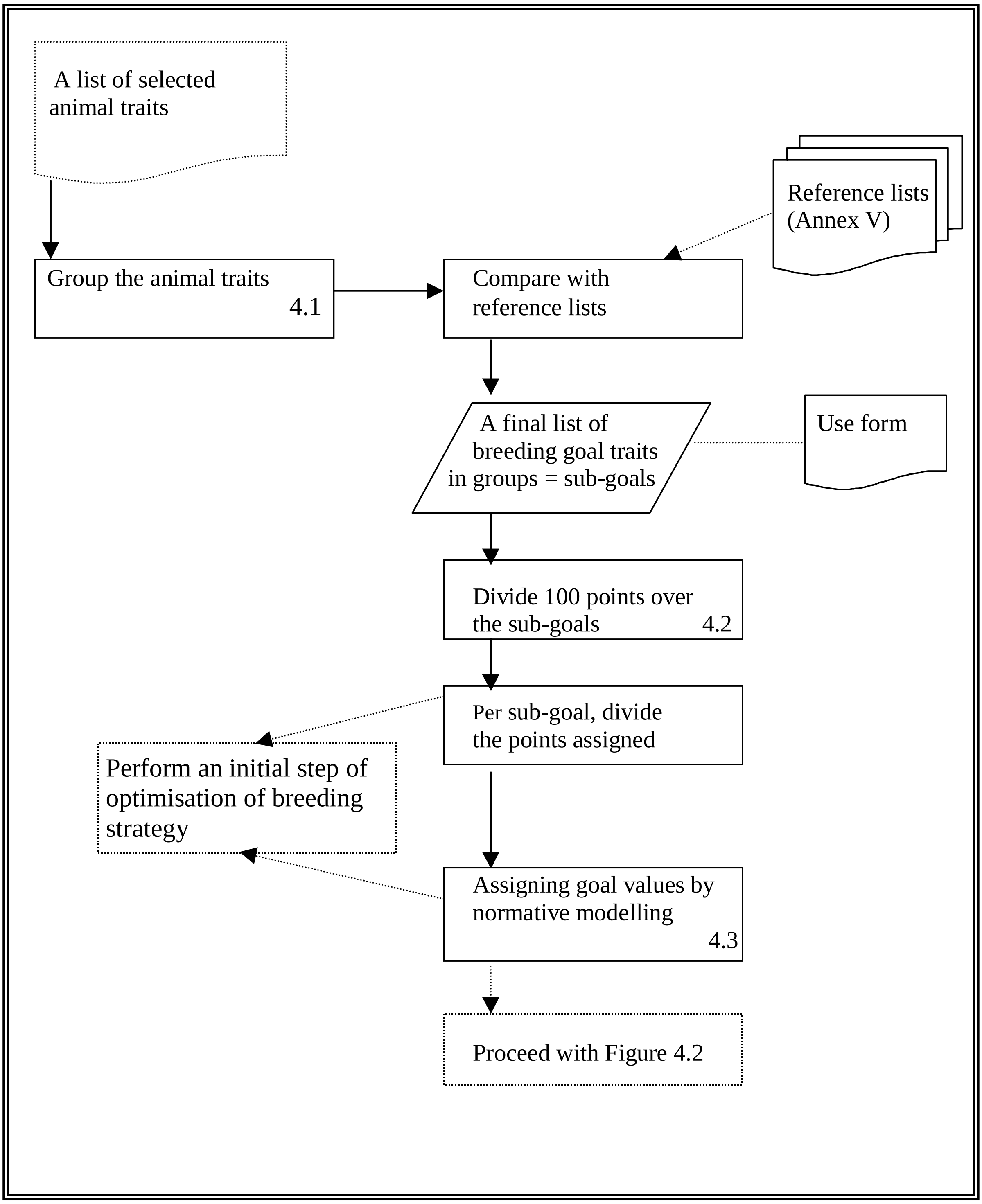


Figure 4.1. Stepwise procedure in listing breeding goal traits and assigning goal values.

4.1. Listing breeding goal traits

In Section 3.4, the user made a complete list of animal traits; a list that includes all traits that the user thought of when defining the development objective of agricultural production in the country, when describing the animal production system and when deciding on the breeds to be used.

With the complete list of animal traits as a starting point, a list of breeding goal traits is defined. The list of breeding goal traits should be complete but also comprehensive and mutually exclusive.

- **Complete** means covering the whole of traits of importance in helping to establish the development objective. Completeness means that the breeding goal is a suitable, helpful tool in establishing the development objective. Ignoring important traits means that these traits will not get the genetic improvement desired from the development objective; some traits might even deteriorate from erroneously ignoring them, leading to unfavourable side-effects from selection (e.g. fertility and health will deteriorate when selecting for production traits only). Completeness will also appeal to the decision-maker in selection of animals and give an incentive to indeed use the predicted breeding values on goal traits available.

- The breeding goal should be **comprehensive**. When dividing selection pressure over many traits, genetic improvement for each of these traits will be limited. When making a comprehensive breeding goal, with a limited number of traits, then genetic improvement for each of these traits is more readily obtained, showing that selection indeed can help to establish the development objective. Again, this point is an incentive for the decision-maker in selection to practically implement the selection on breeding goal traits. Also a comprehensive goal can be more easily explained to and understood by the farmers.

- The traits in the breeding goal should be **mutually exclusive**. This condition does not require complete absence of relationships between goal traits; that would even be practically impossible. This condition means, however, that from two traits that are highly correlated and in fact focus at the same characteristic of the animal, only one trait is to be included in the breeding goal. For example, it is better to include only weaning weight of piglets averaged over males and females as a breeding goal trait, not weaning weight for each sex separately. Another example in sheep, includes only female fertility in first and (averaged) later parity when it is known that the number of lambs born in first parity is a clearly different trait while all later parities genetically are the same trait.

① Consider the list of animal traits filled in of these guidelines. Group the traits according to
- production traits
- non-production traits.

- Production traits are traits that are directly linked to the output of an animal product like wool, meat, milk, draught; genetic improvement of a production trait will directly increase the production level per animal.

- Non-production are traits for which a genetic improvement will not directly increase production level of the animal, but a genetic improvement will lead to an increase in efficiency of production by lowering the input of resources per animal.

- *NB. The difference between production and non-production traits is not always straightforward, for example, when considering reproduction in animals for meat production. Do not worry too much; the difference between production and non-production traits is not a goal itself, but only a way to define the main groups of traits in the breeding goal.*

② Within the group of production traits, identify groups according to the product output that is increased. For some species only one product is relevant, for other species multiple products will be relevant. Sometimes it is desirable to distinguish only the main product from a larger group of by-products.

③ Within the group of non-production traits, identify groups according to:
- traits directly related to **health** of the animals, if wanted, distinguish traits for the most important disorders separately;
- traits directly related to **fertility and parturition,** if wanted, distinguish between traits for female and male fertility;
- traits directly related to **feed intake** (requirement) of the animals, for example feed intake capacity, body weight (as an indicator of maintenance requirements), or feed conversion;
- traits directly related to **workability** of the animals, like character (ease of handling), social behaviour and milking speed.

④ After steps ①, ② and ③, some traits may not fit into one of the groups: either remove the trait from the list when not considered important or assign a separate group for this trait.

⑤ Reconsider the groups; each group will represent a sub-breeding goal. Rule of thumb: use no more than six sub-breeding goals and no more than four traits per sub-breeding goal.

⑥ Compare the current list of breeding goal traits with the reference lists in Annex V. Again reconsider that the list is complete, comprehensive and mutually exclusive. Also reconsider that the list of breeding goal traits should correspond to the development objective of agricultural production, the animal production system and the choice of breeds to use.

⑦ Finalise the list of breeding goal traits by filling in the table in the next box and if convenient, list predictor traits per sub-goal.

- Removing traits from the list is important. Consider the following: is it important to improve the trait as such, or is it important to improve the trait because it helps to genetically improve another, underlying trait. For example, udder attachment in goats is an indicator trait for mastitis susceptibility: mastitis susceptibility is the breeding goal traits, not udder attachment. Udder attachment might be a good trait to include in a recording scheme and to use in an index for the prediction of the breeding value for mastitis susceptibility (see also Annex I).

- For the users own convenience these '**predictor**' or index traits can be listed separately.

- Notice, it is not necessary that breeding goal traits can be directly, routinely observed on selection candidates. For example, in pig breeding, selection is for fatness of the carcass. Fatness of the carcass is in the breeding goal, but is not observed on selection candidates, because this would mean that candidates have to be slaughtered, which means that they cannot be used anymore for breeding. As a predictor trait, a routine score on body condition is taken or sub-cutaneous fat thickness is measured ultrasonically.

A list of breeding goal traits

Sub-breeding goal
Other index traits for the prediction of breeding values

- Sub-division of the total breeding goal in groups of sub-goals is a useful way towards the practical implementation of selection of male and female parents. Sub-division allows the direct identification of the main characteristics looked after when genetically improving animals.
- Sub-division of the total breeding goal also enhances a stepwise assignment of goal values; a stepwise weighing of predicted breeding values.
  1. For each breeding goal trait, breeding values are predicted per selection candidate (from direct (= same trait) or indirect (= other predictor trait) observations).
  2. The traits within a sub-goal are weighed to give a predicted breeding value of this whole sub-group per selection candidate. Likewise for every sub-group.
  3. The predicted breeding values per sub-group are weighed to a 'total' breeding value per selection candidate.

This way, the sub-division allows an easy identification of the strong and weak points per selection candidate.

An example - A list of breeding goal traits in dairy cattle breeding

Sub-breeding goal					
Milk production	**Female fertility**	**Health resistance**	**Calving performance**	**Feed efficiency**	**Miscellaneous**
Milk yield Fat yield	Cycling/showing heat	Mastitis incidence	Direct effect Maternal effect	Body weight Feed intake capacity	Character Milking speed
Protein yield	Pregnancy rate		Still birth		
		Mobility		Body condition score	
Other index traits for the prediction of breeding values					
	Interval calving – 1st insemination	Cell count	Rump angle	Muscularity Body depth	
		Claw diagonal Rear legs set		Body width	

4.2. Subjectively assigning goal values

A helpful way to become familiar with the weighing of breeding goal traits is the subjective assignment of goal values. This can be done by an individual user of these guidelines, e.g. policy-maker or farmer, or can be done via a more extensive expert panel or survey.

① The set up is to first divide 100 points over sub-goals as given in the former table.

- Note, the scale is linear: twice as many points for a trait means that the predicted breeding value for the trait gets twice as much emphasis in the total index value of the animal. However, this does not mean that the genetic improvement for the trait will be twice as high. Remember that the level of genetic improvement will also depend on the genetic possibilities of improvement (considering the genetic and phenotypic parameters in the population, such as (co)variances and correlations) and the number of observations on the animal and its relatives.

- At this stage it is useful to perform a 'sensitivity analysis', referring to Figure 2.1. When (preliminary) information on the breeding structure is known and population parameters and discounted expressions (from gene flow) are available (or reasonable assumptions can be made), the user should perform selection index calculations to derive expected genetic gains for the breeding goal traits. By varying the subjectively assigned goal values (at constant other assumptions), a fair picture can be obtained to what extent changes in goal values will give rise to changes in expected genetic gains.

- Notice, that when performing the above steps, the user enters the stage of **optimising the breeding strategy**!

② Next, divide the points per sub-goal over traits within the sub-goal.

- Note, the scale is linear: twice as many points for a trait means that the predicted breeding value for the trait gets twice as much emphasis in the total index value of the animal. However, this does not mean that the genetic improvement for the trait will be twice as high. Remember (page 7) that the level of genetic improvement will also depend on the genetic possibilities of improvement (considering the genetic and phenotypic parameters in the population, such as (co)variances and correlations) and the number of observations on the animal and its relatives.

- At this stage it is useful to perform a 'sensitivity analysis', referring to Figure 2.1. When (preliminary) information on the breeding structure is known and population parameters and discounted expressions (from gene flow) are available (or reasonable assumptions can be made), the user should perform selection index calculations to derive expected genetic gains for the breeding goal traits. By varying the subjectively assigned goal values (at constant other assumptions), a fair picture can be obtained to what extent changes in goal values will give rise to changes in expected genetic gains.

- Notice, that when performing the above steps, the user enters the stage of **optimising the breeding strategy**!

4.3. Assigning goal values by normative modelling

This Section will guide the user to build a model for the objective derivation of goal values for the breeding goal traits. Figure 4.2 summarises the different steps involved. The next paragraphs give background information on each of these steps, especially on what information to base the choice, possible choices and effects of each choice. Referring to Figure 2.1**,** a lot of the information required is gathered during Section 3 when defining the development objective in agricultural production and the characterisation of the animal production system.

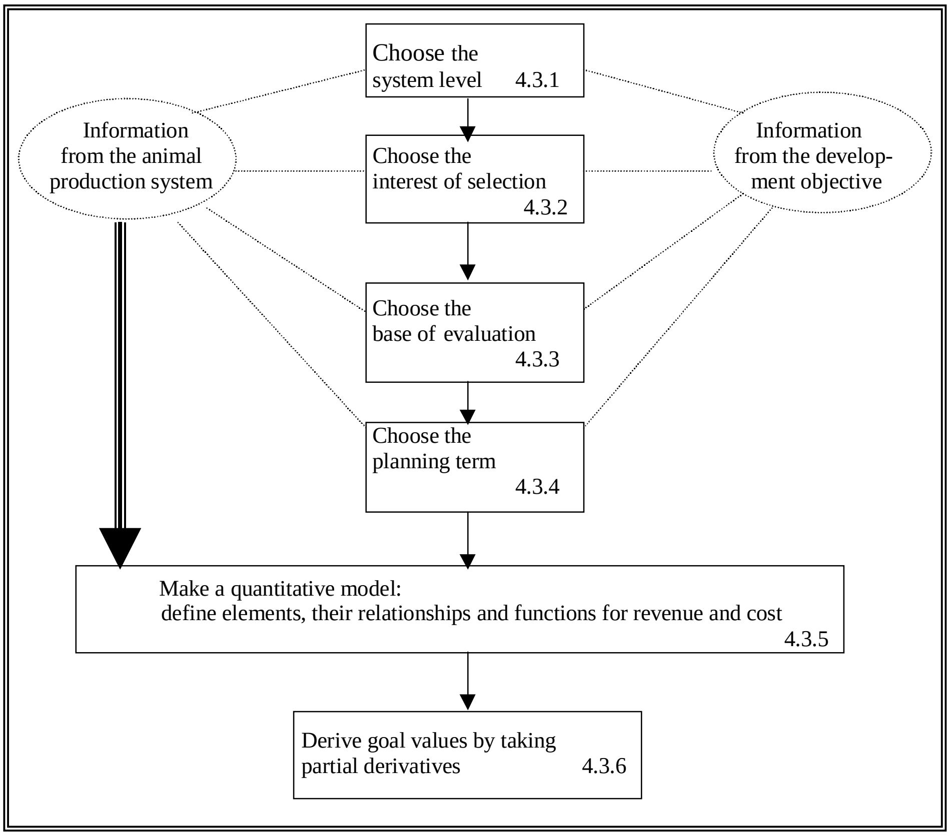


Figure 4.2. Stepwise assigning goal values by normative modelling.

4.3.1. System level

A model is an equation or a set of equations that represent the behaviour of a system. A model is not the complete, real system; it is generally less than complete because it should only include those elements of reality that are relevant for the study undertaken. A model is an ‘abstract’ of the real system in order to study the behaviour of the system. The behaviour of the system is the way in which the system reacts to endogenous or exogenous impulses. In fact, the interest is in finding out how the system reacts on an improvement in genetic merit of the animals in the system.

Figure 4.3. gives a general structure of animal production systems. Genetic merit is tied up to the level of an animal. Therefore, the animal level is the lowest level considered in deriving goal values, but higher levels may be considered as well. Notice, elements and their relationships chosen in a model on animal level depend on biological processes at even lower levels.

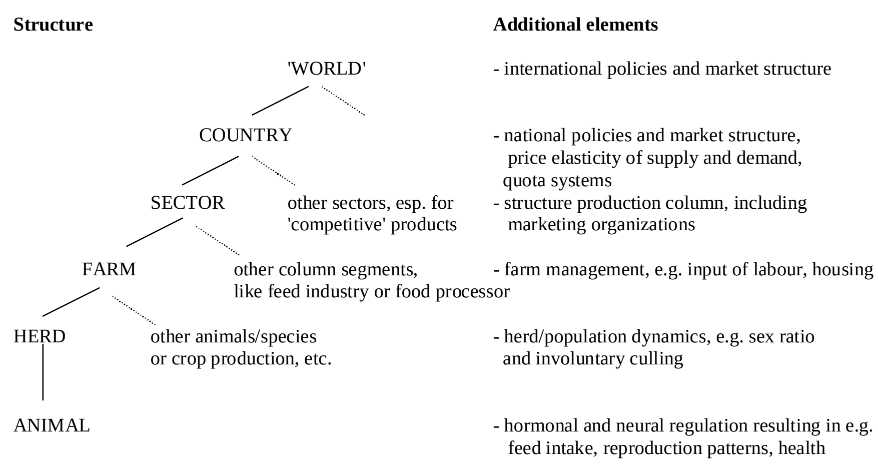


Figure 4.3. A general structure of animal production systems.

Improvement of genetic merit is a technological development; it increases the efficiency of production by saving resources per unit of output. Long-term effects of greater efficiency will be reflected in lower market prices. Yet, a cyclic interaction is observed. Future prices determine goal values; goal values determine genetic change per trait and genetic change per trait will influence future prices. Therefore, the derivation of goal values ideally requires knowledge on future levels of genetic improvement and their price effects.

Make your choice in system level to model. The advice is to consider farm level.

The theoretically appropriate level to be used in deriving goal values is the one for which limited resources and prices of products and resources are influenced by an improvement of the trait. This readily ends up at sector or national level. Although theoretically appropriate, national and sector level are rarely chosen because of methodological difficulties. The potential bias as a result of simplification made by modelling at herd or farm level can be tested by calculating goal values for several assumptions on market prices and production levels (sensitivity analysis).

4.3.4. Interest of selection

The interest of selection denotes the primary interest of the decision-maker. This primary interest will strongly depend upon the position that the decision-maker holds on the market. There are several types of markets, differing in the way that prices are determined and a (long-term) balance is found between total demand and supply for the product. Options for the interest of selection are:

- maximise revenues minus cost (profit maximisation);
- minimise cost per unit of product (or cost price minimisation); or
- maximise revenues per unit of cost (maximise return on investment).

The differences between these options probably do not look readily obvious and there is an overlap between these. For example, cost price minimisation will help to increase profits. Taking this even further, assuming certain market conditions, taking the average over farmers and overlooking the long-term, the approaches are equal. However, there are differences in these options that are interesting enough to consider when defining breeding goals from the point of view of an individual farmer.

The farmer generally deals with a market of free competition; there are many consumers and producers and an individual farmer has no influence on the price setting. In this situation, the interest of the individual farmer will be to maximise profit.

When breeding goals have been developed by and for producers or groups of producers, emphasis is therefore put on profit maximisation. In developing countries, markets are generally more local, but the same mechanism will apply (see example). It is therefore advised to opt for profit maximisation, unless there are clear reasons to deviate from this.

The question “why consider profit maximisation with a taxpayer-financed national breeding structure?” is very relevant. The government sets up the breeding structure and the main interest of the government is to reduce the cost per unit of food for the citizens. There are two possible answers. First situation: the government is in charge of the (national) breeding structure to test and make available good breeding animals. However, they still allow the farmer to make a choice in which breeding animals to use and there is even an option for the farmer not to use a breeding animal from the government. In this situation, the basic decision of which animal to use is still made by the farmer and the farmer will follow his interest of selection. Note the possibilities of governments to impose their interests on the individual producers by creating a social and economic production environment. Secondly, when the government is in charge of the (national) breeding structure and fully controls the decision-making in breeding, then cost price minimisation might be taken.

A commercial investor might also set up a breeding structure. An investor has money available for investments and will choose the branch that gives the highest return on investment. Well, the same type of answering holds as with the taxpayer-financed breeding structure; only with full control by the investor, return on the investment should be considered as the interest of selection. However, the investor (and also the government) will generally give responsibility of the decision-making to the individual farmer, maybe only for the sake of having the farmers involved in the structure.

[The effect of the chosen interest of selection will be presented after making the choice on the basis of evaluation.]

An example

At the market place in a small town in India, farmers (themselves or via merchandisers) are selling their chicken eggs. The people from the small town will generally first look around at the market place before deciding where to buy their eggs. An individual farmer asking too high a price (given a certain quality) will not sell his eggs. Of course, some people will try to buy at lower prices, but at a certain price level the farmer will stop selling his product. This is a market of free competition.

An individual, commercial farmer will try to maximise his profit; he will try to produce a number of eggs where the cost to produce an additional egg is fully compensated by the market price. Producing one more egg will have higher costs (e.g. from feed input) and for that egg, the market price will be too low. He will not produce one egg less, because that egg will have marginal costs that are lower than the market price; producing and selling this egg will give more benefit, i.e. profit.

An individual farmer with 'backyard' production of chicken eggs will probably reason in another way, because his costs of producing one more egg are not directly identifiable. However, the market principle is the same. Also this farmer will not sell his eggs at too low a price, because he will consider the alternative of having the eggs consumed by his own family.

4.3.3. Basis of evaluation

Another hard decision is still to be made: the basis of evaluation. The basis of evaluation is representing the strict limitations for the production system, i.e. the farmer's management over the planning term of decision-making in animal breeding. The system may face:

- a fixed input of a certain resource, e.g. feed, land or labour;
- a fixed output of a certain product, e.g. milk quota.

In the case where no fixed input or output is faced, the basis of evaluation will be:

- a fixed number of animals on the farm.

Limitations as applied at farm level are denoted here, but for the taxpayer and investor financed breeding structures and limitations at higher system level will apply. For example, a fixed amount of product output for a sector in the breeding structure.

Maybe it is not directly obvious why a basis of evaluation is to be chosen. Think of it in the way that somehow the size of the system is to be defined or restricted. When the system size is not constrained by an input or output component, it is convenient to define system size in terms of the number of animals.

Make a decision on the basis of evaluation. When the product output or the input of a certain resource (land, labour or feed) of an individual farm is restricted by legislation, consider this restriction as the basis of evaluation. Also when legislation places a very strict limitation on output of by-products or elements of environmental pollution, take this as the basis of evaluation. When the system is constrained for multiple products or resources, assume these multiple restrictions as the basis of evaluation. When the system size is not constrained by an input or output component, it is convenient to define system size in terms of the number of animals.

It might be that legislation is enforced that does not strictly constrain the input or output but applies levies on surpluses used or produced. For example, a normative figure for the loss of CO_2 to the environment is set per farm and when farms have a loss lower than the normative figure, no levy has to be paid. However, when the loss is higher, a levy must be paid. This situation with levies does not enforce a strict constraint to be considered in choosing a basis of evaluation. It introduces however, non-linearity of prices to be considered when deriving goal values.

What is the effect of a choice on the basis of evaluation? The effect will be considered together with the effect of a choice in the interest of selection.

This is one of the most difficult areas of breeding goal definition and it is a heavily debated area. The basic idea of the effects of the basis of evaluation and interest of selection is summarised in Table 4.1 in terms of economic perspectives.

Table 4.1. Economic perspectives in deriving goal values with different basis of evaluation and different interests of selection.

Basis of evaluation	Interest of selection	
	Maximisation of profit	Minimisation of cost price
Fixed number of animals	Marginal revenue[A] - Marginal cost	Average total cost [A] - Marginal cost [B]
Fixed input	Marginal revenue [A]- Average (revenue-fixed cost per animal)[C]	Average total cost [A] - Average fixed cost farm [C]
Fixed output	Average variable cost [A] - Marginal cost [B]	Average variable cost [A] - Marginal cost [B]

[A] Per δy units of product
[B] Per δy units of product, corresponding to δx_v units of production factor
[C] Per δx_v units of production factor

When maximising profit of the farm assuming a fixed number of animals on the farm, the general question is: are, per animal, the marginal cost of inputs lower or higher than the marginal revenue of outputs obtained? When marginal revenues are higher than marginal costs, a higher level of outputs per animal by genetic improvement is beneficial, i.e. the goal value of the trait is positive.

When minimising the cost price with a restricted output of the farm, the question is: is the marginal cost of additional inputs needed to increase the production of the animal by one unit, higher or lower than the average cost per unit of product? When the marginal costs are lower than an increase in product output per animal (while reducing the number of animals per farm), will it reduce the overall cost price per unit of product, i.e. the goal value of the trait is positive?

Details in Table 4.1 (examples on how these economic perspectives are derived and a discussion on differences and equivalencies) are in Annex VI. Here, it is important that the user of the guidelines understands that the different choices on the basis of evaluation and the interest of selection allows for the goal value to be derived from a different economic point of view. These different economic points of view enforce that different aspects of the (economic) production environment determine the goal values of traits. As an example, when maximising profit with a fixed number of animals, the price of the product becomes a major parameter as it determines marginal revenue. However, when minimising cost price with a fixed output, the price of the product plays no role at all. Another example, generally average variable costs are highly influenced by average production levels, while marginal revenue are not.

The user has already made a choice on the basis of evaluation and the interest of selection. **The advice is to hold on to the choices that were made and to start making a normative model for the derivation of goal values.** After finishing the model, the user should reconsider the choices made and perform a sensitivity analysis on important parameters, preferably when considering different interests of selection and different basis of evaluation. From this sensitivity analysis, the impact of choices made should be fully understood.

4.3.4. Planning term

In the choice of the planning term there are basically three options:

- < 1 year - short or operational term;
- 1-5 years - mid or tactical term;
- 5 years - long or strategic term.

The choice of a planning term should be included in deriving goal values regarding:
1) the choice of price parameters; and
2) the distinction between variable and fixed cost.

The choice of the planning term is also related to the choice of system level. For example, only in the long-term will the improvement of a trait influence limited resources and prices of products and resources at sector level.

For an individual farmer, the choice is primarily based upon his assessment of when revenues from breeding decisions are expected. This will largely differ between livestock species.

Make a decision on the planning term. The advice is to consider long-term price parameters and a clear distinction between cost variable and fixed time.

It is difficult to distinguish between mid- and long-term in estimating future prices. Try to analyse historic price trends over a long period and try to predict from these trends possible future prices. When considering that future prices will depend on a few basic assumptions, for example, regarding governmental policies, define different scenarios.

Selection sometimes has a major influence on the short-term efficiency of a single farm (e.g. value of new-born calf to be sold for beef production). Nevertheless, it is appropriate to consider long-term prices, because the major benefits from selection will appear in the longer term.

Modelling allows for the implementation of mathematical programming techniques to (re-)optimise management variables with changing levels of genetic merit. For example, dynamic programming can be used to determine the optimum replacement policies. Reducing involuntary (reproductive failure, health problems) disposal rates increased optimum voluntary disposal. Ignoring these changes in management variables would underestimate the economic advantage of reducing involuntary culling. Linear programming is used to derive goal values in dairy cattle according to environmental policies. Linear programming also allows easy handling of multiple restrictions. As for example, future governmental policies and their effects on farm structure are yet unknown, different alternatives can be studied and linear programming allows for the definition of optimum farm management for each alternative. In fact, linear programming allows for the best (given farm characteristics) use of saved resources, in others words, the appropriate choice of (marginal) prices for (marginal) feed requirements. Consider optimising farm management as a refinement when modelling for the derivation of goal values; a refinement that might be considered in a later iteration.

The question of optimising farm management given farm structure should not be confused with optimising farm structure. Animal breeding is part of long-term planning of production. Therefore, it is appropriate to consider all cost to be variable in time. However, costs may be fixed (constant or discontinuously variable) with respect to the size of the farm. Considering these fixed costs to be variable per unit of product requires an assumption on the (continuously optimum) size of the farm. However, structural developments in industry are then detached from improvements in the efficiency of production, which is not correct considering long-term effects of the implementation of new techniques. **Therefore, in deriving goal values, clearly distinguish between costs fixed and variable in size, independent or dependent on the level of genetic merit per animal.** For example, housing costs include variable costs per animal, but also fixed costs not related to the number of animals in the stable.

4.3.5. Elements of the model and their quantitative relationships

Choices on the level of the system, the interest of selection, the basis of evaluation and the planning term are now made, the user will make a set of equations, a normative model.

① Consider the flow chart of the animal production system. Define two equations, one for cost as a function of the inputs of the system and one for revenue as a function of the outputs of the system. Combine these two equations in one regarding the interest of selection of the system: profit = revenue – cost and cost price = amount of product / cost.

② Refine the broad equations for cost and revenue by splitting each term into two factors: one factor representing ‘amount’ and one factor representing ‘price’. It may be that a term combines multiple outputs (e.g. feed costs are from feeding grain and grass), then split each term likewise but per output component. When a product is sold with different qualities, consider the amount and price of each product separately. The same should be done for resources with different qualities.

③ While detailing the equations for the revenue and cost, make a listing of all input variables required, distinguish between:
- parameters to be derived from more detailed modelling, **internal parameters,** these parameters are usually variable;
- parameters to be assigned from external information, **external parameters** these parameters are usually considered fixed.

④ Now start detailing the equations further, internal parameter one-by-one, until for each internal parameter an (underlying) equation is derived based on external parameters only.

This is a laborious work that needs a lot of careful detailing. Work precise; write out the equations on paper. A direct transfer of the equations in a computer model (e.g. in a spreadsheet program) is very convenient. Make a good documentation of the model; make sure that other people can understand the model and that other people can retrace the origins of parameters assumed.

Below some literature examples of models in terms of a set of equations are given. Do not use these literature examples as ‘blue prints’ of the model to develop; these references are only given to help the user get started when detailing their own model.

Pigs: De Vries, A.G., 1989. A model to estimate economic values in pig breeding. Livestock Production Science, 21: 49-66.

Beef cattle: Hirooka, H., A.F. Groen and J. Hillers, 1998. Developing breeding objectives for beef cattle production. 1. A bio-economic simulation model. Animal Science, 66: 607-621.

Broilers: Groen, A.F., X.S. Jiang, D.A. Emmerson and A. Vereijken, 1998. A deterministic model for the economic evaluation of broiler production systems. Poultry Science, 77: 925-933.

Sheep: Simm, G. , M.J. Young and P.R. Beaton, 1987. An economic selection index for lean meat production in New Zealand sheep. Animal Production, 45: 465-475.

Dairy cattle: Groen, A.F., 1988. Derivation of economic values in cattle breeding: a model at farm level. Agricultural Systems, 27: 195-213.

⑤ Make a full list of all external parameters and distinguish between the following groups of external parameters:

- external parameters representing the social-economic production environment (e.g. product prices at the market place; levies and subsidies as part of governmental legislation, fixed and variable cost housing), **social-economic parameters**;
- external parameters that represent the technical production environment, (e.g. energy content of feed stuffs, energy requirement per kilogram product or labour requirement per animal), **technical parameters**;
- external parameters that represent the genotype of the animal, these will be the **breeding goal traits**.

The structure of the model should be such that it allows the clear identification of the breeding goal traits. As the user knows for which breeding goal traits goal values are to be derived, perform steps ① to ⑤ directed towards defining equations that relate the cost and revenue of the system to the (assumed levels of) breeding goal traits.

The derivation of goal values requires that the breeding goal traits can be varied independently.

A model is an ‘abstract’ of the real system in order to study the behaviour of the system. The behaviour of the system is the way in which the system reacts to endogenous or exogenous impulses. In fact, the interest is in finding out how the system reacts on an improvement in genetic merit of the animals in the system.

⑥ Define for each external parameter (social-economic, technical and breeding goal) a level. Relate the levels to the animal production system (and its whole environment) and the choice of breeds in the system.

⑦ Use the levels of the external parameters to calculate all internal parameters and, as a summary of it all, the cost and revenue of the system and the interest of selection (profit or cost price).

⑧ Validate the outcome of step ⑦. Validation is perhaps the most difficult, but also the most crucial step of building a model. Validation requires both objective comparison of outcomes of the model to ‘real life’ data (and changing external parameters when necessary) and subjective, heuristic playing around with levels of parameters in order to get close to 'reality'.

Validation of the model requires re-iteration on steps ② to ⑦ until a satisfactory outcome of the model is obtained.

A model is not the complete, real system; it is generally less than complete because it should only include those elements of reality that are relevant for the study undertaken.

⑨ Finalise the model building by redefining the equations such that the interest of selection (i.e. profit or cost price) is a direct function of

$$(\text{Factor}_1 * \text{Level trait}_1) + \ldots\ldots + (\text{Factor}_n * \text{level trait}_n)$$

This way of expressing the equations is most helpful when deriving the goal values.

4.3.6. Taking the partial derivative

The final step in deriving normative goal values is now to observe how the modelled system reacts on an improvement of the genetic merit of the animals in the system.

① Calculate the level of profit or cost price of the system assuming all the base parameters of the model.
② Keep all base parameters constant except for the level of one breeding goal trait; increase the level of this trait by one unit (e.g. from 150 eggs to 151 eggs, from 100 g / day growth to 101 g / day, from 2 300 kg milk per year to 2 301 kg milk per year). Recalculate the profit or cost price of the system.
③ With the interest of selection being profit maximisation, define the goal value of the breeding goal trait as (profit ② - profit ①); with the interest of selection being cost price minimisation, define the goal value as (cost price ① - cost price ②).
④ Repeat steps ② and ③ for all breeding goal traits.
⑤ Validate the goal values. Consider if the goal values are logical and can be interpreted and explained to the farmers. Consider performing a sensitivity analysis, i.e. repeating steps ② and ③ with other base levels for external parameters. If this validation requires redefining the model of the system, do so.
⑥ Make a final list of goal values for each breeding goal trait.

At this stage it is useful to perform a 'sensitivity analysis', referring to Figure 2.1 on page 14. When (preliminary) information on the breeding structure is known and population parameters and discounted expressions (from gene flow) are available (or reasonable assumptions can be made), the user should perform selection index calculations to derive expected genetic gains for the breeding goal traits. By varying the goal values (at constant other assumptions), a fair picture can be obtained to what extent changes in goal values will give rise to changes in expected genetic gains.

Notice, that when performing the above steps, the user enters the stage of **optimising the breeding strategy**!

4.3.7. Advanced topics

Customised goal values

Breeding goals have to correspond to the individual farmer's interest of selection; the farmers for buying a certain stock (or semen or embryo) at a certain price, will be based upon his assessment of how animals will contribute to the efficiency of his farm. As farmers are confronted with different production environments (socio-economic, natural or technical), goal values may differ for different groups of farmers. This is the basis for a diversification of breeding goals among (groups of) farmers and the use of customised indices for (individual) farms. **The study on possible differences in goal values for different groups of farmers should be an advanced step in defining breeding strategies.** The final decision on a practical implementation of diversification of breeding goals or the application of customised indices requires careful consideration of aspects like effects on selection intensities (and thus future genetic improvement) in the breeding strategy and acceptance of the farmers to cooperate in the strategy.

Non-linear goal values

The goal value of a trait may depend on the level of the trait itself or on the level of other traits. **Evaluation of non-linearity of goal values can be performed by deriving goal values at different starting values for genetic merit of the animals.** When goal values are indeed found to be non-linear, regularly updating goal values according to new population averages is a strategy that gives satisfactory results and is easily understood by farmers.

For traits with non-linear goal values, it should be possible to increase the mean value of the objective function in the progeny by planned sire*dam matings. The advantage of planned matings will be greatest for traits with a high heritability and a population mean close to the economic optimum. Mating strategies are to be considered as part of breeding strategies.

Individual animal variation

Generally in modelling to derive goal values, it is assumed that all animals in the system have equal genetic merit. This is a simplifying assumption, because in a real system there will be variation among animals in a herd or flock. For the derivation of goal values for some traits (especially traits like involuntary culling of the animals) ignoring individual animal variation might bias resulting goal values. However, including individual animal variation in the model is a complicated advanced step. **Necessity should first be carefully considered for example by performing a sensitivity analysis on non-linearity of goal values with respect to genetic merit of the animals.**

Annex I. Selection index theory

The aggregate genotype and selection index

The choice of an aggregate genotype is the starting point in setting up breeding structures. The aggregate genotype is used to represent the genetic merit of an animal: the sum of its genotypes for several traits (assuming a distinct genotype for each trait), each genotype being weighted by the predicted contribution to the increase in the overall development objective. Usually, a breeding structure has different selection paths. A classical example is when four different selection paths are distinguished: SS (sires to breed sires), SD (sires to breed dams), DS (dams to breed sires) and DD (dams to breed dams). Selection paths differ in the generation interval (see later), the amount of information available for the selection decision and also in the intensity of selection (see later). Therefore, although the traits in the aggregate genotype are the same for each selection path, selection paths differ in the relative weighing of traits in the aggregate genotype.

In each selection path, selection for each genotype trait is on predictive observations (the phenotypic performance of the animal itself and of related animals). These observations maybe on the trait itself or on correlated traits. Observations will be combined in a selection index. The calculation of index co-efficients (or weighing factors, regression co-efficients) for observations in the selection index maximises the response to selection by maximising the correlation between genotype trait and index, considering:

- the number of observations in the index;
- the (family) relationship between the animal being evaluated and the source of information;
- the genetic and phenotypic (co) variances among the genotype trait and the index observations.

$$I_{ykl} = \mathbf{b}'_{ykl}\,\mathbf{x}_{yl} \qquad \mathbf{b}_{ykl} = \mathbf{P}^{-1}_{yl}\mathbf{G}_{yl}$$

where,

I_{ykl} is the selection index value of an animal for genotype trait *y* in situation *k* and selection path *l* (CU.animal^{-1});

$\mathbf{b}_{ykl}$ is an *n* x 1 vector with the index coefficients of *n* index traits for genotype trait *y* in situation k and selection path *l* [CU.(animal.unit)$^{-1}$];

$\mathbf{x}_{yl}$ is an n x 1 vector with the phenotypic performance for n index traits (unit) for genotype trait y, specified for a selection path l;
$\mathbf{P}_{yl}$ is an n x n matrix with the covariances between n index traits for genotype trait y, specified for a selection path l;
$\mathbf{G}_{yl}$ is an n x m matrix with the covariances between genotype trait y and n index traits, specified for selection path l.

The vector x should not contain the 'crude' observations on animals, but should contain the phenotypic performances as a deviation from a 'comparable average'. For example, when the milk production of a Zebu cow is 7 kg, while on average Zebu cows in the same herd on the same day at the same stage of lactation produce 6.5 kg, the observation on this individual cow is denoted as 7 - 6.5 is 0.5 kg.

In fact, the index value I_y is the predicted breeding value of the animal for trait y (PBV_y). When we use a full multi-trait approach, i.e. the vector ***x*** and the matrix ***G*** consider all observations used to predict genetic merit of all genotype traits, then the total index value I_T is a weighed summation of I_y 's:

$$I_{Tkl} = \mathbf{a}'_{kl} I_{ykl} \qquad \mathbf{a}_{kl} = \mathbf{c}_l \mathbf{v}_k$$

where,

$\mathbf{a}_{kl}$ is an m x 1 vector with the discounted goal values of m genotype traits in situation k and selection path l ($CU.animal^{-1}.unit^{-1}$; where unit stands for e.g. kg milk, egg number or kg growth);
$\mathbf{c}_l$ is an m x m diagonal matrix with the cumulative discounted expressions of m genotype traits in selection path l [$(animal.timeperiod).animal^{-1}$; timeperiod is e.g. week or year];
$\mathbf{v}_k$ is an m x 1 vector with the goal values of m genotype traits in situation k [$CU.(animal.timeperiod)^{-1}.unit^{-1}$].

The so-called cumulative discounted expressions (calculated from geneflow, Annex III) and the goal values determine this contribution. The goal value of a trait expresses to what extent the efficiency of production is improved at the moment of expression of one unit of genetic superiority for that trait. The cumulative discounted expression of a trait reflects time and frequency of the future expression of superior genes originating from the use of a selected individual in a breeding structure. Multiplying the goal values by the cumulative discounted expressions gives the discounted goal values.

In fact, the above description is a two-step procedure. First we predict genetic values (using bs and xs) and then we weigh predicted genetic values to aggregate the breeding goal, the aggregate genotype. When I_y are fully multi-trait prediction (i.e. all xs are used for each I_y then I_T as above is fully equivalent to the aggregate genotype H, as originally introduced in the selection index by Hazel (1943):

$$H_{Tkl} = \mathbf{a}'_{kl}\,\mathbf{g}_{kl} \qquad I_{Tkl} = \mathbf{b}'_{kl}\,\mathbf{x}_{l}$$

where H_{Tkl} is the (total) aggregate genotype of an animal in situation k and selection path l (CU.animal^{-1}) and g is an *m* x 1 vector with the (true) genetic superiorities of m genotype traits.

The two-step procedure is practically more appealing to breeders because it more clearly shows the predicted breeding values per trait (PBV_y) of interest and how the PBV_ys should be weighed in selection decisions.

In practice, PBV_ys tend not to be predicted by a fully multi-trait approach. In the predictions simplifications are made to reduce computational efforts. These simplifications usually include considering only single traits or small groups of traits to predict a PBV_y, e.g. only milk observations used to predict PBV_{milk} and only udder conformation traits used to predict $PBV_{mastitis}$. The error of this simplification is dependent on the accuracy of Iy (lower error with higher accuracies) and on the correlation structure G (lower error with less correlated traits).

Selection index theory

Breeding Goal			Symbol
	Also called:	Aggregate genotype	H
	Includes	Genotype traits	g
	weighed by	Discounted goal values	a
	In fact is	True breeding value	
Selection tool			
	Also called	Selection index	I
	Includes	Observations	x
	weighed by	Index co-efficients	b
	In fact is	Predicted breeding value	PBV

How well does the tool fit with the goal? - Accuracy of selection=correlation between breeding goal and selection tool; given by the ratio of the standard deviation on the index over the standard deviation on the goal.

Accuracy of selection

The variance on H among animals in a population is

$$\sigma^2_{H_{kl}} = \mathbf{a}_{kl}\mathbf{C}\mathbf{a}_{kl}$$

where,
C is a m x m matrix with the co-variances between m genotype traits.

The variance on I among animals in a population is

$$\sigma^2_{I_{kl}} = \mathbf{b}_{kl}\mathbf{P}_l\mathbf{b}_{kl}$$

The suitability of the selection index I to predict (true) genotype values in the aggregate genotype H is given by the correlation between I and H

$$r_{IH_{kl}} = \frac{\sigma_{I_{kl}}}{\sigma_{H_{kl}}}$$

When the correlation is 1, the variance in I is equal to the variance in H, denoting that the index can fully reveal the variation in true genotype values. This correlation between I and H is generally called the accuracy of the index (the quadrate being called the reliability of the index), or accuracy of the prediction.

Defining (co)variances matrices C, G and P

When defining co(variance) matrices, three different types of co-variances will be encountered:
1. (co)variance among animals (for the same trait);
2. (co)variance among traits (for the same animal);
3. (co)variances when multiple observations are considered.

Ad 1.

The co-variance among two animals A_1 and A_2 can arise from a common genetic background and from a common environmental background. The common genetic background is given by the additive genetic relationship between the animals. So,

$$Cov_{A_1A_2} = a_{12} \times \sigma^2_A + c^2 \times \sigma^2_P$$

where,

a_{12} is the additive genetic relationship between animals A_1 and A;
σ^2_A is the additive genetic variance (for a given trait);
c^2 is the common environmental variance as a fraction of the total phenotypic variance σ^2_P

c^2 is usually defined for a specific group of related animals, for example, full sib litter mates or mother and daughter producing in the same herd.

This equation ignores genetic covariances between animals other than additive genetic co-variances.

Another common way to write the same formula is:

$$Cov_{A_1A_2} = t \times \sigma_P^2$$
$$t = Rh^2 + c^2$$

where t is the intraclass correlation; R is another symbol for a_{12}; h^2 is the heritability of the trait, equal to the additive genetic variance as a fraction of the total phenotypic variance.

With 1 and 2 being the same animal, t is called the repeatability of the trait and c^2 denotes the permanent environmental variance as a fraction of total phenotypic variance; the co-variance between repeated measurements is then equal to the genetic variance plus the permanent environmental variance.

Ad 2.

Calculation of the co-variance between two traits y and z is based on the knowledge of the correlation co-efficient r_{yz}

$$\mathrm{cov}_{yz} = r_{yz} \times \sigma_y \times \sigma_z$$

where, σ denotes the standard deviation on the trait. This principle can be applied for phenotypic, genetic and environmental correlations. With y and z being the same trait, of course the co-variance becomes the variance on the trait.

Ad 3.

Assume that we have n observations on trait y. Variance on the average of y is:

$$\sigma_{\bar{y}}^2 = \mathrm{var}[(y_1 + y_2 + ... + y_n)/n] = \mathrm{cov}[(y_1 + y_2 + ... + y_n)/n, (y_1 + y_2 + ... + y_n)/n]$$

So, the variance on the average of y is equal to $1/n^2$ multiplied by [n times the variance on the observation y_i itself plus n(n-1) times the co-variance between two observations y_i and y_j

$$\sigma_{\bar{y}}^2 = \frac{1}{n^2}[n \times \mathrm{cov}(y_i, y_i) + n(n-1) \times \mathrm{cov}(y_i, y_j)] = \frac{1}{n}[\sigma_y^2 + (n-1)t\sigma_y^2] = [(1 + (n-1)t)/n] \times \sigma_y^2$$

where t represents either the repeatability or the intraclass correlation.

Likewise it can be derived that the covariance between one observation on trait z and the average of n observations on y is:

$$\text{cov}_{\bar{y}z} = \frac{1}{n} \times n \times \text{cov}(y_i, z) = \text{cov}_{y_i z}$$

Having these three types of co-variances, we can work out the (co)variance matrices C, G and P.

C-matrix, the co-variances between genotype traits, these will always be genetic co-variances, always considers the same animal (for which the genotype value is calculated) and does not deal with multiple measurements

- diagonal: same trait

$$\text{cov}(g_y, g_y) = \sigma^2_{A_y}$$

- off-diagonal: other trait

$$\text{cov}(g_y, g_z) = r_{A_{yz}} \times \sigma_{A_y} \times \sigma_{A_z}$$

G-matrix, the co-variances between genotype traits and index observations

- general

$$\text{cov}(x, g_y) = a_{ij} \times r_{A_{xy}} \times \sigma_{A_x} \times \sigma_{A_y}$$

- special situations
  - same animal, same trait (i = j, x = y)

$$\text{cov}(x, g_y) = \sigma^2_{A_x}$$

  - same animal, other trait (i = j)

$$\text{cov}(x, g_y) = r_{A_{xy}} \times \sigma_{A_x} \times \sigma_{A_y}$$

  - other animal, same trait

$$\text{cov}(x, g_y) = a_{ij} \times \sigma^2_{A_x}$$

P-matrix, the co-variances between selection index observations

- diagonal: same trait, same animal

$$\text{cov}(x, x) = [(1+(n-1)t)/n] \times \sigma^2_{P_x}$$

- off-diagonal:
  - same trait, different animals (a_{ij} now is the relationship between animals in the group for which the average is calculated)

$$\text{cov}(x, x) = a_{ij} \times \sigma^2_{A_x} + c^2 \times \sigma^2_{P_x}$$

  - other trait, same animals

$$\text{cov}(x, y) = \frac{1}{n} \times [r_{P_{xy}} \sigma_{Px} \sigma_{P_y} + (n-1)(a_{ij} r_{A_{xy}} \sigma_{A_x} \sigma_{A_y} + r_{e_{xy}} \sigma_{e_x} \sigma_{e_{yy}})]$$

$$\text{cov}(x, y) = a_{ij} r_{A_{xy}} \sigma_{A_x} \sigma_{A_y}$$

- other trait, other animals

(Maybe you will also have to account for environmental correlations here, but environmental correlations between different traits on measured different animals are generally ignored).

Selection intensity

What is selection intensity? Assume a certain selection based on criterion c. Assume S_c to be the selection differential for the selection criterion c: the mean for c of the selected group of individuals. c is assumed to be distributed normally, with mean μ_c and variance σ^2_c. When standardising observations on c to x according to

$$x_i = \frac{c_i - \mu_c}{\sigma_c}$$

x_i will be distributed normally with mean zero and variance 1. Now, the selection intensity is equal to the standardised selection differential S_x, given as

$$i = S_x = \frac{S_c - \mu_c}{\sigma_c}$$

i can also be calculated as *i* = z / p, where z is the value of normal distribution with mean zero and variance 1 at culling point with fraction p selected. Thus, for any given p and corresponding z, i can be computed. Tabulated selection intensities for given fraction p are given for example by Falconer (1989). Note that in applying selection theory c = I and I ~ $N(0,\sigma^2_I)$.

It is important to mention that in calculating i as z / p it is assumed that selection is in a population of infinite size with the criterion for selection being normally distributed. Another assumption is that observations on the selection criterion are independent and originate from an infinite population. These aspects will generally not hold in animal breeding as populations of potentially selected animals are small and breeding values are derived using mixed model methodology (i.e. sire or animal models). Adjustments of i for both aspects can be made.

Selection response

After one round of selection, the genetic superiority (GS) of the selected animals for each genotype trait m is

$$GS_{klm} = (i_l / \sigma_{I_{kl}}) \times \mathbf{b}'_{kl}\mathbf{G}_m$$

where,

i_l is the intensity of selection in path *l*,
$\mathbf{G}_m$ is the m^{th} column of **G**.

A breeding goal is defined for the reference 'predicted' future situation and the corresponding 'predicted' discounted goal values. The obtained economic revenues are the sum of genetic superiority for all *m* genotype traits due to selection in all *l* selection paths, weighed by the 'actual' discounted goal values ('actual' denoting at the future moment of expression of the superiority). When the predicted goal values equal the actual goal values (i.e. predicted production circumstance equal actual production circumstances), optimum levels of improvement per trait and maximum economic revenues (MER, CU per animal in the population) of the breeding structure will be obtained

$$MER_k = \sum_l \left[i_l \times \sigma_{I_{kl}} \right]$$

This equation is equal to the formula by Rendel and Robertson (1950)

$$\delta GS_k = \frac{\sum_l GS_{kl}}{\sum_l L_l}$$

when all cumulative discounted expressions in all selection paths equal 1 over the sum of generation intervals (*L*) for all selection paths. This will hold when cumulative expressions are derived for an on-going breeding structure, evaluated over an infinite time term and are not discounted (or discounting rate is 0). In fact, δGS is the steady state predicted genetic gain per year when applying a certain breeding strategy (H, I and i) in a population. Calculation of MER is more flexible, as the cumulative discounted expressions included can deal with both discounting and irregular patterns of response to selection, especially in periods when starting a breeding structure (see Annex III).

Note that in calculating both MER and δGS it is assumed that variances of traits and other genetic parameters, as well as selection intensities are independent of each other and do not change over time, notwithstanding applied selection.

Annex II. Mixed model methodology

This is only a very short introduction to mixed model methodology, merely aiming at showing its equivalence to selection index theory.

In a mixed model, we assume observations to be influenced by fixed and random effects. In matrix notation, a mixed model can be expressed as

$$\mathbf{y} = \mathbf{Xb} + \mathbf{Zg} + \mathbf{e}$$

where,

y n x 1 vector with n observations;
b f x 1 vector with f fixed effect levels;
g s x 1 vector with s random effect levels (e.g., s is the number of animals a breeding value has to be derived for using the data);
e n x 1 vector with error terms;
X n x f incidence matrix indicating for each observation the fixed effects by which it is influenced;
Z n x s incidence matrix indicating for each observation the random effects by which it is influenced.

Expectations and variances on the observations and random effects are:

$E(\mathbf{y}) = \mathbf{Xb}$ $\quad Var(\mathbf{y}) = \mathbf{V} = Var(\mathbf{Zg} + \mathbf{e}) = \mathbf{ZGZ}' + \mathbf{R}$ $\quad Cov(\mathbf{y},\mathbf{g}) = \mathbf{ZG}$
$E(\mathbf{g}) = \mathbf{0}$ $\quad Var(\mathbf{g}) = \mathbf{G}$
$E(\mathbf{e}) = \mathbf{0}$ $\quad Var(\mathbf{e}) = \mathbf{R}$

From solving such a mixed model 'best estimates' (accurate and unbiased) for fixed effects (Best Linear Unbiased Estimates; BLUE) and for breeding values (Best Linear Unbiased Prediction; BLUP) are obtained simultaneously. Henderson showed that solving the model can be performed using the so called 'Mixed Model Equations' (MME)

$$\begin{vmatrix} \mathbf{X'R^{-1}X} & \mathbf{X'R^{-1}Z} \\ \mathbf{Z'R^{-1}X} & \mathbf{Z'R^{-1}Z + G^{-1}} \end{vmatrix} \times \begin{vmatrix} \hat{\mathbf{b}} \\ \hat{\mathbf{g}} \end{vmatrix} = \begin{vmatrix} \mathbf{X'R^{-1}y} \\ \mathbf{Z'R^{-1}y} \end{vmatrix}$$

where,
X is sized n x f, so **X**' is f x n (*number of rows* x *number of columns*);
R and $\mathbf{R}^{-1}$ are n x n. **Z** is n x s; **Z**' is s x n.
The total size of the left hand side matrix equals f+s rows and f+s columns and this matches with the size of the vector containing estimates for **b** and predictions for **g** and with the size of the right hand side of the equation.

The left hand side of the MME can be quite large, especially when going to animal models and multiple trait models.
Breeding values **g** can be predicted from

$$(\mathbf{Z'R}^{-1}\mathbf{X})\hat{\mathbf{b}} + (\mathbf{Z'R}^{-1}\mathbf{Z} + \mathbf{G}^{-1})\hat{\mathbf{g}} = \mathbf{Z'R}^{-1}\mathbf{y}$$

which is equivalent to

$$\hat{\mathbf{g}} = (\mathbf{Z'R}^{-1}\mathbf{Z} + \mathbf{G}^{-1})^{-}(\mathbf{Z'R}^{-1}\mathbf{y} - \mathbf{Z'R}^{-1}\mathbf{X}\hat{b}) = (\mathbf{Z'R}^{-1}\mathbf{Z} + \mathbf{G}^{-1})^{-}\mathbf{ZR}^{-1}(\mathbf{y} - \mathbf{X}\hat{b})$$

Now remember the selection index theory (Annex I), where the predicted breeding values were identified as I_y = $\underline{\boldsymbol{b}_y\boldsymbol{'x}_y}$ where **x** was a vector of observations and **b** was a vector with index co-efficients calculated as $\underline{\boldsymbol{P}}^{-1}\underline{\boldsymbol{G}}$ (italics and underlining is used to clearly differentiate between symbols used in selection index theory and mixed model methodology). Reformulating the selection index derivations in terms of mixed model methodology:

- $\underline{\boldsymbol{x}}$ in the selection index relates to **y** in the mixed model; in Annex I it was denoted that $\underline{\boldsymbol{x}}$ should be corrected for a 'comparable average'; in fact the mixed model methodology accomplishes this by correction for estimated fixed effects;
  $\underline{\boldsymbol{x}}$ = **y -Xb**
- $\underline{\boldsymbol{P}}$ is the co-variance matrix of the observations and is therefore equal to Var(**y**) = **V** =**ZGZ**'+**R**
- $\underline{\boldsymbol{G}}$ is the co-variance matrix between observations and breeding goal traits and is therefore equal to Cov(**y**,**g**) = **ZG**

As a result for the selection index

$$\hat{\mathbf{g}} = \mathbf{GZ'}(\mathbf{ZGZ'} + \mathbf{R}^{-1})^{-}(\mathbf{y} - \mathbf{X}b)$$

Henderson proved that the solutions for the breeding values g are equal for both selection index theory and mixed model methodology, apart from the fact that selection index theory assumes that comparable averages (or **Xb**) are known without error, while mixed model methodology estimates these comparable averages from the data. The full proof is not given here, but similarity is shown for a simple example. Assume we have an average of n observations on the animal, then

$$\mathrm{var}(\bar{y}) = \mathrm{var}(g) + \mathrm{var}(e)/n = \sigma_A^2 + \sigma_e^2/n$$
$$\mathrm{cov}(\bar{y}, g) = \mathrm{var}(g) = \sigma_A^2$$

The estimate of g from both the mixed model methodology and selection index theory then becomes:

$$\hat{\mathbf{g}} = n \Big/ \left(n + \sigma_e^2/\sigma_A^2\right) (\mathbf{y} - \mathbf{X}\hat{\mathbf{b}})$$

See for basic theory and advanced applications of mixed model methodology Henderson (1994, book).

Annex III. Calculation of GeneFlow

The basic principle of a breeding structure is that genetically superior animals are used to breed the progeny. The genetic response is the increased genetic value of the progeny because of using genetically superior parents. GeneFlow calculates genetic response and specifies its dynamics by modelling in detail **the flow of (superior) genes** through the population.

GeneFlow can be thought of in terms of the question: what proportions of genes do parents of different groups contribute to the genome of a certain group of progeny? To structure this analysis, first the population is divided into groups according to age classes of (breeding and production) animals within each sex. The choice of the length of age classes depends on the species concerned and the production system of interest. For example, in pig production age classes of half a year are convenient; in dairy cattle usually one year is used, while in broilers weekly periods relate better to the production system in use. Secondly, because the interest is in following the flow of genes in time, time is also divided into periods with the same length as age classes.

Now, let $m_t(i)$ be the proportion of genes of interest in age class i at time t. There are two processes that give a transfer of genes in time from one class to another class: reproduction and ageing.

Two matrices can describe the processes of reproduction and ageing, R for reproduction and Q for ageing. The total transfer of genes by reproduction and ageing is given by matrix P = R + Q.

An example

A population with the following specifications is considered:

1) *Males are kept for two age classes (i=1,2) and progeny is born to males in age class two only. These males are two years old at birth of progeny.*
2) *Females are kept for three age classes (i=3,4,5); culling takes place after age class three only. Females produce progeny when they are in the second and third age class. Female replacements are taken equally from two and three year old dams; male replacements are taken for 75 percent and 25 percent from two and three year old dams, respectively.*

Putting these words to mathematical equations, males in age class one at time t ($m_t(1)$) obtain half of their genes from males in age class two (i=2) at time t-1, 3/8 from females in age class two (i=4) and 1/8 from females in age class three (i=5):

$m_t(1) = ½\ m_{t-1}(2) + 3/8\ m_{t-1}(4) + 1/8\ m_{t-1}(5)$.

Likewise,

$m_t(3) = ½\ m_{t-1}(2) + ¼\ m_{t-1}(4) + ¼\ m_{t-1}(5)$.

Genes get into class two, four and five by ageing

$m_t(2) = m_{t-1}(1)$
$m_t(4) = m_{t-1}(3)$
$m_t(5) = m_{t-1}(4)$.

In the example

$$\mathbf{R} = \begin{vmatrix} 0 & \frac{1}{2} & 0 & \frac{3}{8} & \frac{1}{8} \\ 0 & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{2} & 0 & \frac{1}{4} & \frac{1}{4} \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{vmatrix} \quad \mathbf{Q} = \begin{vmatrix} 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \end{vmatrix} \quad \mathbf{P} = \begin{vmatrix} 0 & \frac{1}{2} & 0 & \frac{3}{8} & \frac{1}{8} \\ 1 & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{2} & 0 & \frac{1}{4} & \frac{1}{4} \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \end{vmatrix}$$

R-elements denote proportions of genes in age classes obtained from an age class one time period earlier. **Q** contains only zero's and one's. The sum of elements per row of **P** should always be one.

For specific purposes, one might be interested in the dissemination of genes using one single initial selection path. For example, what is the future contribution by sows that are selected as boar mothers when compared to those by sows that are selected as sow mothers? To answer this question, one should study the gene flow as transmitted to the first generation of offspring through one single path, while transmission to following generations is by all paths. To do this, a matrix $\mathbf{R}_l$ is defined, containing zeros except for the one row describing the transmission of genes through path l. If an $\mathbf{R}_l$ is defined for all paths (including those which do not really represent a path of gene transmission), then

$$\mathbf{P} = \sum_l \mathbf{R}_l + \mathbf{Q}$$

(Note, that all $\mathbf{R}_l$s should be equally sized.) In matrix algebra, the transmission of genes can be described as two processes

$$\mathbf{n}_{l,t} = \mathbf{Q}^t \mathbf{n}_{l,O}$$
$$\mathbf{m}_t = \mathbf{P}\mathbf{m}_{t-1} + \mathbf{R}_l \mathbf{n}_{l,t-1}$$

The vector $\mathbf{n}_{l,0}$ will generally contain zeros but a one in the class for which the fate of genes has to be followed. The first process describes ageing and allows genes to arrive in those classes of $\mathbf{n}_{l,t}$ which contribute to reproduction. When there, the second term of the second process describes how these genes are transmitted by reproduction to the whole population, to $\mathbf{m}_{l,t}$. Vector $\mathbf{m}_{l,t}$ contains zeros initially ($\mathbf{m}_{l,0} = \mathbf{0}$), but as soon as genes have arrived in $\mathbf{m}_{l,t}$, further transmission to following generations is described by $\mathbf{Pm}_{l,t-1}$. After genes considered reach the oldest age class, $\mathbf{n}_{l,t}$ gets $\mathbf{0}$ (the initial genes die). At this stage, the second process simplifies to

$$\mathbf{m}_{l,t} = \mathbf{P}\mathbf{m}_{l,t-1}$$

The example – we will follow an initial set of genes present in young males that will be used as sires of sires.

Define $\mathbf{R}_{SS}$, $\mathbf{n}_{SS,0}$, $\mathbf{m}_{SS,0}$

$$\mathbf{R}_{SS} = \begin{vmatrix} 0 & \frac{1}{2} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{vmatrix} \qquad \mathbf{m}_{SS,0} = \begin{vmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{vmatrix} \qquad n_{SS,0} = \begin{vmatrix} 1 \\ 0 \\ 0 \\ 0 \\ 0 \end{vmatrix}$$

Step 1.

$$\mathbf{m}_{SS,1} = \mathbf{P}\mathbf{m}_{SS,0} + \mathbf{R}_{SS}\mathbf{n}_{SS,0} = \begin{vmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{vmatrix}$$

Initial genes are still in age class one and as only age class two males are used for reproduction, no transmission to next generation yet.

Step 2.

$$\mathbf{n}_{SS,1} = \mathbf{Q}\ \mathbf{n}_{SS,O} = \begin{vmatrix} 0 \\ 1 \\ 0 \\ 0 \\ 0 \end{vmatrix}$$

The initial genes of males (age class one time zero) are ageing and transmitted to age class two times one.

Step 3.

$$\mathbf{m}_{SS,2} = \mathbf{P}\mathbf{m}_{SS,1} + \mathbf{R}_{SS}\mathbf{n}_{SS,1} = \begin{vmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{vmatrix} + \begin{vmatrix} 0 & \frac{1}{2} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{vmatrix} \times \begin{vmatrix} 0 \\ 1 \\ 0 \\ 0 \\ 0 \end{vmatrix} = \begin{vmatrix} \frac{1}{2} \\ 0 \\ 0 \\ 0 \\ 0 \end{vmatrix}$$

The initial set of genes has now got its first crop of sons in the population.

Step 4.

$$\mathbf{n}_{SS,2} = \mathbf{Q}\ \mathbf{n}_{SS,1} = \begin{vmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{vmatrix}$$

The initial genes 'died' after having aged beyond the oldest age class.

Step 5.

$$\mathbf{m}_{SS,3} = \mathbf{P}\mathbf{m}_{SS,2} + \mathbf{R}_{SS}\mathbf{n}_{SS,2} = \begin{vmatrix} 0 & \frac{1}{2} & 0 & \frac{3}{8} & \frac{1}{8} \\ 1 & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{2} & 0 & \frac{1}{4} & \frac{1}{4} \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \end{vmatrix} \times \begin{vmatrix} \frac{1}{2} \\ 0 \\ 0 \\ 0 \\ 0 \end{vmatrix} + \begin{vmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{vmatrix} = \begin{vmatrix} 0 \\ \frac{1}{2} \\ 0 \\ 0 \\ 0 \end{vmatrix}$$

The first crop of sons has aged one year. As the second part of the equation is no longer important (n is always zero) we will proceed with the simplified equation.

Step 6.

$$\mathbf{m}_{SS,4} = \mathbf{Pm}_{SS,3} = \begin{vmatrix} 0 & \frac{1}{2} & 0 & \frac{3}{8} & \frac{1}{8} \\ 1 & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{2} & 0 & \frac{1}{4} & \frac{1}{4} \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \end{vmatrix} \times \begin{vmatrix} 0 \\ \frac{1}{2} \\ 0 \\ 0 \\ 0 \end{vmatrix} = \begin{vmatrix} \frac{1}{4} \\ 0 \\ \frac{1}{4} \\ 0 \\ 0 \end{vmatrix}$$

The first crop of sons has got progeny themselves, both male and female progeny.

When this process of steps is continued, the following table is obtained; m-vectors are now presented as rows

$M_{SS,t}$	Age class				
	Male		Female		
	1	2	3	4	5
0	0	0	0	0	0
1	0	0	0	0	0
2	0.5	0	0	0	0
3	0	0.5	0	0	0
4	0.25	0	0.25	0	0
5	0	0.25	0	0.25	0
6	0.219	0	0.188	0	0.25
7	0.031	0.219	0.063	0.188	0
10	0.156	0.062	0.145	0.078	0.156
15	0.100	0.132	0.104	0.127	0.099
20	0.119	0.108	0.118	0.110	0.120
25	0.113	0.117	0.113	0.116	0.112

So far, the theory gives us derivation of $m_{l,t}$: the response to selection in different age classes in year t as a result of gene transmission and one cycle of selection. Following the dissemination of genes through age classes and time is not the final purpose of GeneFlow. The interest is in computing the contribution of a basic set of genes to future expression of traits. To obtain the total response in terms of expression of genetic superiority in improved performance in different age classes in different years, one needs to account for:

1. which age classes express genetic superiority together with their frequencies (at any time); this is specified in the incidence vector **h**;
2. discounting of future revenue to a base year (t=0); this is accomplished by regressing revenue in year t by a factor

$$\delta^t = \left[\frac{1}{1+q}\right]^t$$

where q is the interest rate in real terms.

Summarising, the cumulative discounted expression up to time horizon t_h from one cycle of selection for a single trait in a breeding structure equals

$$c_{l,t_h} = \sum_{i=0}^{t_h} h' m_{l,t} \delta^i$$

Two more advanced subjects of GeneFlow are (1) in the use of additional 'dummy' rows for the direct calculation of expressions by certain groups of animals and (2) in the use of multiple stages in the production column.

An example

Two types of traits are considered: (female) reproduction and production traits. Females in the 2nd and 3rd age class express reproduction traits, both age classes contributing equally. One-year-old slaughter progeny expresses production traits, like growth rate. As (breeding) males are replaced unequally from dams of both age classes (more from 2nd year old), somewhat more slaughter animals will have a 3rd year old dam. For simplicity, this aspect is ignored and a 50 percent contribution by each female age class is assumed.

Reproduction traits are expressed by age classes already included in **P** and contributions in year t are given directly by individuals in these age classes one and two of year t-1. Production traits are not expressed by breeding animals but by slaughter animals not yet considered in **P**. Therefore, contributions in year t are indirectly taken as contributions of parents of slaughter animals in year t-1: 50 percent males aged class two, 25 percent females aged class two and 25 percent females aged class three. P becomes

$$\begin{vmatrix} 0 & \frac{1}{2} & 0 & \frac{3}{8} & \frac{1}{8} & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{2} & 0 & \frac{1}{4} & \frac{1}{4} & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & \frac{1}{2} & \frac{1}{2} & 0 & 0 & 0 \\ 0 & \frac{1}{2} & 0 & \frac{1}{4} & \frac{1}{4} & 0 & 0 \end{vmatrix}$$

Note, that the last two columns of **P** are zero, because these dummy classes are not supposed to describe gene transfer. This expanded **P** matrix can be used in the sequential steps of calculating cumulative discounted expressions.

Note that contributions to expression of production traits are equal to proportions of genes in age-class females (i=3). Contributions to expression of reproduction traits are averaged proportions of genes in classes four and five. This means that inclusion of additional classes for producing and reproducing animals is not necessary; the incidence vector h can also do the job. However, when including additional classes the matrix algebra directly gives more information and the incidence vector **h** is simplified.

A closer look at the structure of **P** in the example shows resemblance to the selection paths defined earlier, SS, SD, DS and DD, and elaboration to paths for gene transfer to reproducing and producing animals.

$$\mathbf{P} = \begin{vmatrix} \mathbf{P}_{SS} & \mathbf{P}_{DS} & \mathbf{0} & \mathbf{0} \\ \mathbf{P}_{SD} & \mathbf{P}_{DD} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{P}_{DR} & \mathbf{0} & \mathbf{0} \\ \mathbf{P}_{SP} & \mathbf{P}_{DP} & \mathbf{0} & \mathbf{0} \end{vmatrix} = \begin{vmatrix} \mathbf{P}_{11} & \mathbf{0} \\ \mathbf{P}_{R1} & \mathbf{0} \\ \mathbf{P}_{P1} & \mathbf{0} \end{vmatrix}$$

(**0**s are matrices containing only 0-elements.)

P can be divided in sub-matrices describing gene transfer by different selection paths ($\mathbf{P}_{SS}$, $\mathbf{P}_{SD}$, $\mathbf{P}_{DS}$, $\mathbf{P}_{DD}$) and transition of genes to expression of female reproduction traits ($\mathbf{P}_{DR}$) and production traits ($\mathbf{P}_{SP}$, $\mathbf{P}_{DP}$). $\mathbf{P}_{11}$ is a matrix representing the flow of genes within the breeding population (or nucleus), while $\mathbf{P}_{R1}$ and $\mathbf{P}_{P1}$ describe the flow of genes from the breeding population to reproduction and production traits. This latter notation illustrates the possibilities of applying GeneFlow in levelled breeding structures as commonly applied in poultry and pig breeding, but also increasingly in cattle and sheep breeding.

Literature examples

Dairy cattle: Groen, A.F., 1990. Influences of production circumstances on the economic revenue of cattle breeding programmes. Animal Production, 51: 469-480.

Broilers: Jiang, X., A.F. Groen and E.W. Brascamp, 1998. Discounted expressions of traits in broiler breeding programs. Poultry Science, 78: 307-316.

Beef cattle: Wilton, J.W. and Ö.E. Danell, 1981. Relative rates of discounted expressions of traits in beef crossbreeding programs. Acta Agriculturae Scandinavica, 31: 207-216.

Hirooka, H. and A.F. Groen, 1999. Effects of production circumstances on expected responses for growth and carcass traits to selection of bull in Japan. Journal of Animal Science: in press.

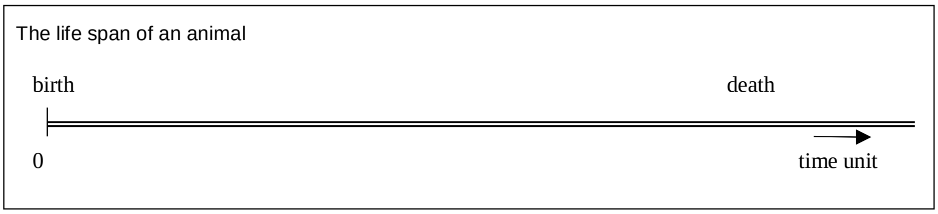
Swine: Danell, Ö.E., K. Rönningen, H. Ström, K. Andersson and P.-E. Sundgren, 1976. An extension of the discounted gene flow method with example in pig breeding. Acta Agriculturae Scandinavica, 26: 203-210.

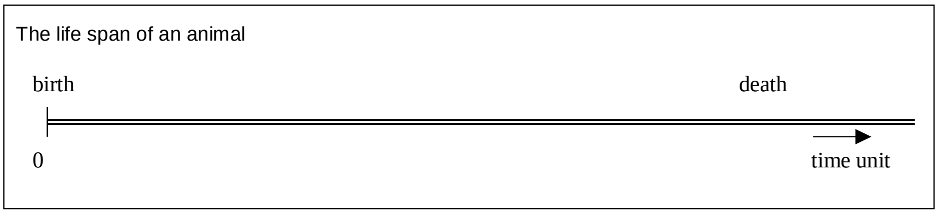
Annex IV. Characterisation of the Animal Production System and Development Objective

Annex IVa. A list of activities in the whole production system

Activity	Specification
Crop production	Production of grass and vegetables, only animal fertiliser used
......	......

Annex IVb. Herd composition





(multiple copies)

Average herd composition				
Animal category		Age period (in ......)	Number in the herd	Specification
Reproducing female				
Total				
Reproducing male				
Total				
Slaughter female				
Total				
Slaughter male				
Total				

Annex IVc. A list of outputs of the animal activities

Animal activity	Output	To activity	In case of surplus to activity	In case of shortage from activity	Use for	Price differentiation[i]

[i]Is there any payment for quality of the product ? If yes, how much?

Annex IVd. A list of animal characteristics

Animal activity	Input	From activity	In case of shortage input	In case of surplus input	Owner	Price differentiation[i]

[i]Is there any payment for quality of the product ? If yes, how much?

Annex IVe. **A list of animal characteristics**

Animal activity, Species	Animal characteristic	Specification

Annex IVf. **A flowchart**

Set up the flowchart by first giving each activity a box. Then start adding arrows according to inputs and outputs.

Arrow	From activity	To activity	Commodity transferred	Specification of quality	Others ..
..	*animals cow*	*crop grass*	*dung*	*dried*	
A					
B					
C					
D					
E					
..					

Annex V. Reference lists of breeding goal traits

(to be completed for several species by experts)

A list of breeding goal traits in ………..

Sub-breeding goal					
Other index traits for the prediction of breeding values					

A list of breeding goal traits

Sub-breeding goal					
Other index traits for the prediction of breeding values					

A list of breeding goal traits

Sub-breeding goal					
Other index traits for the prediction of breeding values					

A list of breeding goal traits

Sub-breeding goal					
Other index traits for the prediction of breeding values					

Annex VI. Perspectives in deriving goal values

After Groen, A.F., T. Steine, J.J. Colleau, J. Pedersen, J. Pribyl and N. Reinsch, 1997. Economic values in dairy cattle breeding, with special reference to functional traits. Report of an EAAP-Working Group. Livestock Production Science, 49: 1-21. (see this paper for references).

Three different interests of selection can be distinguished:

1) to maximise profit (= revenues - costs);
2) to minimise costs per unit of product; and
3) to maximize revenues / costs.

The base of evaluation establishes the size of the system considered in deriving economic values, according to social and economic production circumstances. The three possibilities are:

a) a fixed number of animals within the system;
b) a fixed amount of input of a production-factor into the system; and
c) a fixed amount of output of a product out of the system.

For illustrative purposes, derivation of three perspectives is worked out in detail; concepts of other perspectives can be derived from the same equations. The micro-economic approach of an individual farm is chosen. Equation (7) gives revenues and costs of the farm (in CU=currency unit).

$$\text{Revenues farm} = Y\, p_y = n\, y\, p_y \qquad (\text{CU.year}^{-1})(1)$$
$$\text{Cost farm} = X_v\, p_v + C_{fa} + C_{ff} = n\,(x_v\, p_v + c_{fa}) + C_{ff} \qquad (\text{CU.year}^{-1})$$

where,

n : number of animals on the farm;
y : level of product output (kg.animal^{-1}.year^{-1}; Y = n y);
p_y : price per unit product (CU.kg^{-1});
x_v : level of input of production-factor v, variable per animal (kg.animal^{-1}.year^{-1}; $X_v = n\, x_v$);
p_v : price per unit production-factor v (CU.kg^{-1});
c_{fa} : costs of input of production-factor fa, fixed per animal (CU.animal^{-1}.year^{-1}; $C_{fa} = n\, c_{fa}$);
C_{ff} : costs of input of production-factor ff, fixed per farm (CU.year^{-1}).

Profit and cost price per unit product of the farm can be expressed as:

$$\text{Profit farm} = Y\, p_y - (X_v\, p_v + C_{fa} + C_{ff}) \qquad (\text{CU.year}^{-1})(2)$$
$$\text{Costs per unit product farm} = (X_v\, p_v + C_{fa} + C_{ff}) / Y \qquad (\text{CU.kg}^{-1})$$

The economic value of a goal trait represents the change in profit or costs per unit product as a result of one unit change in genetic merit of the trait considered. It is assumed, that change in genetic merit of an animal will change y and x_v by δy and δx_v per animal, respectively. Depending on the base of evaluation, changes in y and x_v give rise to changes in n, Y, X_v and/or C_{fa}. With a fixed number of animals, it is assumed that marginal products produced and marginal production-factors required per animal are sold and purchased on the market, respectively. With fixed output it is assumed, that the amount of product Y produced at the farm is fixed. This implies, that an increase in production per animal (δy) will not increase the selling of a product on the market, but will reduce the number of animals on the farm. The reduction in number of animals is

$$(n+\delta n)(y+\delta y) = n\, y \quad \longrightarrow \quad \delta n = n * [- \delta y / (y+\delta y)]. \tag{3}$$

Related to the micro-economic approach, assuming agricultural price-taker markets, the prices of products and production-factors are constant. Change in profit of the farm is calculated as 'profit after change in genetic merit' minus 'profit before change in genetic merit', as the interest is maximization of profit. Change in cost price is calculated as 'cost price before change in genetic merit' minus 'cost price after change in genetic merit', as the interest is minimisation of cost price. Economic values within the cost price interest will be positive when increase in genetic merit results in a decrease in cost price per unit product. Levels of genetic merit of aggregate genotype traits are tied up to individual animals. Therefore, in deriving economic values, changes in profit of the farm are divided by the number of animals n (present before change in genetic merit). Changes in cost price per unit product for the farm are multiplied by the original level of output y per animal.

The economic value (EV) within the profit interest is:

$$\text{EV } \textbf{`profit'} = 1/n * \{\, \delta(\text{revenues farm}) - \delta(\text{costs farm})\, \}. \tag{4}$$

With a **fixed number of animals**, changes in revenues and costs of the farm originate directly from changes in revenues and costs per animal multiplied by number of animals. So, $\delta(\text{revenues}) = n\, \delta y\, p_y$ and $\delta(\text{costs}) = n\, \delta x_v\, p_v$. In other words, the economic value 'profit, fixed number' is equal to the margin between marginal revenues and marginal costs of production of δy units product per animal

$$\text{EV } \textbf{`profit, fixed number'} = \delta y\, py - \delta x_v\, p_v. \tag{5}$$

With a **fixed output**, change in revenues of the farm is zero. Change in profit of the farm originates only from a change in costs of production-factors v and fa: change in costs of v per animal ($\delta x_v\, p_v$) corrected for change in costs due to a change in number of animals

($\delta n * [(x_v+\delta x_v)p_v + c_{fa}]$; δn is given by eqn (3)). The value of δy units of product originates from a reduction in variable costs of the farm due to a decrease in number of animals.

$$\text{EV } \textbf{‘profit, fixed output’} = \delta y[(x_v+\delta x_v)p_v + c_{fa}] / [y+\delta y] - \delta x_v\ p_v \qquad (6)$$

The economic value within the cost price interest is given by eqn (7): the cost price before genetic improvement minus the cost price after genetic improvement, multiplied by original level of output y per animal.

$$\begin{aligned} \text{EV } \textbf{‘cost price’} &= y \{ (\text{costs farm}) / Y - (\text{costs farm} + \delta(\text{costs farm})) / (Y + \delta Y)\} \\ &= y / (Y+\delta Y) \{ \delta Y / Y * (\text{costs farm}) - \delta(\text{costs farm}) \} \qquad (7) \end{aligned}$$

With a **fixed number of animals**, δ (costs farm) is given by n * marginal costs per animal = $n\ \delta x_v\ p_v$. Change in production of the farm $\delta Y = n\ \delta y$. Substituting this in eqn (7) gives eqn (8). The economic value ‘cost price, fixed number’ is positive, when marginal costs of producing δy are smaller than average total costs of δy units product.

$$\begin{aligned} &\text{EV } \textbf{‘cost price, fixed number’} = \\ &= y / (n\ y + n\ \delta y) \{n\ \delta y / (n\ y)\ (n\ x_v p_v + C_{fa} + C_{ff}) - n\ \delta x_v p_v\} \\ &= \delta y\ [n\ x_v p_v + C_{fa} + C_{ff}] / [n\ y + n\ \delta y] - [y / (y+\delta y)]\delta x_v p_v \\ &= \delta y\ [n(x_v+\delta x_v)p_v + C_{fa} + C_{ff}] / [n\ y + n\ \delta y] - \delta x_v p_v \qquad (8) \end{aligned}$$

Concepts are derived for a situation with one product and one variable production-factor per animal. However, concepts can easily be extended to situations with more products and more variable production-factors. The costs of other production-factors with variable input are always to be considered on average variable or average total costs. When the inputs of other variable production-factors are influenced by the level of genetic merit, the marginal costs of production will contain more terms. Analogously, the revenues of other products are always to be considered on average revenues. When the output level of other products is influenced by the level of genetic merit, marginal revenues will contain more terms. When the output level of other products is not influenced, within the profit, interest average variable costs are extended. In the latter case, the revenues of other products are ‘negative costs’ components. For the cost price interest, the consideration of the revenues of other products to be negative costs is optional. For example, in dairy cattle production, the gross or net cost price of milk can be calculated. The net cost price considers all costs minus revenues of beef production per unit of milk. The theory given is based on a single base of evaluation.

The essence of improving the efficiency of a production system is: saving inputs of production-factors per unit of product and / or a change towards the use of cheaper production-factors. Saved production-factors can either be used in the system where they are saved from (and thus extend the product output of this system) or transferred to another system (via the market). Likewise, additionally required production-factors are either to be drawn from the market or from an alternative use in the system. Obtained differences in concepts of production theory originate directly from differences in the assumed use of saved production-factors. Example given, for the 'profit, fixed number' perspective, saved production-factors are sold on the market. In other words, differences in concepts between perspectives will only lead to differences in economic values when the values of (saved) production-factors differ between alternative uses. Assuming (1) markets of products and production-factors being purely competitive markets and (2) industry and all individual firms to be in equilibrium, market prices will equal average total costs of production. This is the approach considered by Brascamp *et al.* (1985) in proposing to set profit equal to zero. Economic values based on a fixed number of animals are equivalent when derived within profit and cost price interests. On the base of fixed output, economic values within a profit interest are equivalent to economic values within a cost price interest. These economic values will also be equivalent to economic value 'fixed number, cost price' when (3) all costs of the farm are considered to be variable per unit of product. This equality was pointed out by Smith *et al.* (1986), who proposed to express fixed costs per animal or per farm, like variable costs, per unit of output.

To conclude: assuming that all costs are variable and that also the costs of producing the variable production-factor on the farm equals the market price, all perspectives are equivalent. However, in agricultural industries, products and production-factors are commonly heterogeneous and not fully divisible. Heterogenity of products and production-factors lead to division of markets and cause the average costs of production to be different for individual farms. Given (equilibrium) market prices, some farms will have a lot of profit; others will be just efficient enough to continue production. As an important result, the equivalent of perspective may hold in certain conditions for the sector as a whole but will not be valid from an individual producer's point of view. In defining breeding goals, the definition of efficiency function has to correspond to the individual livestock producer's interest of selection; the producer's primary reason for buying a certain stock at a certain price, will be based upon his assessment of how animals will contribute to the efficiency of his farm. These concepts form the theoretical base for a diversification of breeding goals among (groups of) farms, and the usefulness of customised indices for (individual) farms.

Livestock straight-breeding system structures for the sustainable intensification of extensive grazing systems

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Section 1 Animal breeding and breeding structures

1.1 Animal breeding-directional improvement

Animal breeding aims for genetic improvement of livestock by utilising the genetic variation available, both within breeds and between breeds. The animal genetic variation can be used to accommodate interests and farmers' wishes to make livestock more efficient in using available resources to produce human food and other agricultural products. In general, improved performance leads to more animal products for the same amount of input resources. As selection and breeding of animals is a gradual process, it is more likely that the main stakeholders in the production system are able to adapt to the intended changes. Moreover, genetic change is permanent and the improved production system does not necessarily require a continuous use of more expensive or more sophisticated input factors. Gradual genetic improvement is the most sustainable form of improvement of the efficiency of a production system.

Breeding goal definition is the first step to be made in designing animal breeding structures. The breeding goal identifies those animal traits that farmers would like to be improved. Then, a second step is to implement a structure of gathering information, a recording system to identify those animals that have the highest breeding value for traits in the breeding goal. This step of identifying high genetic merit animals is called 'breeding value prediction'.

A third step is to make a well-organized structure for the use of animals with highest genetic breeding value. This structure should facilitate the dissemination of superior genotypes through the population, a quick and widespread use of selected animals. These second and third steps could involve considerable investments, especially the second step of recording. Investments will have to be recovered by the increased efficiency of production in later generations. Development of breeding structures that will be effective is of great importance.

Animal breeding helps to achieve the development objective

• Defines what is the 'best' animal	- Breeding goal
• Identifies the best animals by recording	- Breeding value
• Uses the best animals	- Breeding structure

Why does selection lead to improved productivity?

Part of the observed differences between animals is due to genetic effects. Since parents pass their genes on to progeny, we are able to obtain 'better progeny' if we use the best animals to become a parent.
A breeding programme works according to the following principles:
- order animals according to performance. The better performing animals are expected to have above average genotypes;
- selected animals will pass on their better genes to their offspring, therefore, average genetic value of offspring will be higher than the previous generation.

Selection and dissemination

Improvement of animal performance through genetic selection can be achieved through decision-making towards selection of the right breeding animals and making the right matings. The genetic value and phenotypic performance of future offspring can be improved if the better breeding animals are used as parents for the next generation. We refer to this process as genetic improvement.

An important second issue is which animals are actually improved? The value of superior individuals is limited if they do not efficiently contribute to the improvement of the gene pool of a whole population of animals in a village or a region. Genetic improvement should not be isolated and limited to just the animals in a single herd (or a few herds). The industry-wide impact of genetic improvement depends on the process of dissemination of breeding animals.

Genetic improvement and dissemination of genetic improvement are the two main factors of a regional breeding programme.

If parents are selected based on observed performance, we can increase the average genetic value of offspring and therefore achieve a sustained improvement of performance over generations.

- **Genetic improvement** can be obtained by selecting and mating the best animals as parents.
- **Dissemination** of selected genes through a whole population achieves increased productivity of a production system in a region.

Structures in genetic improvement

Running a breeding programme involves more than simply 'selecting the best animals and mating them'. To select animals and to be able to allow the right matings requires a provision of a certain infrastructure. Selection decisions need to be based on information. Some kind of visual appraisal or a more formal performance measurement of animals is needed as well as an animal identification system. Matings can be carried out by physically joining the mating pairs that were planned or alternatively, genetic material (e.g. semen) of the selected breeding animals could be provided otherwise, e.g. in the form of straws of fresh or frozen semen.

The **structure of a breeding programme** provides:
- a system for gathering information about the assessment of animals in the production system;
- the ability to compare animals for genetic merit and select the best;
- the conditions that the selected males and the selected females are mated in a desired way.

There are several levels of sophistication here.

Data recording can be by:
1) visual appraisal (cheap, maybe not easy and possibly subjective);
2) objective recording of performance traits related to profitability (more accurate); and
3) additional pedigree recording and animal identification (allowing the use of information on related animals and accurate estimation of breeding value).

The mating provision can be a matter of :
1) not allowing the inferior males to mate with females in the herd (e.g. by castration, separation);
2) using separate paddocks for different males, allowing the matings of the right males with the right females; and
3) using artificial insemination, allowing more specific matings, intensive use of sires and dissemination of its genes over a larger area.

Breeding structures can be defined even under the most basic conditions, they do not necessarily require sophisticated systems of data recording and genetic evaluation, nor do they require use of reproductive technology. Those technologies can have a large impact on rates of genetic improvement, as well as on the design of the most optimal structure. The optimal breeding structure is very much determined by 'what is possible' and 'what is optimal'. Environmental or infrastructural restrictions, tradition and socio-economic conditions have to be considered when planning a breeding programme.

Socio-economic importance of breeding structures

Structures are important, not only because they have an effect on the efficiency of genetic improvement, but also because they have an impact on the structure of the whole animal production system. For example, the introduction of artificial insemination in dairy production systems has a whole range of consequences. Not only can bulls now be used widespread and selected based on an accurate progeny test, but also the selection decisions are now made by the AI organization rather than by small farmers or stud breeders. It requires a cultural acceptance of the technology, it introduces a dependence of farmers on the AI organization and it requires the AI organization to deliver semen when needed and a communication system between farmers and AI-provider. This has obvious socio-economic implications and may be a key to the success of failure of a breeding programme. Therefore, besides considering discussing the technical elements of genetic improvement and alternative structures that may be considered, socio-economic as well as genetic implications of such structures will both be discussed.

With the introduction of breeding methods, the right balance has to be found between:

- what is possible from a technical point of view? and
- what is optimal and accepted by the decision-makers and users within the socio-economic context of a production system.

Communication and logistics in breeding structures

A breeding programme is focussed on the improvement of a population. Usually this implies that activities related to the breeding programme have to take place at different locations, but in a coordinated fashion. A breeding programme requires a structure where information and animals or genetic material are exchanged between locations. This requires a lot of interaction and communication between many stakeholders. It is ultimately the (small) commercial farmer who will have to profit from genetic improvement in the context of his production system. For genetic improvement he has to select animals within his herd, but more likely he will need to import breeding animals from elsewhere. Stud breeders could provide these breeding animals or breeding organizations, or they could be obtained from a centralised nucleus, which is run by a cooperative where the farmer is one of the members. The farmer has to understand the added value of improved breeding animals, otherwise he is unlikely to cooperate or willing to make a contribution to any investment in genetic improvement. Also, the farmer may have a role in providing performance information about his animals and such information should be collected according to a defined protocol. Some people will be involved in the recording and analysis of information and this information has to stream back to the persons that have to make selection and culling decisions. Other people are involved in the actual animal selection and are responsible to ensure that the selected animals are mated in an optimal way. Therefore, a very important aspect

> A breeding programme description requires a blueprint for roles and responsibilities of key players

in starting up a breeding programme is in **defining roles of key players and how they interact**.

1.2 Guidelines on breeding structures

These Guidelines help policy-makers, field technicians and farmers to define their breeding structures, they account for a broad range in country capacity and are applicable to all important animal species and production environments. Designing a breeding programme means taking a range of decisions in a logical order. This paper deals with each of these decisions in further detail and tries to achieve such an order. To provide a helpful tool the decision-making process is broken down in sequential steps and users will be guided step-by-step. For each step or decision, examples are used to illustrate the step, background information is given as to why this step is important, how to find data to make a sound decision and possible pitfalls that may occur in some areas. Some examples of breeding structures for different species will be presented and discussed.

1.3 Links to other guidelines for development of farm animal genetic resource management plans

The purpose of the Guidelines is to assist nations to develop National Farm Animal Genetic Resource Management Plans which will become both a component of the National Diversity Plan and a basis for developing livestock breeding policies. In these Guidelines, management of AnGR includes identification, description and characterisation of AnGR, the active utilisation of AnGR to increase food production (including animal productivity and product quality) and other agricultural production, the conservation of endangered livestock breeds for future use, access to AnGR and the monitoring and reporting elements.

For domestic species, issues of utilisation and conservation cannot be separated; both are critical components of management of AnGR. Most AnGR reside in developing countries where the need to increase food production and to reduce poverty are greatest. The breeds that farmers use today are different from the breeds that they used in the past and from the breeds that they will use in the future.

Management of livestock AnGR seeks to ensure that appropriate genetic material is used and developed and will be available to meet future challenges of changing environments and human preferences. The most important use of these Guidelines is to set priorities for the design and implementation of national AnGR management activities thereby better targeting needs. In addition, the Guidelines will assist in describing the nations' AnGR to the global community.

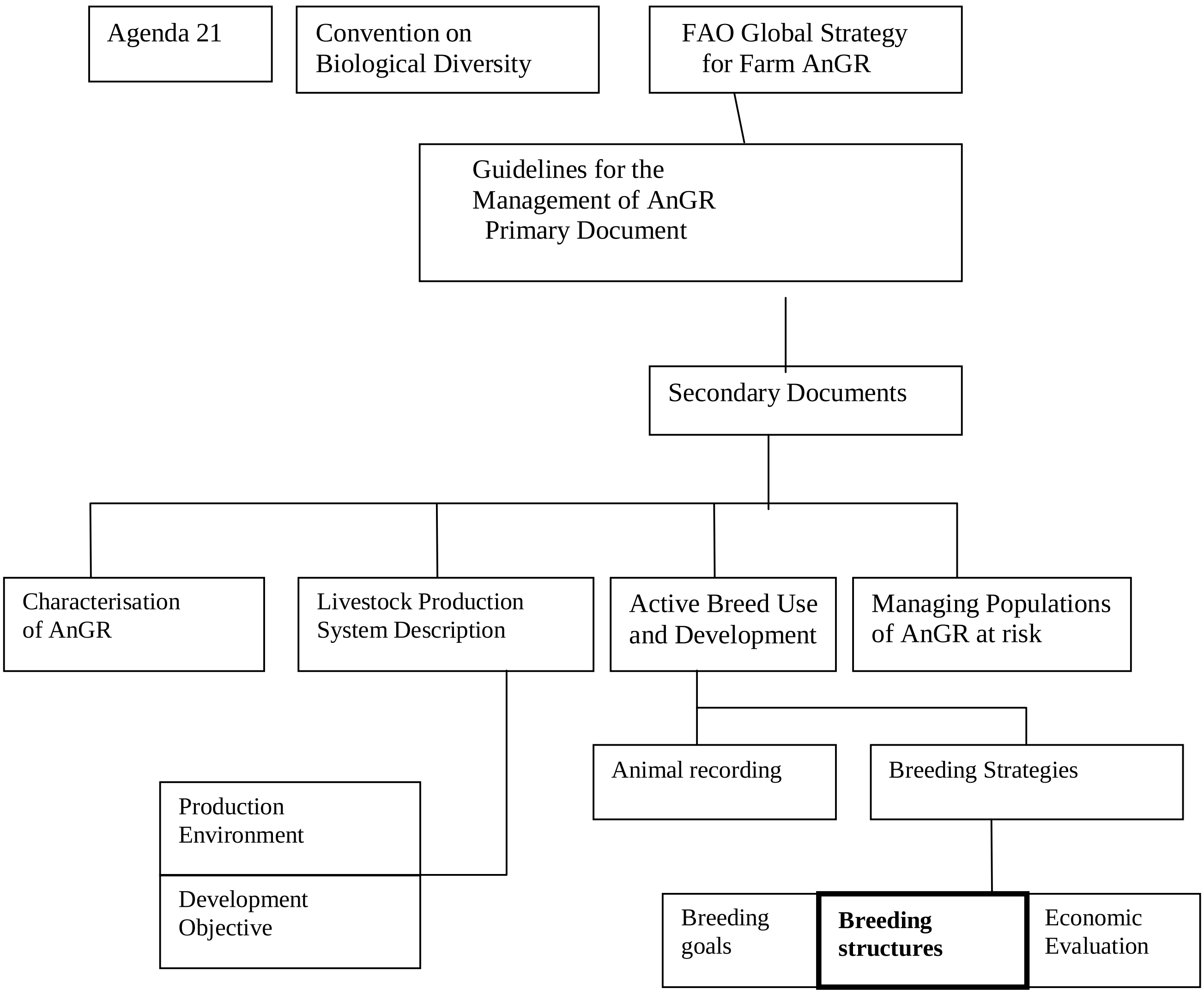


Figure 1.1. Breeding structure guidelines in the context of National Farm Animal Genetic Resources Management Plans.

Structure of these guidelines:

- definition of terms and issues in breeding structures:
  - terminology;
  - key issues and stakeholders;
- definition of the main factors determining genetic improvement;
- analysis of current situation, breeding structures in production systems;
- a step-by-step approach for design of breeding structures;
- creating of alternatives and making decisions in a breeding programme;
- discussion on socio-economic implications, risk factors, success factors.

Section 2. Structure of breeding programmes (definitions)

2.1 What are breeding structures?

The word ‘structure’ is an abstract term and particularly in the context of a breeding programme, it is somewhat hard to identify or define. These Guidelines will help you to determine your current breeding structure and define possible alternatives. Before doing that, we will introduce some of the terminology.

The **structure of a breeding programme** provides:

- a system for gathering information about the assessment of animals in the production system;
- the conditions that allow selection of males and females as parents for future progeny and the matings of these animals in a desired way.

It is relevant for two aspects of an improvement scheme:

- the <u>genetic improvement aspect</u>: how do we determine the genetically superior animals and how can we mate them?
- the <u>dissemination aspect</u>: how do we ensure that those superior animals disseminate their genes quickly throughout the whole population.

Every owner of domesticated animals has to consider how he wants to breed his female stock. He can use males that were born from his own stock but only to a very limited extent, as inbreeding has to be avoided. Consequently, the germplasm has to come from elsewhere. One model is that a group of farmers work together and exchange their male livestock. Another option is that germplasm is obtained from a local farm (known as a ‘good breeder’) as a one way delivery route, without having to return another male. Breeding males could also be obtained from another village or another region.

A farmer is interested in obtaining ‘good breeding stock’. If obtained from elsewhere, someone has to produce such stock and the definition on ‘what is good’ has to be agreed upon. The seedstock breeder could invest in continuously improving his animals genetically and this improvement has to be recognised by the local producer. In defining the breeding structure, the roles of the different players in a breeding structure have to be made clear. For this purpose, <u>identification of the roles</u> is required. This can be based on two questions:

- where does a farmer obtain his germplasm?
- is a farmer involved in producing improved germplasm?

Knowledge of such roles is important, as with one group of farmers (“the producer”) it is relevant to discuss how and where to obtain replacement stock (males) whereas with another farmer (“the breeder”) it is relevant to discuss performance and pedigree recording and selection strategies. It may be that these roles are combined in one person, depending on whether the breeding programme has a one tier structure or a multi-tier structure, with breeders, multipliers and commercial producers (see Section 2.3).

A distinction needs to be made between cross-breeding structures and straight-breeding structures. In a cross-breeding system, the males and females originate from different populations. In a straight-breeding structure, males and females originate from the same population. This also creates another important breeding issue, which is avoidance of inbreeding by avoiding the mating of animals that come from the same or related parents. Avoidance of inbreeding should be an explicit objective of a breeding programme, in addition to the other main objective of making genetic improvement with respect to a number of traits defined in the breeding objective.

2..2 What is the breeding population?

In general, a breeding population is basically a group of animals that share a common gene pool. The animals have common parents and in principle mate with each other to sustain the population size. A small farmer with only a few sheep cannot consider his flock as a breeding population because he will have to introduce a new male almost every breeding season. Otherwise he would have to mate his ram to his own offspring. The farmer may buy a ram from the neighbour and in turn sells his own young ram to another neighbour and so on. The whole set of flocks in the area would then be considered as a breeding population, as the genetic makeup is determined by the genetic constitution of rams that were swapped across herds. Even if only one of the farmers in the region is actually selecting and manages to breed genetically superior rams, the whole region will ultimately profit from this, as the genes are flowing through all flocks. Of course, the first farmer who uses this good ram will profit first, but offspring of the ram will be sold to others later on. This process can possibly take many generations. A more efficient way of quickly spreading the genes of the very good ram is to use him across flocks but this may not always be physically possible.

Larger herds or flocks could consider themselves as one breeding population if they import relatively few new animals as breeding parents. However, to avoid inbreeding, importation of animals from outside is necessary on a regular basis**.** The rate of inbreeding is closely correlated with population size (see also the Guidelines on Management of Small Populations at Risk). Local breeding populations of larger groups of farmers are mostly the kind of population that the FAO AnGR programme is targeting. A local population is usually adapted to a local environment and improved productivity can be achieved with a genetic improvement programme. Moreover, a population consisting of a larger group of farmers is usually more viable, as it has more potential for genetic improvement. The reason is that in larger populations there is more opportunity to exploit the existing variation among animals (there is a greater chance of finding very good animals). Furthermore, a selection programme in a larger population would be less restrained by inbreeding problems.

> A breeding population consists of a group of animals that share a common gene pool and that can sustain themselves by intermating. Ideally, a breeding population is large and there is sufficient movement of animals (or genetic material) across herds or flocks and across different areas covered by the population.

A <u>regional or national population</u>. From a breeding point of view, the larger the population, the better, for reasons described in the previous paragraph. However, there are two potential dangers of considering breeding populations on too large a scale. The main issue is that organizing a breeding programme on a larger scale requires a high standard of infrastructure and communication across the working area. If these standards cannot be met, there is a high risk of failure. The other issue is that the natural or social environment may be quite different across the region considered. Climatological and social factors are an integrated part in the definition of breeding objectives. If breeding objectives are different, it is more difficult to improve the animals in such a way that it pleases the producers across all regions (environments). However, breeding objectives should be quite different before the advantages of working in a large breeding population is offset by targeting more specific breeding objectives in a split population. For example, production environments in temperate climates for dairy production may vary to some extent but there is worldwide exchange and use of bulls across these environments.

> From a <u>breeding perspective</u>, a breeding population is preferably large, to utilise more variation and to avoid inbreeding.
> Breeding objectives may slightly differ across sections within the population, but exchange of suitable animals across areas can be extremely fruitful.
>
> From an <u>organizational perspective</u>, the main restriction for the population size is the degree of infrastructure that is available. Sufficient communication across the different locations of the breeding programme area is needed to successfully run and coordinate a breeding programme.

2.3 Examples of breeding structures

The tier system

Different breeding structures can be distinguished by identifying different tiers. The simplest structure is a one tier breeding programme. The herd of mature animals consists of males and females. As in most species the male fecundity is much higher than the female fecundity, many less males are needed to produce the next generation of offspring. As males and females are born in equal proportions, we can select the best males for the breeding herd, but we may need all females that are born to replace the breeding female from the current generation.

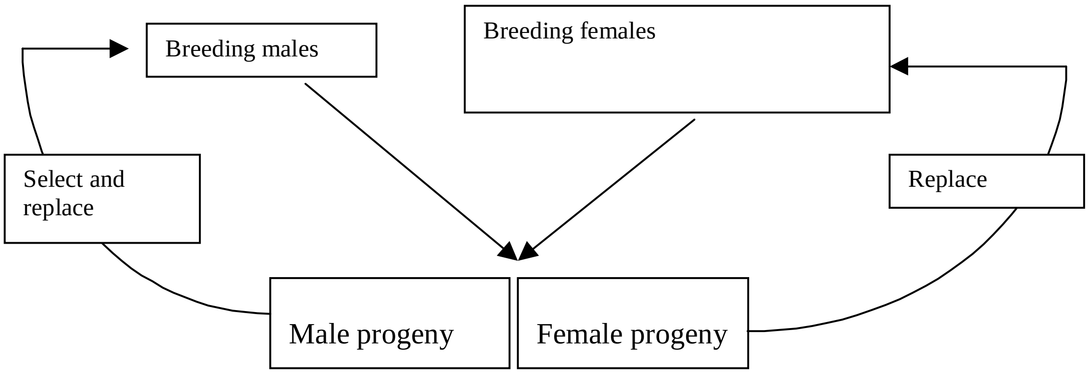


Fig. 2.1 Example of a simple one tier breeding structure.

Features of the one tier breeding structure are:

- males and females in the population are replaced by their own progeny;
- less males than females are needed for reproduction, therefore, males can be selected more intensely and females cannot be selected, or with less intensity.

Notice the provisions by the structure that condition a breeding programme:

- information needs to be available on the animals to know which of the males are best;
- the mating condition has to be fulfilled. The unselected males should NOT mate with the females. We may want to keep them for fattening, but unselected males either have to be castrated or kept apart from the female herd.

Two tier breeding structure

If a large group of farmers does not obtain their replacement breeding animals from their own progeny, they have to go out and buy them. More often than not, it is the males that are brought into the herd. In a multiple tier structure, selection and genetic improvement take place in one group of herds, where replacements are generated and selected in herds with the highest genetic level, indicated as breeding nucleus. The farmers at the commercial level just obtain (buy) these selected animals for use in their herd, i.e. they obtain their replacements from the nucleus herds. Usually, only male replacements are obtained from the nucleus, female replacements are often generated on farm. Commercial farmers can genetically improve their herd without having to performance record or select themselves.

The two-tier model is used in many animal production systems. The nucleus is formed by ‘stud breeders’, farmers who are actively selecting and try to improve their seedstock. They sell seedstock to commercial farmers, a group of producers mostly focussing on animal production itself. Producers are (and need to be) less worried about breeding and selection. Their way of genetic improvement is to buy seedstock from a higher tier. In breeding terms, they continuously receive new and improved genes from the nucleus tier. The genetic mean of production tier is somewhat lower than that of the nucleus, but the rate of improvement is, in principle, equal. The difference is indicated as genetic lag. The reason for this difference is that stud breeders (in the nucleus) will use their very best animals for further improving their own stock, whereas the other animals are sold to the lower tier.

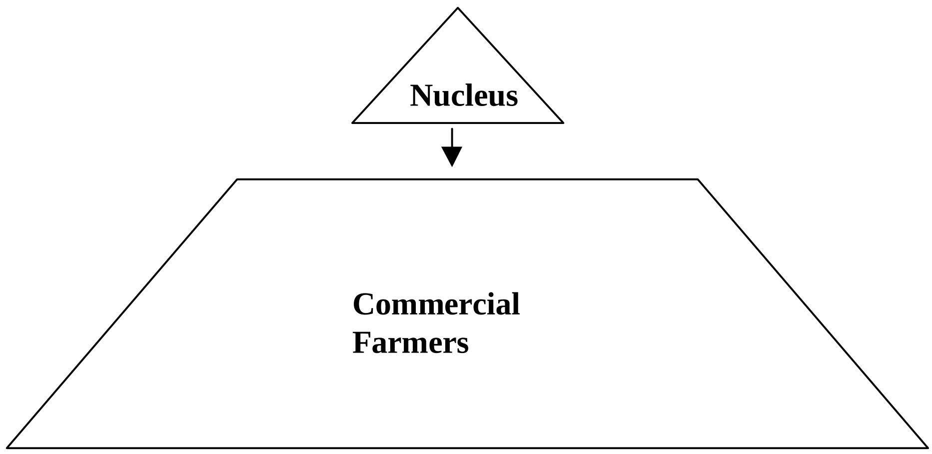


Figure 2.2. The two tier breeding structure

Obviously, a farmer would buy a ‘good’ male, i.e. he needs a male that he considers having good ‘breeding value’. Breeding values are determined within the breeding programme, as will be discussed later. They could be of high accuracy (e.g. the bulls could already have progeny and these can be evaluated) or have lower accuracy (the bull is bought based on visual appraisal, without formal recording of performance). In a two (or multi-) tier breeding structure, there has to be a flow of germplasm and information from nucleus to commercial. The only flow back would be a (financial) reward for obtaining the breeding animal (or service). A two tier breeding structure only works if the commercial farmers have the capacity to acquire breeding stock from the nucleus.

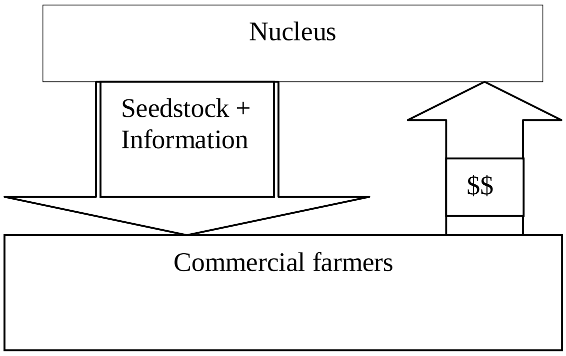


Figure 2.3. The nucleus delivers seedstock to commercial farmers and needs to include information on animal pedigree and estimated breeding value.

Three (multiple) tier system

A multiple tier system, i.e. a structure with more than two layers, is in fact not different from a two-tier structure. Selection and genetic improvement takes place in the nucleus and breeding animals are sold from the nucleus to have progeny in lower tiers. A reason why more than two tiers are needed is that the number of nucleus animals are usually not enough to breed all animals that are in the commercial tier.

Example
Imagine a nucleus with 500 breeding females, producing 250 male offspring every year. Some males are needed within the nucleus and a few others may die, hence, there will be about 200 males available to breed to commercial females. However, if the commercial population encompasses 100 000 animals, each of the nucleus males would have to serve 5 000 females. In natural mating conditions, this is not physically possible. Suppose a male can be mated to 50 females. A multiplier layer can be established of 10 000 breeding females. These will all be mated to the 200 males from the nucleus, bringing 5 000 male offspring. It is easy enough to sire the whole commercial population as only 2 000 males (=100 000 / 50) are needed.

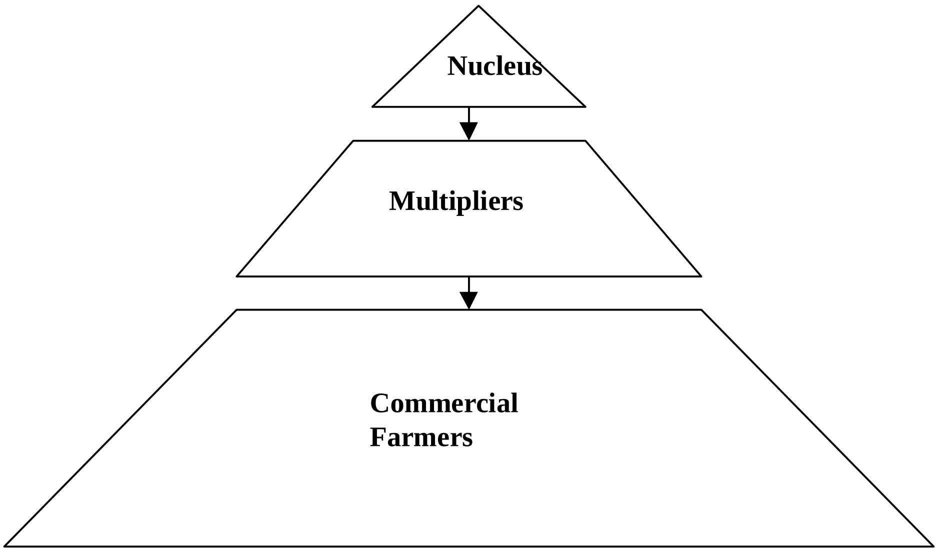


Figure 2.4. The three tier breeding structure.

2.4 Exchange and communication between tiers

The recording of performance and/or pedigree takes place within the nucleus tier, being either one or a group of herds. In existing breeding programmes, such a group is commonly known as the 'stud breeders'. The extent of recording will have an effect on the rate of genetic improvement in the nucleus (see later). Also, the exchange of genetic material between different nucleus herds affects genetic improvement. This will be discussed in Section 3.

Between the nucleus and a lower tier (either multiplier or commercial) there is simply a flow of germplasm. This could refer to animals, semen, eggs or embryos. The point is that the improved genes are transported from one tier to contribute to the next generation in the lower tier.

It is not strictly necessary that the flow of animals (or semen) be accompanied by any other information. In the simplest case, the commercial farmer is happy about obtaining a bull and does not worry about its breeding value. However, a commercial farmer could also be given the opportunity to pick a bull from a list of bulls, each of them having a breeding value and ranked accordingly. Such information requires that commercial farmers would understand the concept of 'breeding value' and also that there is a reliable genetic evaluation system in place that unbiasedly ranks all bulls produced in the nucleus.

There are a few advantages if commercial farmers can pick bulls based on information on breeding values:

1) it ensures that commercial farmers are more sure to get 'value for money';
2) they could better use bulls that they think are particularly good for their situation. For example, a farmer that has some problems with fertility would pick a bull that is particularly good in fertility. In a way this allows for some individual variation in breeding objectives within a more generic objective that is targeted within the whole population;
3) there is some psychological advantage of presenting breeding values as it may stimulate commercial farmers to pay attention to using 'good bulls' thereby stimulating their participation in genetic improvement.

Even in many developing countries it has been a formidable task to teach commercial producers the ideas behind breeding values. The first extension task is to convince them that bulls produced from the nucleus can be expected to produce better offspring than any local unknown bull. Identifying variation in breeding value in the group of bulls coming from the nucleus does not essentially increase the rate of improvement, but it may stimulate participation in and uptake of genetic improvement.

Roles of different tiers in a breeding structure

- Nucleus:
  - Performance and pedigree recording, selection and genetic improvement. Needs to be at least a part of the population.
  - Replacements for nucleus parents are recruited from selected progeny born from nucleus parents.

- Commercial:
  - The part of the population of animals in the production system that does not actively take part in recording and selection can be improved genetically by obtaining breeding stock from the nucleus.
  - Replacements for commercial parents are recruited from progeny born from nucleus animals (usually the males at least).
  - Most male progeny will not have offspring themselves, young females are usually needed for replacements in the existing herd.

Roles of different tiers in a breeding structure (cont'd)

Multiplier:

- If the nucleus is too small to serve the commercial population with breeding stock, nucleus males are mated to a group of females to form a multiple tier. Progeny born from multiplier dams are used to breed commercial animals.
- Males usually pass on genetic improvement from the nucleus to lower tiers.
- Commercial farmers simply buy (obtain) bulls that were born from the tier above them, i.e. from the nucleus or from the multiplier.
- All genetic improvement is made in the nucleus. The other layers will be improved at the same rate, but their genetic value lags some generations behind.

2.5 Further comments on multiple tier structures

Size of nucleus population

The nucleus population needs to have an adequate size of a breeding population, such that the inbreeding rate is limited. The effective size should be large enough (roughly at least a few hundred animals (preferably more). The size of the nucleus population is not determined by the number of animals born, but by the number of male and female parents used. It is important to realise that the effective population is mainly determined by the lesser represented sex (usually males). Enough males should be used in each generation to keep sufficient population size and therefore to prevent high rates of inbreeding. (See also Section 3, Annex 2 and Guidelines on Small Populations).

The size of the nucleus is mainly determined by the minimum number of males and females that should be kept for a sufficient effective population size. Roughly, this implies that at least ten to 15 males should be used in each generation for a viable population size.

Selection in a multiple tier structure

The best nucleus animals are selected as parents of the next generation of nucleus animals. Animals born from elite mating (i.e. nucleus-born animals) that are not selected as parents for the nucleus will be used as parents for the lower tier. Hence, the expected mean of the nucleus should be higher than that of the lower tier.

If genetic improvement only takes place in the breeding nucleus, this group of individuals will have the highest genetic mean. The multiple tier will have a lower genetic mean, equal to two generations of genetic improvement if only males are transferred from nucleus to multiplier and one generation if both males and females are transferred. The difference is referred to as genetic lag. The same lag will appear for the difference between multiplier and commercial. In a three-tier structure with only males contributing to lower tiers, the genetic mean of nucleus and commercial tiers is expected to be equal to four generations of genetic improvement. When some selection takes place in a lower tier, this will decrease the genetic lag (with a higher tier), but the lower tier will not have a higher rate of response than a higher tier (for more detail, see Bichard, 1971).

Some of the very best animals of lower tiers contribute to the nucleus as well, given that their breeding value could be estimated and compared with breeding values in the nucleus. Such individuals would migrate upwards to the nucleus. A nucleus that is open to imports from lower tiers or from sister tiers is indicated as 'open nucleus'.

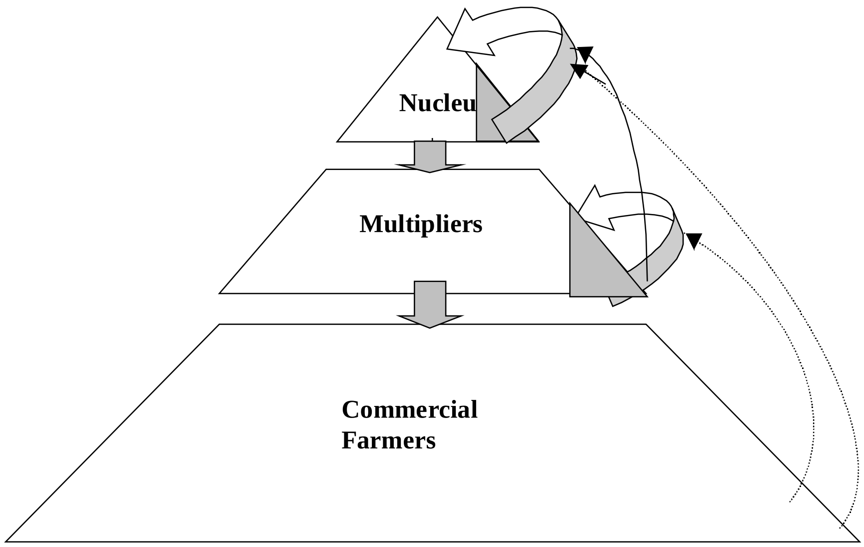


Figure 2-5. A multi tier breeding structure with selection in nucleus and possibly in lower tiers and downward and possibly upward migration of genetic material.

Open nucleus systems

Import from lower tiers

The structure presented here shows a one way stream of genetic material from the nucleus down to the commercial population. In practice, it is possible that animals from lower tiers become parents in the nucleus. For example, an animal with superior performance could be born in multiplier and could be very interesting to use as a parent in the nucleus. Of course, this is only possible if some kind of performance recording in lower breeding tiers (other than nucleus) is used.

Open nucleus systems provide about ten percent more genetic gain than a closed nucleus system, as the breeding programme will profit from the additional chances from more animals potentially being candidates for selection. When performance recording is carried out beyond the nucleus, a nucleus breeding structure should be open to the influx of the best animals from lower tiers.

Note that the inbreeding level does not substantially decrease by opening the nucleus to lower tiers. The reason is that animals in a lower tier are somehow already related to nucleus animals.

Import from other nuclei

A breeding nucleus should in principle always be open to other nuclei. The main advantage here is that this will introduce new families (‘fresh blood’), therefore rejuvenating the nucleus gene pool and decreasing inbreeding. Another reason for introducing genetic material (or animals) from other (genetically better) nuclei is that it is a quick way to improve the genetic mean of the existing nucleus. For example, most European dairy breeding programmes have upgraded with Holstein-Friesian genes during the eighties. Basically, many of the sires that were used to obtain young bulls were imported (by way of semen) from the USA, leading a rapid change in genetic mean. The population that is imported has to be genetically interesting with a high genetic mean for the breeding goal traits. As different breeding populations are often not genetically connected and jointly evaluated, breeding values of animals from different populations are usually not so easy to compare.

> The breeding nucleus could be open to good animals from lower tiers, giving some more genetic improvement. However, trait measurement below nucleus level would be required.
>
> The nucleus should be open to other populations with comparable or higher genetic means. This can bring fresh blood (lower inbreeding) and potential rapid genetic importation of valuable genes into the breeding population. Exchange of genetic material between nuclei is needed to be able to compare their relative genetic level.

Genotype by environment interaction

When ranking of genotype based on merit differs between environments, we speak of genotype by environment (GE) interaction. This phenomena is quite likely to happen between environments that are distinctly different, e.g. pure-bred Friesian perform better than tropical breeds in temperate environments, but they are not competitive in most tropical conditions. GE also exists within breed, as some bulls are better for one environment (or market) and other bulls are better for another environment. GE interaction is relevant in breeding programme design, as there is a danger that animals are selected in the nucleus in much better conditions than in which the commercial population produces. Typically, a nucleus is held at central research facilities with abundance of feed whereas the commercial population produces in much harsher conditions. Selecting breeding animals based on performance in nucleus conditions will be less efficient for improving commercial performance if there is a significant GE interaction. The efficiency is proportional to the genetic correlation between the nucleus and the commercial environment. For correlation between nucleus environment and commercial environment of 0.5, only 50 percent of the selection differential in nucleus animals will be expressed at the commercial level. The best advice here is to create a nucleus environment that is as close as possible to the commercial environment. There is some advantage to having better controlled environmental conditions in the nucleus environment, as it increases heritability and selection accuracy.

> If the nucleus environment is very different from the commercial environment, then the efficiency of selection at the nucleus level is reduced proportionally to the genetic correlation between performances in the nucleus and the commercial environments. The environmental conditions for performance testing in the nucleus should mimic the commercial conditions.

2.6 Who are the key players in a breeding programme?

Although it may be easy to draw a structure of a breeding programme, as in Figures 2.1 to 2.4, in practice it is not at all easy to identify such a structure. However, identifying the existing breeding structure is an important condition for being able to run the breeding programme. In particular, the roles of the different participants in a breeding programme have to be clear and each key player should be aware of his or her role.

Identifying nucleus and commercial herds

The nucleus is identified as the group of 'elite breeders'. Formally, it is the group of animals with the best (estimated) genetic merit. With a genetic evaluation system and genetic links across herds / flocks, the best animals can easily be identified. Without such a system, it is more difficult to identify the best animals across herds or flocks. In that case, the part of the population that actively records performance and pedigree and selects animals based on some estimate of breeding value, is going to be the nucleus, as those animals are more likely to show superiority due to selection.

Farmers that do not actively record and select animals are part of the commercial. On average, the animals born in these herds are not as good as nucleus animals, as their parents are less highly selected. Commercial farmers should seek genetic improvement by obtaining stock from the nucleus. In practice, these will be males (or just semen).

It is quite possible that commercial farmers occasionally have a superior animal. This would be unnoticed if performance were not recorded. If a commercial animal's performance is obviously outstanding, she should be part of the nucleus, meaning that she should be mated to a top male. In practice, such an animal can be bought by nucleus farmers or by a central nucleus cooperative. The farmer may also keep this promising animal, inseminate it with semen from a top-bull and sell a male calf to the nucleus (cooperative). This would be an example of upward migration: the best animals in a lower tier can be promoted to a higher tier in the breeding structure. An open nucleus scheme would allow such migration.

- The nucleus consists of the group of animals with the highest genetic mean. Usually, those are owned by 'elite breeders' or by a central cooperative, where an active recording and selection policy is in operation;
- ideally, an across herd / flock system of genetic evaluation confirms these roles (if selection takes place in a group of animals performing at several locations);
- producers that do not record or select should obtain replacements from the nucleus. In practice, they buy males (or semen);
- occasionally, outstanding performers at the commercial level (if detected) could become part of a nucleus.

How does a farmer define his role?

Every farmer should be free to buy or to replace from his own stock. The point is that given his role, one strategy is better than another. A commercial farmer with no recording cannot select his animals. The genetic mean of his herd can be expected to be lower than that of nucleus herds. He is better off by buying his males from the nucleus.

A breeder with a high genetic mean and with a recording system in place is generally better off by replacing his stock from within the herd, with an occasional importation of breeding stock from another herd.

Emergence of nucleus herds

In a village-breeding programme, with many small farmers, there may not be such a distinction initially between breeders and producers. When animal recording is set in place in some herds, these will emerge as the nucleus herds because of the initial genetic lift possible due to selection. Also, those farmers who import germplasm from other areas could be lifted genetically and a genetic lag created. If all village herds are recorded, each animal could potentially be selected as breeding animal for the next generation. The nucleus animals are the best animals based on estimated genetic merit and their offspring will be genetically better than those of lower tiers. All progeny born in the next generation would profit from this selection immediately. When farmers are somehow privatised, some distinction will gradually evolve between farmers who are better able to select and utilise best breeding stock and others who are not. The first group will typically become the 'elite breeders' who will be favoured by local buyers and effectively a nucleus structure will emerge.

Other roles

The requisites in the breeding structure, namely:
- gathering information;
- making selection decisions;
- carrying the desired matings;

require coordination. As a breeding programme involves communication between nucleus breeders and producers or among breeders themselves, important roles have to be defined for coordination purposes. The social economic infrastructure is very important here. Exchange of breeding animals maybe feasible, but buying breeding stock may not be feasible for smallholders. Two socio-economic models can be distinguished:

Cooperative village structure with smallholder farmers

If farmers have smallholdings and little buying power, a cooperative structure may be the best working model. Each participant could measure a number of animals (e.g. his own) and a coordinator would need to be appointed to keep track of records and to analyse the information that was collected. There needs to be a consensus about measuring standards and recording practices need to be checked regularly. For example, animals need to be measured for weight at similar ages and muscularity would have to be scored in a predefined way. Selection decisions have to be made, preferably based on the recorded traits and turned into an index of estimated breeding value. Some additional inspection of candidate breeding animals usually takes place here, to ensure physical and reproductive fitness of the breeding animals. The mating scheme could be simple if all animals of the cooperative were in the same central herd. Males that are not selected for breeding should be castrated or kept separate from the breeding females otherwise, there would be a need for a facility where selected breeding males are kept and participants could come to breed their female livestock. The largest challenge here is that sufficient consensus and participation be achieved regarding the decisions made. The coordinating role therefore involves:

– designing and facilitating a performance recording system, ensuring cooperation of participants;
– making selection and mating decisions, designing a system of mating and exchange of breeding animals between locations, again ensuring participation and cooperation through extension and education.

Privatised small farmer structure

Where farmers have some economic independence and sufficient economic power to buy (and sell) livestock, coordination of the breeding programme could be modelled based on private initiative. For example, measuring efforts could be left to the farmers' own initiative, as they may or may not want to acquire the role of breeding nucleus animals. Selection and mating decisions would be driven by competition, where quality and price of breeding stock would be the driving forces. Such a system may seem self-sustainable and self-regulating. However, it is far from guaranteed that it will succeed. It is required that producers understand the concept of genetic improvement, breeding value and that they have to be willing to pay for breeding animals with higher genetic merit. Furthermore, there has to be an agreement on the information that is provided with breeding animals, i.e. agreement on the selection index. The producer needs access to information about breeding animals available and the logistics have to be in place to acquire the improved genetics (through bull or semen). The coordinating role here involves:

- extension and education about genetic improvement, breeding objectives, breeding values and selection index;
- standardising performance-recording procedures, agreement on breeding objectives;
- provisions for livestock or semen trading.

Summarising

Critically important coordinating tasks are needed to facilitate the performance and pedigree recording scheme, the selection decisions and the mating provisions;

the coordinating role is coloured in depending on socio-economic infrastructure. The role varies from managing and decision-making to educating and facilitating. In either case, the degree of participation of producers is the measure of success;

farmers take a role either as breeders or producers and sometimes these are combined. Breeders need to be aware of methods to improve animals. Producers need to be aware of the availability of genetically improved seedstock.

Section 3. Making genetic improvement

In essence, the two key questions in animal breeding are: *Where to go?* and *How to get there?* Running an animal breeding programme, either on a single farm or in a larger context, involves answers to these questions. These can be worked out in more detail as follows:

- What is the breeding objective: which traits need to be improved and how important are different traits in relation to each other?
- What and who do we measure? Which traits, which animals?
- Do we need to use any reproductive technology (Artificial Insemination, Embryo Transfer) if possible?
- How many and which animals do we need to select as parents for the next generation?
- How to mate the selected males and females.

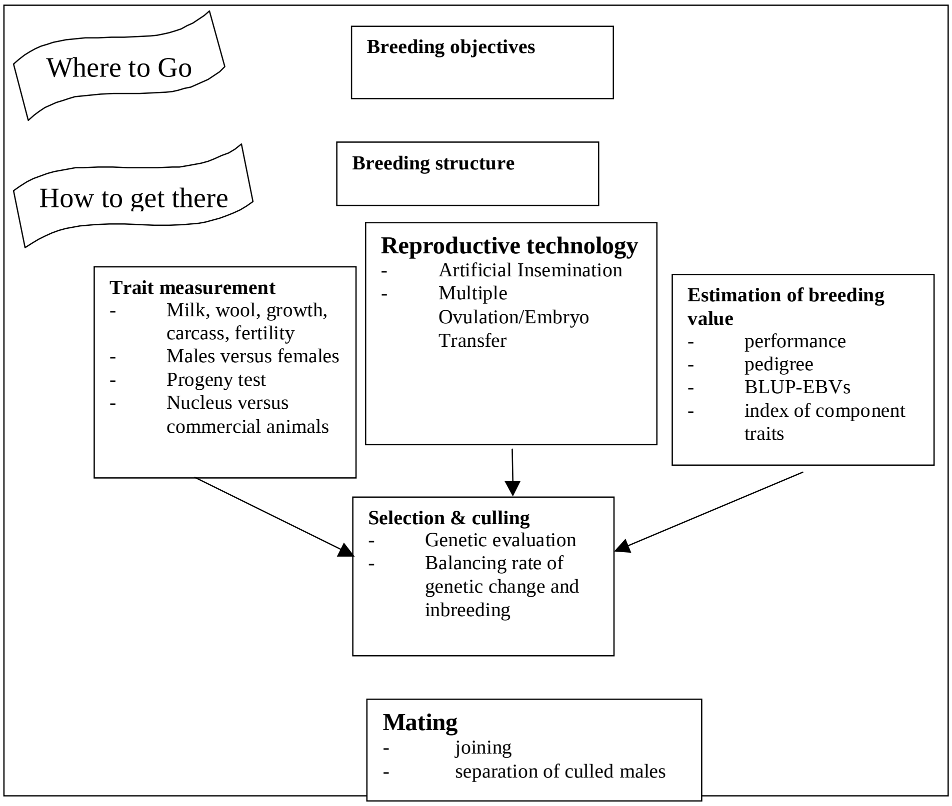


Figure 3.1. Decision issues in animal breeding.

3.1 Breeding objective

The definition of the *breeding objective* is the first and probably most important step to be taken (see also The Guidelines on Breeding Objectives). Improving the wrong traits could be equivalent or even worse than no improvement at all! If many breeding animal males are considered for reasons *irrelevant to* the breeding objective, then the selected group will not be as good with regard to the breeding objective as was expected. It is important in the selection process that the selection criterion is clear and that the selection is efficient in relation to the breeding objective.

Many practical breeding programmes suffer from the fact that the objectives are not properly defined. Selection decisions are often influenced by attention for characteristics that are not formally defined in the objective. Furthermore, the outcome for breeding programmes is noticed many years after selection decisions are made. Hence, objectives have to be designed for future circumstances. It is quite difficult to predict such circumstances and it is even harder to define objectives that are reasonably stable over time. Taylor (1997) has given examples of the beef industry where breed objectives have either been fluctuating or consistent over the last decades, resulting in either little change or significant progress, respectively.

3.2 Breeding Strategies

3.2.1 Basic elements of genetic improvement

The amount of genetic improvement that can be made depends on four key factors:

• Selection Intensity	Should be as high as possible
• Genetic Variation	Is more or less a given fact
• Accuracy of selection	Should be as high as possible
• Generation interval	Should be short

These key components together form the complete picture of genetic improvement and they interact with each other. A more detailed explanation on the prediction of genetic improvement rates for a given design is presented in Annex 1.

Before any selection decisions can be made, there is a need for selection criteria. This implies a definition of a breeding objective and assessment or recording of performance related to this objective.

In this Section, we will follow through the steps that affect genetic improvement and consider how each of them can be influenced in various circumstances.

Besides the four main components that determine rate of genetic improvement, extra consideration has to be kept in mind continuously, that is that the number of animals selected should be high enough to avoid inbreeding.

3.2.2. Who is involved in steps to achieve genetic improvement?

Genetic improvement can only be made if there is performance recording and preferable pedigree recording. In extensive livestock systems, measurement effort is mainly concentrated in the nucleus, i.e. a centralised nucleus herd and a group of progressive farmers working together in recording and selection. Sometimes, selection decisions can be made by individual farmers, but it is more efficient if the breeding strategies are coordinated between them. This depends also on the size of each of the herds.

When there is no breeding structure in operation, the breeding strategies need to apply to a population that has started to record performance. This could either be a whole village herd or flock, or only a part thereof.

In this Section, we will refer to such specific circumstances, if it is relevant.

3.2.3 Steps in selection of animals

A: Create Selection criteria

For each animal, we transform phenotypic information into Estimated Breeding Values (EBVs). This process is called genetic evaluation:

- the simplest form considers individual performance only. Selection is then on phenotype;
- a correction of performance for environmental effects (herd, season, age) is needed;
- more sophisticated methods such as Best Linear Unbiased Prediction (BLUP) use information in locations and throughout the years, using links through the pedigree. Moreover, information from relatives can be used;
- when more traits are measured, each of them needs to be weighed by its relative economic value, which can be done in a selection index framework (see Annex 1 of Breeding Objectives);
- multiple trait selection combined EBV of different traits, again by weighing them with the relative economic value (see Annex 3).

> It is important that selection criteria represent, as closely as possible, the pre-defined breeding objective!

Pitfalls

There are numerous examples where at the moment of selection many other traits and criteria are considered that are NOT part of the breeding objective. This can seriously decrease the actual selection intensity (and therefore limits genetic improvement).

<u>Other criteria that are acceptable:</u>

- traits like infertility, sperm quality, etc. naturally need to be considered;
- some type traits like scores for legs, udder, etc. These are often indicated as 'functional type traits' and have some relation to a sustainable animal productivity (e.g. related to longevity). Ideally they should then be part of the selection index and their value should be considered in relation to the breeding objective. Considering them separately, besides a formal index, gives a large risk that such traits might get more attention than they deserve. It may be hard to realise a sound objective scoring system for functional type traits, but it is

quite essential if they are perceived to be of economic value (see further Guidelines on Breeding Objectives);
- a genetic defect is a valid reason for excluding animals from selection.

Other criteria that are doubtful:
- some traits may be related to productivity, but they are indirect measures. An example is the size of a dairy cow. Many dairy farmers believe that a cow needs to have 'body volume' in order to be a good producer. However, a much wiser option is to directly assess the productivity itself. Direct selection for the objective traits is in most cases much more efficient than selection on traits that may be distantly related. Selection on a correlated trait is only advisable if the objective trait itself is hard to measure or has low heritability;
- colour characteristic (spotted skin, black wool, red-cattle). This may be a selection criterion for cultural or commercial reasons, as in some markets such deviations are not accepted or attract lower prices. However, if such arguments are not valid, selection for 'beauty' should be avoided, otherwise breeding can become a costly hobby!

Other criteria that are not recommendable:
- other type traits such as scores for frame size, 'dairyness', etc. One problem with such traits is that they are often scored or assessed quite subjectively. A bigger problem is that such traits are often not related to production efficiency. If they are, they should be measured and/or given an economic value in the breeding objective;
- inclusion of production of (distantly) related individuals. There are examples where highly productive cows were not selected because dams or grandam did not produce terribly well. If relatives' information is used in EBV estimation, such criteria are completely redundant and they would be counted twice. If such information was not used in the formal EBV, it is likely to be overvalued, as distantly related phenotypes say little about an individual's genotype.

B: Compile a list with selection candidates

From each sex, all animals at reproductive age are selection candidates. Selection should predominantly be based on the selection criterion.

C: Selection of breeding animals

– *How many to select from each sex?*

In principle, select as few animals as possible from each sex.
The restriction here is mostly reproductive rate. The number of males and females that are needed as breeding animals need to be sufficient to maintain the herd size. Breeding animals need to leave enough mature

progeny from their own sex during their lifetime to replace them and their contemporaries.

> **Example**
> Ewes drop on average 0.8 lamb per year and they have on average five lambings. Each ewe produces four offspring in her lifetime. Half of those lambs will be females, so from every two female lambs born, one is needed for replacement.
>
> Rams are joined with 25 ewes and they are used for two breeding seasons. In total a ram produces 40 offspring and one out of 20 new-born male lambs needs to be selected for replacement of old / culled rams.

Note that only those progeny that survive to maturity and are able to reproduce themselves need to be considered. Therefore, a breeding animal needs to produce at least two progenies that survive to maturity. If more progeny can be produced, we can select among the new-born progeny since we do not need to keep all of them.

As reproductive rates of males are generally much higher than that of females, we generally need a lot less breeding males than females. In other words, males can be selected more intensely and can generally be replaced at a younger age. Also, if breeding males can have a large impact due to their high reproductive rate, we wish to make sure that their breeding values are accurately known. If AI is used, males can be selected based on an accurate progeny test. Note that waiting for progeny test results may take a while and introduces a longer generation interval. This has to be offset by higher accuracy of selection. In an optimal situation, BLUP-EBVs can be used to optimise the proportion of very best young bulls with no progeny test and the very best progeny tested bulls (see next paragraph).

– *Comparing animals with unequal amounts of information.*
  If selection index or BLUP is used to estimate EBVs, animals can be easily and fairly compared when they have unequal information. The selection criteria should be in equal units (e.g. dollar value index). Animals with less information will have less accurate EBVs and their EBVs are likely to be closer to the mean (remember an animal with no information has an EBV value of zero). Animals with more information have more chance to be in the top, only the very best animals with less information could make it to the top. Therefore, selection is optimal, taking more animals with accurate EBVs and only the very best animals with less accurate EBVs.

Note that unequal information is often caused by unequal age. For example, older males may have a progeny test, whereas younger animals have only their own performance or information on dam or sibs.

Although BLUP-EBVs optimise the use of young animals with inaccurate EBVs and older animals with more accurate EBVs, it does not take risk into account. If bulls are going to be very widely used in the commercial population (using AI), there is an argument for minimising the risk that the bull is less glorious than expected (in terms of true breeding value as well as in terms of possible carrying of some significant genetic defects). To avoid risk, a decision could be made that only progeny tested bulls be used in the commercial population. In this case, some possible genetic gains (from optimising generation interval) are sacrificed for limiting risk.

– *Comparing animals from different age classes*

By keeping breeding animals longer, more offspring can be produced on each of them and we can therefore select more intensely among those progeny. More intense selection means greater selection differential among the selected parents, thus increasing the rate of improvement. However, using breeding animals for a long time leads to long generation intervals, which decreases the rate of response. The optimum generation interval for a static situation can be found as in the example (Annex 1). It turns out that if selection is based on BLUP-EBVs, which are comparable over age classes, we simply select the best animals from all the candidates *irrespective of age class*. The reason is that BLUP-EBVs are fairly comparable over age class. The larger the rate of genetic improvement, the more we would select the younger animals, since they have an advantage due to genetic trend. The optimum generation interval can therefore easily be found by simply ranking animals of BLUP-EBV and ranking them.

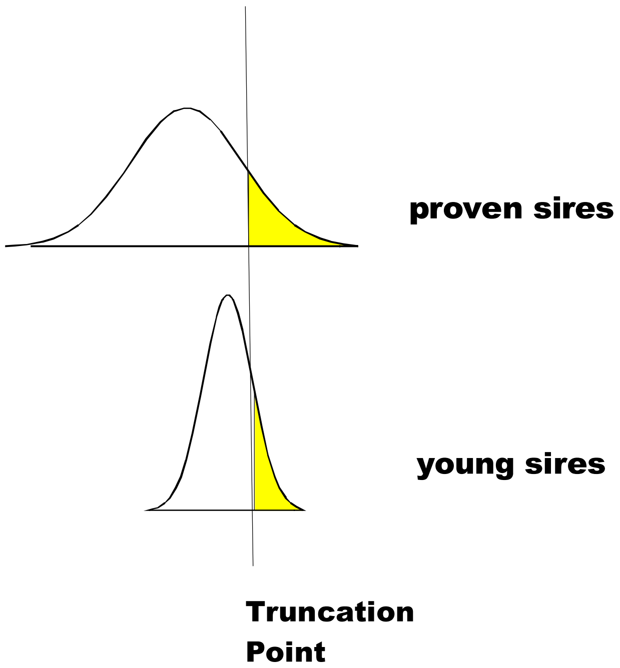
– *Limiting the rate of inbreeding*

The rate of inbreeding in a population depends on effective population size (see Annex 2). In practice, a sufficient number of males should be used for each generation. In the Guidelines on Management of Small Populations, the target is to have a minimum effective population size of 50, corresponding to a rate of inbreeding of one percent. This means that at least 13 males should be used in each generation in a closed population. A village herd could use fewer males if they regularly import new males from neighbouring villages.

Note that if the candidate males are related to each other, the population size is effectively smaller. Either more males would need to be selected or selection should be such that the selected males are not too closely related.

However, if an outstanding male exists, selection of some more of his sons should not be avoided. Software exists to optimise the number of males selected, given the genetic relationships of the selection candidates and their breeding value (see next section).

Optimising generation interval by using BLUP-EBVs



When optimising a breeding programme, a dilemma often arises whether young or older animals should be selected. Selecting young animals is good for achieving a short generation interval, leading to more genetic gain. However, younger animals usually have less accurate EBVs and less accurate selection leads to less genetic gain. Older animals generally have more accurate EBVs but selecting them would lead to longer generation intervals. Another (but essentially similar) argument against selecting older animals is that they are expected to have lower EBVs. If there is a genetic gain per year, animals born x years apart are expected to differ x times the annual genetic gain.

It is not easy to optimise selection over different age classes. However, the solution appears to be remarkably simple. The optimum strategy is a compromise, i.e. select the best of each of the age classes. The proportion that should be optimally selected from each age class is automatically achieved if simply the best animals are selected based on their BLUP-EBVs. James (1986) has given a formal proof of this result. Selecting animals on BLUP-EBVs irrespective of their age automatically optimises the generation interval. The condition is that EBVs need to be 'corrected for age' or, in other words, they need be comparable over age classes. The figure illustrates this point. Younger animals have on average better EBVs, but also generally less variation in EBVs. The optimum proportion of younger animals depends on the difference in the variance of the EBVs within age classes (i.e. on the accuracy) and on the genetic lag between age classes (i.e. on the genetic gain per year and the number of years).

Selecting on BLUP-EBVs across age classes is an example of such a dynamic rule, to determine the genetically best animals at a given moment.

D: Creating mating lists.
To create an optimal mating list from a given set of selection candidates, each with their estimated breeding values, is not an easy task, given that the selected animals should be both sufficiently good and not too closely related to each other. Particularly BLUP-EBVs could be quite similar for related animals as the BLUP method uses relative's information, making EBVs of related individuals more alike.

Ad hoc advice to be given here is:
Be sure to use at least ten to 15 males every generation and more if many of the males used are related to each other. Do not overuse breeding animals within the nucleus.

Import regularly from populations with similar genetic mean. It is important to have exchange programmes with other groups that have similar breeding objectives and similar breeding strategies, such that it can be expected that their population is improved at the same rate.

In the nucleus, the most important aim of a particular mating structure should be to make connections between animals used in different locations, seasons or years, meaning that progeny from as many parents as possible are compared with a location at a given time.

Generally, mating strategies can be formulated, such as:

- avoiding direct mating of closely related individuals;
- mating the very best of the selected males to the very best of the selected females (known as assortative mating). On average, the group of progeny born in the next generation is not affected, but there will be more variance among the progeny. This has some advantage in terms of genetic gain (typically about five percent);
- "nicking": for breeders it is often important to be able to make specific combinations of bull B mated to cow C (and daughter of famous grandsire G). Such dedication is extremely important for the enthusiasm and interest in the breeding programme (as long as the breeding objective traits are targeted). In scientific language, nicking is indicated as 'utilising dominance'. Utilising dominance variation is often not of primary importance for improvement of pure-breds. It can have more impact if breeding animals are selected from different breeds or lines, as heterotic effects between breeds can be utilised. When multiple traits are involved in the breeding objective, assortative mating could be useful, matching qualities in different parents for different traits. Formally, this is only useful if the traits show optimum values. Otherwise, improvement of traits is linear and a certain disadvantage for trait A could be offset by increased advantage for trait B.

Making such specific matings to match different traits is generally more useful at the commercial level, where most of the production is realised.

In a nucleus, such matings are less useful, because the specific interactions between sires and dams cannot be passed on to progeny and the main objective of a nucleus is to produce genetically improved progeny to be disseminated to the commercial level.

Software

Computer programmes exist to optimise selection decisions for a given list of candidates with pedigree information and EBVs on each of them. Such programmes can be very valuable tools, especially when EBVs are estimated with the BLUP procedure. Brian Kinghorn at the University of New England (Armidale, Australia) has developed software to create mating lists that allow finding the right balance between genetic progress and genetic diversity within the population. From a list of selection candidates, their EBV-values, pedigree and optimal mating lists are produced. The method allows for very practical considerations like 1) logistical constraint like mates being on different locations; 2) possibility and cost of using AI or MOET mating group size, etc. (e.g. paddock system); 3) cost and ease of importation within the herd or flock. This software is particularly useful for low input extensive breeding systems. For further information see http://metz.une.edu.au/~bkinghor/matesel.htm

Summarising:
Select as few breeding animals as possible from each sex, as a small proportion selected leads to high selection intensity and parents with higher merit.

The lower limit is determined by reproductive rate and inbreeding:

- the selected proportion needs to be 2/p at least, where p is the number of mature progeny produced by a breeding animal in her/his lifetime;
- the number of males used in each generation should be at least 15.

Animals with unequal information content and from different age class can be fairly compared and generation intervals are optimised when using BLUP-EBVs for selection criteria.
When breeding animals are going to be intensely used in the commercial population, a progeny test could be a requirement for AI bulls to avoid risk.

Generation intervals should be short

Only the very best breeding animals should be kept for another breeding season, others can be replaced by new and young breeding stock.

3.2.4. Give balanced attention to each of the factors that determine genetic improvement

It is important that each decision taken in an animal improvement programme should be taken in the context of the central dogma that determines rate of gain:

Genetic gain = (selection intensity * selection accuracy * genetic SD)/ generation interval

To be cost effective, judge which of the factors is easiest to improve!

For example, accuracy of selection as well as intensity of selection are directly related to genetic improvement and increasing either of those by five percent will give a five percent improvement of the rate of genetic gain. Increased accuracy could be achieved for example by a more accurate measurement of correlated traits. However, this may be costly and in the same breeding programme it may be much easier to increase the selection intensity by five percent (e.g. by simply using less parents for breeding).

It is important to know in a breeding programme where the big gains are

Those are changes that are easy to implement and most cost effective. A good breeding programme is not characterised by sophisticated reproductive technology and genetic evaluation software, but rather by cost effective decisions, giving the biggest part of the possible genetic gains for the limited resources available.

These are discussed in more detail, giving examples and typical pitfalls for each component. Subsequently, how the different components are related to each other is discussed.

Pitfalls in obtaining sufficient selection intensity

In the starting up phase of a genetic improvement programme, not achieving sufficient selection intensity is one of the most common failures. This is very unfortunate since improving selection intensity is usually among the cheapest and most cost-effective measures that can be taken in breeding programmes for extensive production systems.
Some common pitfalls are:

- *The number of animals used for breeding is much higher than necessary.* There are examples of village flocks running together with as many male as female stock. However, the number of males needed for breeding purposes should be much lower: the male to female ratio should be around 1:10 to 1:50, depending on the species. A simple first step in the breeding programme is therefore to select among males and only to keep the better part and *ensure that other males do not contribute to reproduction!*

- *The actual number of candidates considered for selection is much lower than necessary*.
  The actual selected proportion is usually lower than it seems because animals are usually assessed for a number of reasons. The effective selection intensity depends on the number of animals selected as taken from a group *assessed for the breeding objective considered.*

Example
Milk production in the Sahiwal herd mean 1 500 kg / lactation, phenotypic SD=300 kg.

One hundred young cows are available for selection and to improve milk production the best 40 are kept for breeding and making another lactation. We should only consider taking the best based on the criteria 'milk production'. Suppose 20 percent is not eligible for another lactation due to disease or other health problems. The selected proportion could be 50 percent, giving selection intensity of 0.8, hence the average production of the selected cows could be
1 500 + 0.8*300 = 1 740 kg.

In practice, other selection criteria are often considered as well, e.g. the size of the cow, their temperament or their colour. In that case, effectively, there are fewer animals available for selection for milk production. Suppose 25 percent of the 80 eligible cows are considered inappropriate for such 'other reasons', then the selected proportion for milk production would be 40 / 60 = 67 percent, giving a selection intensity of 0.5. The average production of the cows would only be
1 500 + 0.5*300 = 1 650kg.

The loss in dam superiority would be 37.5 percent and loss in genetic improvement in progeny would be nearly 20 percent.

In most breeding programmes, the main reason for obtaining a smaller response than possible is due to sub-optimal selection intensities because animals are not rigorously selected using the criteria defined as breeding objectives.

In practice, this point therefore needs to be of primary concern. It is indeed not always easy to define selection criteria as a 'trait' and attach a dollar value to it, as is needed for inclusion in the breeding objective. The Guidelines on Breeding Objectives discuss this point in more detail.

Pitfalls in selection accuracy

- *Biased estimation of breeding value*
  The basis of estimation of breeding value is phenotypic performance. However, phenotypic performance is to a large extent determined by environmental factors. The performance of animals should be evaluated as relative to a contemporary group, i.e. a group of animals kept in the same conditions, measured at (more or less) the same age, etc. Comparison of different animals across herds, ages, etc., is only possible when genetic evaluation methods have been corrected for such influences.

It is not the green grass that an animal eats that makes him a valuable breeding animal, but its performance relative to other animals kept in the same conditions!

- *Confounding environment and genetic effects*
  Problems arise if environmental factors are confounded with genetic factors. The most common are that different sires are kept in different paddocks. If the paddock effect is large, an apparently good performance of a bull's offspring could be not the results of his genes, but of the good paddock. Notice that even sophisticated genetic evaluation systems like BLUP cannot correct for such complete confounding. If the performance of animals or their sires is going to be compared, it is important to create genetic links between such fixed effects. Hence, bulls should not be repeatedly bred to the same group of dams, bulls should be used throughout the years and across herds (if possible). See Annex 3 for an example.

Genetic links, i.e. usage of animals across herds and throughout the years, is critical for the ability to compare breeding value of individuals across herds and throughout the years.

- *Inaccurate recording and measurement errors*

  The reliability of a recording system is obviously an important factor in the reliability of estimated breeding values. If pedigree information is used, reliability of the animal identification system and correct knowledge of parentage is very important. See Guidelines on Animal Recording.

Pitfalls in obtaining a short generation interval

The value of a quick turnover of generations is often underestimated in animal improvement programmes. The longevity of good breeding animals is often respected.

A good breeding animal is very valuable. However, some of the offspring will soon be better.

In each breeding season, a good system replaces part of the breeding animals with young replacements. If replacements were selected based on breeding value, they are likely to be better than many of the older breeding animals. On average, the progeny drop is equal to their parents, but the selected progeny should be better. The best breeding animals from previous breeding seasons could remain in the herd. Once a breeding programme gets going, each new progeny drop is (on average) genetically superior compared to the previous because of continuous genetic improvement.

Replacement rates should be particularly high for males, as few are needed and they can be selected with high intensity.

3.2.5 Different factors in genetic improvement are interdependent

Alternative options for breeding programmes need to be assessed, which can be done based on an analysis of the most important factors that determine rate of genetic gain:
- selection intensity
- selection accuracy
- generation interval.

However, it should be pointed out that the different factors interact and a balance has to be found.

The most important interactions are:

- *Generation interval versus selection accuracy*
  Selection of young animals will not only lead to short generation intervals, but may also imply lower selection accuracy because young animals have generally less information available (no repeated records, maybe no own performance, no progeny test).

  Solution: Selection based on BLUP breeding values optimises generation interval. If risk is to be avoided, some more weight could be given to more accurate EBVs, for example, breeding bulls for the commercial population need a progeny test as a minimum requirement.

- *Generation interval versus selection intensity*
  If more young animals are retained as breeders and a high replacement rate is applied, the generation interval may be shorter, but selection

intensity will also be lower since more animals of the new-born generation are needed for replacements.

Solution: First determine the number of breeding animals needed, then select based on BLUP-EBV. The number of young animals to replace older breeding animals will be optimised. Without BLUP, a good feel for the optimum replacement rate can be obtained using calculations as in Annex 1. Very useful software to assist in such calculations exists: GENUP, module AGES, see http://metz.une.edu.au/~bkinghor/genup.htm

- *Selection accuracy versus selection intensity*

  In many cases limited resources are available for trait measurement. Decisions have to be made like:

  1. Measure fewer traits (giving lower selection accuracy) or measuring fewer animals (giving lower selection intensity).

  Solution: A balance has to be found here. The loss in accuracy from measuring less traits can be evaluated using selection index theory. The loss in selection intensity can be easily determined by comparing different proportions selected and the associated selection intensities.

  2. Testing fewer bulls in progeny testing, with more progeny per bull, or testing more bulls with fewer progeny each.

  Solution: Suppose five bulls need to be selected and 200 progeny can be tested. Testing ten bulls with 20 progeny each gives a selection intensity of 0.8 and selection accuracy of 0.76 (heritability 25 percent), whereas testing 20 bulls with ten progeny each gives a selection intensity of 1.27 and a selection accuracy of 0.63. As 0.8*0.76 is smaller than 1.27*0.63, it is better to test more bulls with fewer progeny.

3.2.6 Balancing rates of genetic change and inbreeding

To make selection decisions, we need to consider:

- The number of males and females selected:
  - select as few breeding animals as possible to increase selection intensity;
  - select enough breeding animals in order to drop enough progeny for replacements;
  - select enough breeding animals in order to limit the rate of inbreeding.
- Which animals are selected?

\- select the animals with the highest estimated breeding values (EBV);

- select enough animals from different families to minimise co-ancestry of future parents (i.e. to minimise the genetic relationships among selected animals in order to minimise inbreeding).

• How intensively is each of the selected breeding animals used?

- how many matings per male, are some used for AI? The very best breeding animals could be used more intensely, but too much use of them would lead to more inbreeding.

Select as few animals as possible and only the very best.
Select enough breeding animals with enough genetic diversity (different families) and do not overuse breeding animals.

For high rates of genetic improvement, as few as possible breeding animals should be selected, but a minimum number of about 15 males per generation is needed to restrict inbreeding. If selected breeding animals are related to each other, a higher number is needed or other unrelated animals should be selected. Breeding animals should not be used excessively.

Intensive use of the best breeding animals outside the nucleus is acceptable. If an exceptional bull is available and AI can be used, there is no problem to let it have many progeny in the commercial population. It is the inbreeding in the nucleus that is relevant for the sustainability of the breeding programme. However, using AI-bulls from the same family very intensively will ultimately also lead to repeated inbreeding in the commercial population.

Remember that controlling inbreeding is equivalent to controlling genetic variation and controlling risk of a breeding programme. The risk of a breeding programme can be described as the probability that due to chance, the result is much worse than expected. The factor chance is greatly increased when only a few breeding animals are used or when they have animals with many genes in common. **One should never bet too much on one horse** (or bull or ram, in this case)! Therefore, rules to limit inbreeding will also limit risk in the breeding programme and ensure sufficient variation in the population.

3.3 Decisions about investments in a breeding programme

Limits in making genetic improvement through selection are set by:
- the reproductive rate of breeding animals;

One could invest in boosting reproductive rates (e.g. artificial insemination);

- uncertainty about true genetic merit of animals;

One could invest in better or more trait measurement, pedigree recording and in improved genetic evaluation methods and in creating a linkage between information obtained from different locations and periods, genetic markers.

- Reproductive rates determine the minimum requirement of animals needed for reproduction of the population. If animals could have more offspring, less would need to be selected and selection intensity would be higher.

- Uncertainty about genetic merit forces us to measure performance of animals and its relatives. Genetic evaluation is used to obtain the best estimate of genetic merit for a given amount of information (data and data-structure). More information gives more selection accuracy but often with diminishing returns.

As pointed out earlier, investment decisions in animal breeding programmes can be assessed in the context of the three components contributing to the rate of genetic change: selection intensity, selection accuracy and generation interval. It is important to know in a breeding programme where the big gains are. Those are changes that are easy to implement and most cost effective. In this section, some ‘easy’ and ‘costly’ measures in breeding programmes will be evaluated.

3.3.1 Measurement Effort

The benefit of abundant and good measurement is that we are better able to identify the genetically superior animals. Using more information leads to more accurate selection and more genetic improvement.

If resources are limited, trait measurement may be confined to a small group of animals, e.g. only nucleus animals are measured. A next option could be to perform a progeny test. This would increase male selection accuracy, particularly for low heritable and / or sex-limited traits but the expense is a longer generation interval and the actual costs of organizing a progeny test.

There are two main questions:

- Which traits should be measured?

  This depends on:
  - the breeding objective: preferably traits in the breeding objective should be measured;
  - ease and cost of measurement;
  - how important is the trait compared to other traits?

  Some breeding objective traits are not easy or very costly to measure and there could be correlated traits that are easier / cheaper to measure. When measuring correlated traits, the genetic correlation between the measured trait and the breeding objective should be high.

  The marginal value of measuring an additional trait can be determined by using selection index methods (see Annex 1 in Breeding Objective Guidelines).

- Which animals should be measured?

  At least the nucleus animals should be measured for performance and pedigree.

  When starting from scratch, a part of the population could be measured, usually consisting of a group of 'progressive farmers'. Such a group will automatically form the nucleus.

  Whether more animals in the population will be recorded depends on the social and technical infrastructure and on costs. Furthermore, animal recording serves more purposes than for genetic improvement (see the Guidelines on Animal Recording). Recording more animals has some advantages with regard to genetic improvement:
  - effectively, a larger nucleus could be established, with a larger possible selection intensity and less inbreeding;
  - an open nucleus system could be applied with the possibility for the best animals in lower tiers to become nucleus parents.

When recording is an investment for genetic improvement, a cost-benefit analysis could help in deciding whether more animals should be measured. The benefit can be determined from the increase in rate of genetic improvement, using principles of basic theory and considering the change in each of the main factors determining rate of genetic gain. The increased selection intensity and increased selection accuracy will be the main factors to change. The rate of improvement can be given a dollar value and be multiplied by the number of animals in the breeding population. Such an assessment is at sector or national economic level, which is appropriate if government funds are invested into the breeding project. In a privatised breeding structure, individual breeders can gain from more measurement by increasing their chances of obtaining the best breeding animals, therefore selling more breeding stock. The economic value from such a perspective is more difficult to estimate.

3.3.2 Optimising testing efforts

There is clearly a cost component involved in animal recording. However, animal recording is not only useful for the purpose of genetic improvement. It also is a very important tool in herd management and it allows the comparison of alternative production systems. (For a detailed discussion on this topic, see the Secondary Guidelines in the AnGR-FAO Programme on Data Recording). If done for the purpose of genetic improvement only, it is usually not necessary to measure all animals in the commercial population. Typically, a pig breeding company would not record the whole commercial pig population but rather concentrate their efforts on measurement of nucleus animals only.

In general, there are two reasons why it is usually not cost effective to record a whole population for the purpose of genetic improvement.

Firstly, the purpose of recording many animals is to obtain high selection intensity but there is not a linear relationship between proportion selected and selection intensity. Suppose we need to select 100 breeding animals. For a selected proportion of ten, one and 0.1 percent we would need measurements on 1 000, 10 000 and 100 000 animals, respectively. The selection intensities would be 1.755, 2.665 and 3.367, respectively. Hence, for a tenfold of measurements each time, the increase in selection intensity would be only 52 and 26 percent, respectively.

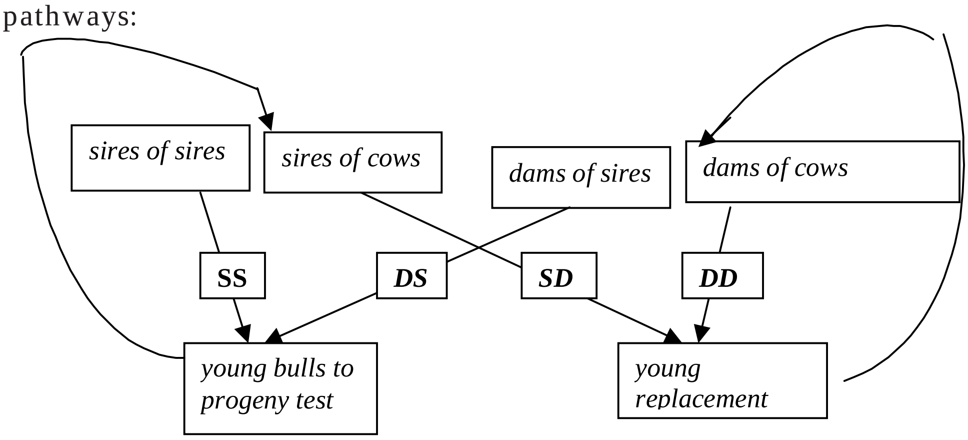
Secondly, some animals have a lot more chance to be good future breeding animals, even before they are measured. Those are the offspring of the best animals. Hence, if a limited number of animals is to be recorded, then recording an elite group of offspring from the best parents is most cost-beneficial. Animals from average parents have a smaller chance to be selected and measuring these is therefore less useful. Hence, nucleus animals have highest priority when it comes to investing measurement effort.

A special case of investment in measurement is a progeny test. Typically, not all males are progeny tested but only the males born from ‘elite matings’, i.e. the matings of the very best males with the very best females.

Progeny testing and the 4-pathway breeding structure

Progeny testing is only a practical option if AI is used. AI facilitates testing of progeny across herds and the investment in progeny testing is only paid off if the bulls selected based on progeny tests can be widely used. Progeny testing is expensive and obviously not all males born in the population are progeny tested. Only the best young males are progeny tested, i.e. the offspring of the very best dams and sires.

A typical design of a breeding programme arises in the case of progeny testing: the 4-pathway breeding structure. It consists of the following pathways:



More detail and an example of a 4-pathway breeding structure is given in Annex 4.

The example shows some different parameters that need to be evaluated in deciding on a progeny-testing programme. Those are 1) the number of males progeny tested; and 2) the number of offspring generated per progeny tested male.

An important feature when designing a progeny test is to distribute the progeny over different herds or locations. In genetic evaluation, the phenotype from the progeny is compared with the phenotypes of progeny *from other sires*. If the animals in a particular management group are all descending from one sire, there is no basis for comparing them with offspring from other sires. For examples on distribution of progeny over different herds see Appendix 4.

The effective number of progeny is maximised when each progeny of a bull is compared with progeny from a maximum number of other bulls.

3.3.3 Genetic evaluation effort

Phenotypic measurements are turned into *Estimated Breeding Values (EBVs).* In principle, animals can be selected based on own performance when performance is recorded. For sex-limited traits (recorded on females only), selection of males could be based on performance of the dam. Adjustment for important environmental effects increases the selection accuracy. Effects that need to be adjusted for are like season, year and herd of performance and age of the animal.

Pedigree recording adds significant value to genetic evaluation. Firstly, it allows the use of information on relatives, leading to increase selection accuracy (five to 20 percent, depending on heritability). Secondly, it allows across herd comparisons, as different herds have generally offspring from common ancestors (sire or sire of bulls used). Across herd evaluation has the advantages of allowing fair comparisons of EBVs across herds, leading to selection of more animals from the genetically superior herds.

Nowadays, sophisticated statistical methods are readily available, leading to *Best Linear Unbiased Prediction* (BLUP) of breeding values. See Annex 3 for properties of BLUP. A genetic evaluation system using BLUP relies on good data measurement, a good structure of data (breeding animals across herds) and proper pedigree recording. If these prerequisites are in place, investment in BLUP methodology is usually highly cost- effective. However, putting a genetic evaluation system in place has two sides to it:

- the technical side of organizing performance and pedigree recording to a central unit, the actual genetic evaluation (data analyses) and return of EBVs and other data summaries (genetic trends, culling advice, etc.) to the breeders;
- the extension side: breeders have to understand and accept the EBVs that are produced and they have to know how to use them. There is no sense in running a genetic evaluation if the results are left untouched by the end-users.

3.3.4 Investment in reproductive technology

Use of reproductive technology can be another *investment option*. Most of the main factors that determine genetic gain are directly influenced by the reproductive rate of the breeding animals. A higher reproductive rate leads to the need for a decreased number of breeding animals, therefore increasing the intensity of selection of these animals. If reproductive technology is technically possible, for example AI, the benefit can be expressed in terms of increased genetic rate of improvement, which in turn has a dollar component attached to it. More offspring per breeding animal also allows more accurate estimation of breeding value.

Reproductive technology allows the intensive use of superior breeding stock. An obvious consequence is possibly that the most popular breeding animals are overused and the population could encounter inbreeding problems. Typically, as new technologies in animal breeding allow faster genetic change, long-term issues such as inbreeding and maintenance of genetic variation become more important.

Besides a direct effect on rate of genetic improvement, mostly due to a higher selection intensity and increased selection accuracy, another important consequence from increasing reproductive rates is to disseminate superior genetic stock more quickly. The influence of a superior beef bull would be much higher if thousands of offspring could be born, rather than if the superiority is passed on through the production of sons via natural mating. As reproductive rates are basically multiplying factors in a breeding structure, any improvement in reproduction will justify higher investment in improvement of the nucleus breeding stock.

Any introduction of reproductive technology has to be cost effective and accepted by the farming society.

Artificial Insemination

Technically, there is a need for:

- resources and expertise in AI services (semen collection, freezing and / or storing and insemination);
- a certain infrastructure. Once an AI service is running, the distribution centre has to be contacted by individuals who need the service and the service needs to be delivered within 12 hours. Communication lines (telephone) are therefore essential.

Advantages of AI appear at two levels:

- Distribute semen across a number of nucleus herds. This is useful for establishing genetic links between the different nucleus herds (essential for genetic evaluation in the whole nucleus). Furthermore, particular mating may be better targeted, e.g. the best bulls mated to the very best cows. AI use in a dispersed nucleus may be feasible, as the nucleus farms maybe expected to have higher management skills, being able to detect heats, separate females from other bulls and communicate their request for insemination services to the distribution centres. With nucleus farms of reasonable size, semen might be stored on site, but it requires the presence of AI technicians on the site.

- Distribution of AI-semen from proven bulls to commercial farmers for the purpose of dissemination of genetic improvement may be more problematic. In many countries, producers are smallholder farmers and the skills and infrastructure may be insufficient to allow AI services. Again, when inseminating by AI, the farmer has to be able to detect heat and contact the semen distribution centre, which has to be able to serve within 12 hours. Furthermore, he needs to be able to muster and tie up the cows that need to be served. For most extensive production systems, this will be very labour intensive. For dairy production systems it may be feasible, but for meat production under extensive grazing systems, it is likely to be impractical. To facilitate communication with local farmers, local distribution centres at village level are advisable. More importantly, local centres can familiarise farmers with the concept of AI and with information about the breeding animals that they will be using.

Multiple Ovulation and Embryo Transfer

The use of multiple ovulation and embryo transfer (MOET) is costly and requires highly developed technical skills. Application of the technique is feasible in large centralised nucleus herds. The main advantage is a higher selection in the females and more accurate breeding value estimation. The latter is due to the fact that animals will have more siblings and if performance recorded, more information from relatives (provided that BLUP is used for genetic evaluation). The result is that animals have a reasonably reliable breeding value at a younger age, particularly when the main traits are only recorded for one sex (females). Practically, this could mean that with the selection of males, there is no need to wait for a progeny test. Males could be selected based on half sib sisters. The gain in generation interval is large and overcomes the loss of selection accuracy from replacing a progeny test by a sib test. MOET breeding programmes are therefore characterised by:

- increased reproductive rates of females;
- selection at younger age (especially of males in case of sex limited traits);
- more potential for high rates of inbreeding.

The cost and skills involved in MOET breeding programmes are likely to be high and in most cases it may be better to invest these resources in more basic pre-requisites of a successful breeding programme: performance and trait recording, extension and dissemination.

Effect on breeding structures and socio-economic implications

Use of reproductive technology and reproductive rates by themselves has a large impact on socio-economic structures of a livestock industry. In breeding structures where AI is used, the ownership of the breeding animals is usually transferred to larger breeding organizations, such as AI cooperatives or private breeding companies. If the large part of genetic improvement is removed from the farm or village level, the dedication to genetic improvement may disappear. Moreover, the farmers have to be willing to accept AI as a tool for reproduction and breeding.

3.3.5 Investment in mating structures

The first and most important mating decision is to make sure that the selected males and females are mated with each other. Culled males should be kept separate or castrated. Culled females should not be bred and should be removed from the herds at an appropriate time.

Any mating strategy will require provisions. With natural mating, animals to be mated have to be joined in the same paddock but separate from

AI has great potential in breeding programmes to exchange semen between different nucleus herds and to disseminate genetic improvement to the production tier.

AI requires technical skills at the AI centre as well as on the farm end, with most important communication lines between the two. It is not likely to be used at the commercial level in extensive grazing systems for beef production.

Use of AI will take genetic improvement activities away from the farm, resulting in an increased need for extension and communication to farmers about their need to participate in genetic improvement.

other animals at reproductive age. AI can be used to target specific matings but AI again requires other provisions, as described in Section 3.3.3.

Section 4. Identifying structures and key decisions

This Section gives a step-wise guidance towards identification of current breeding structures. Case studies describing very basic structures moving to more advanced structures exemplify the issue.

4.1 Is there any performance and/or pedigree recording?

Recording here is used in the broadest meaning of the term. Even the simplest form of recording (e.g. 'in the farmer's memory') and selection (the farmer picking his 'best animal') could lead to small amounts of genetic improvement. However, recording and selection should be preferably formal, objective and documented, as it is more likely to be accurate and unbiased.

4.2 Is there any selection based on performance traits?

Without recording and selection, there can be no genetic improvement. Production systems without recording can only be improved genetically by bringing animals that were selected elsewhere based on merit, into the population.

4.3 What is the current breeding structure?

Breeding structures should always exist, even without recording, selection or importation. They would not contribute or enhance genetic improvement but they are simply designed for the purpose of reproduction and avoidance of inbreeding. Genetic improvement can be built into such existing structures.

Case 1: No recording, exchange of breeding males between different village flocks

A village consists of a hundred small farmers, each with ten chickens and a rooster. Farmers exchange roosters each year to avoid breeding their chickens to their own male progeny. From all new-born progeny, all females are kept as replacements and one male is randomly chosen for further breeding (to exchange with a young male from another farmer). There is no further pedigree or performance recording. The production system is such that chickens are kept for egg production and produce one offspring annually.

In this case, the breeding structure is flat, there is only a commercial population and the nucleus is basically absent. There is no selection and therefore no genetic improvement. There is some organized breeding (exchange of roosters) to keep inbreeding at sufficiently low levels. Hence, the only breeding objective is control of inbreeding, but there is no breeding objective in terms of definition of performance traits that are defined and need to be improved.

4.4 Identify selection possibilities

1. **Selection is possible if not all progeny born in a population are needed for reproductive purposes.**

   Females
   In species with low reproductive capacity (cattle, sheep) most females born are needed to replace older animals in the breeding herd or flock. With higher reproductive rates (some prolific sheep breeds, goats, pigs, chicken), each female leaves sufficient progeny such that not all new-born females are needed for breeding purposes. Also, when breeding females are kept longer in the herd, replacement rates are lower and less females are needed for replacement.
   The last strategy is not always advisable. In an on-going breeding programme, new-born individuals are (on average) better genetically than animals from older age classes and turnover of breeding females should be reasonably high to keep generation intervals short (see discussion in Section 3.2.2).

   Males
   Males generally have a high reproductive rate as each male can be mated to several females. Selection in males is always possible, the more so with higher reproductive rates (higher females to male ratios).

2. Identify who is eligible for selection

Selection should take place before reproductive age. Selection should be based on some information about breeding value. Animals not selected should be culled if they do not contribute to the production system.

There are several situations possible:

- no performance recording. Animals are selected based on visual appraisal or a ‘subjective’ score of performance. This can be the phenotype of the individual or the phenotype of the parents. For example, in dairy production systems, males are selected at birth and non-selected males are culled (or sold to other production systems). Also, females from bad performing cows are culled after birth, as there is no sense in raising them until first calving;
- performance recording, measurable on females only after reaching the reproductive age (dairy situation).
  Males cannot be selected based on own performance. Breeding sires are selected based on dam performance. If AI is used, they can be selected based on progeny tests but only a small group of males will be progeny tested. The selection of males to be progeny tested (first stage of selection) will be based on dam performance, or on sire and dam EBVs if a genetic evaluation system is up and running. The best strategy is to mate the best dams to the bet sires (elite matings) and progeny test the males coming out of such matings, as described in the 4-pathway breeding structure. The males with the best progeny test will be selected as breeding bulls for the larger population (second stage of selection of males).
  Females are generally all needed for herd replacement. There can be some culling by not keeping the female calves from the worst-producing cows;
- traits are measurable before reproductive age (beef and wool).
  Animals can be selected based on own performance or on an estimated breeding value based on all available information (BLUP-EBV). Animals not selected for breeding still contribute to the production system, so there is no loss in keeping them until after trait measurement.

The best parents that were selected can be called ‘parents of nucleus’. These animals are elite animals either because they are selected themselves or because they descend from the best animals in the previous generation, from a small group of animals that were selected based on performance recording. Their offspring will automatically be more valuable than offspring from average animals. The best of the offspring from nucleus animals become nucleus animals themselves. Investment in performance recording should first be targeted to such nucleus born animals. Investment in progeny testing is an example of limiting recording to ‘nucleus born’ animals.

A typical role of commercial animals is that they generate animal products but never will create progeny for the next generation. This is the fate of most males, as only a few of them are needed for breeding. Generally, females have low reproductive rates and it is necessary that most females leave progeny to keep up the size of the population of production animals.

Case 2. Additional to Case 1 there is subjective assessment of performance

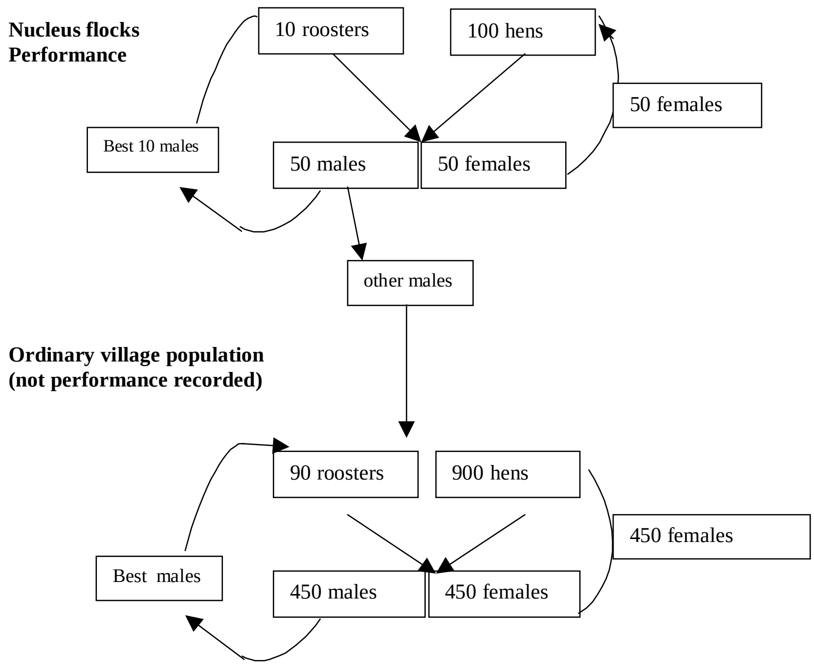
In addition to Case 1, farmers now assess their chicken. Suppose they have a fair idea of ranking their hens based on egg production. Even for this simple assessment of performance, it may be already necessary for each hen to have her own nest or cage. If all farmers in the village would subjectively assess their animals, the whole population is 'performance recorded' (although not very accurately). For example, each farmer can nominate his very best hen. As there is no official and objective recording, we assume it is not possible to compare animals from different farmers. The rooster that will be picked now will descend from the best female (with a male offspring). Here it is necessary to identify which males descend from which hen.

The breeding structure is a flat structure: a single tier structure. The reason is that all animals are performance recorded (assessed) and the breeding animals that are used (one male and all females from each flock) are equally contributing to the next generation of chickens. We cannot identify some breeding animals that are from an 'elite group', i.e. that we expect beforehand to be better than others because of some special selection of parents.

Hence: Single tier breeding structure.
Some genetic improvement, as the selected roosters can be expected to be better than average.

Case 3. Formal performance recording in part of the population.

Suppose now that ten farmers (ten percent) start to officially record egg production. They count and record the eggs laid over a certain time period. They also register the pedigree for each new-born (pedigree recording). Other farmers in the village do not record (or only subjectively record as in Case 2). Within the group, the ten farmers only exchange their best roosters.
Initially, nothing changes to the chicken population in the village. However, after one year it may be expected that the chickens of the group of ten farmers are better than average, as the farmers have more accurately selected their best males. The difference may not be extremely large if they used only dam performance as a selection criterion for males. However, the group might even apply BLUP, allowing them to use information on relatives (more accurate EBVs) allowing comparison of animals across flocks. The best ten males can now be selected from the best ten hens across flocks, allowing a higher selection intensity (best ten out of 100 rather than best out of ten giving i = 1.78 rather than i=1.52). More animals will be selected from the flocks that happen to have better animals. As the elite group will have higher genetic means after some time, it makes sense that all progeny born in the elite group become the source for other farmers in the village for roosters. Animals born in elite flocks are likely to have a higher genetic mean than ordinary village flocks. A two tier breeding structure emerges.
When a nucleus emerges, the elite group provides males to other "commercial" farmers. These producers do not use males born in their own flocks; rather they recruit them from the elite flocks, with a higher genetic level.



In Case 3, it is easy to identify the nucleus, as it consists of the group of elite farmers, who performance record and work together in selection and use of males. Genetically, there is initially not much distinction between males in ordinary and nucleus flocks, as they both will be used as a rooster in a village flock and their genetic mean does not differ very much. In the longer term, the nucleus animals will have a higher genetic mean, as they descend from the best animals. The males in other flocks are average animals in their own generation but from the best nucleus parents in the previous generation. There will be a genetic lag of two generations between the nucleus animals and commercial animals, meaning that the genetic mean in the nucleus today will be achieved by the commercial in two generations.

Case 4. All farmers record performance and pedigree on their animals.

The males born in ordinary flocks can now be selected, making the genetic lag between nucleus and commercial tier a bit smaller than two generations. As breeding values can be determined for all village animals, the selected males used as nucleus sires do not all have to be born in the nucleus themselves. The best village males might be just as good as some nucleus born males (although the village average is lower). The smaller the genetic lag between nucleus and commercial, the less difficult it will be for a male born in ordinary flocks to compete with males born in the elite flocks.

If performance recording commenced for all village animals at the same time and the selected males were randomly distributed over the different village flocks, then there would be no reason to distinguish a nucleus from the commercial population. However, it makes sense to mate the best males to the best females, as this increases the chance of genetically good offspring. Under such circumstances, the nucleus consists of the best male and female parents, who are possibly dispersed over several herds.

The logistics of natural mating may prevent to exactly mate the best males and females, as the good hens are probably scattered over many flocks. A practical solution is to gather the best hens and keep them together in one, or a few nucleus flocks, each joined with a selected male. The actual nucleus is then physically centralised (central nucleus). If AI was used, it would not be necessary to physically bring together the best animals and the nucleus could be dispersed over many herds (dispersed nucleus). However, in most low input production systems, natural mating is used and a centralised nucleus would have to be formed. A central nucleus is also a good, more intensive trait measurement or measurements that are hard to standardise in field conditions.

4.5 Create mating provisions

Mate best males to best females. This is straightforward in a centralised nucleus. In a dispersed nucleus, AI is needed to target specific matings. Some practical reasons for specific matings are:

1) targeting heterosis (between breeds) or dominance (within breeds);
2) target optimum values in non-linear traits (e.g. birth weight).

Summarising:

A nucleus is formed when a group of animals can be expected to have a higher genetic mean because they are more effectively selected (due to performance and/or pedigree recording and cooperation in exchange and joint use of males.)

The genetic mean of the nucleus will be lagging behind the next tier. The genetic lag is equal to two generations if only males are used at a lower tier. This lag is reduced to one generation if both females and females born in the nucleus are used as parents in the next tier.

In a breeding programme, the best males should be mated to the best females. In a low input production system with natural mating, this can be realised when the best females are physically brought together in a centralised nucleus.

An individual animal qualifies to be a nucleus parent if it is among the best of its contemporaries. If all animals are recorded and artificial breeding can be used, animals do not need to be physically part of a central nucleus. However, performance recording would be confined to a smaller group of herds and natural mating requires the best females to be physically together with the best males, making a central nucleus an easy and workable option.

Section 5. Decision-making

Breeding Objective

Description of a clear breeding objective, definition of the relevant traits involved and determination of their relative economic value in the production system which is targeted by the genetic improvement efforts. Decisions are made by the breeding cooperative or by private breeding organizations, in both cases to optimise genetic improvement and to maximise use of breeding animals at the commercial level and ultimately, to increase animal productivity of commercial production systems.

Recording

Which animals?

Determine trait and pedigree recording. If insufficient recording is taking place, a recording system needs to be set up. This area requires a conscious decision about investment of resources in a recording project (see Guidelines on Trait Recording).

With limited resources, recording of males should have first priority (if traits are measurable on males), higher selection intensities can be achieved in males.

Next, measurement could be restricted to a nucleus or to a small group of herds to become a nucleus. The number of animals that are performance recorded should be at least equal to the size of a potential breeding nucleus, i.e. several hundred breeding females. Recording a larger part of the population has some advantages like:

1) making producers more aware of productivity and therefore more interested in genetic improvement;
2) monitoring the actual progress in the commercial population;
3) some additional (about ten percent) possibility for genetic improvement by making use of superior commercial animals as nucleus breeding animals.

Progeny testing should be considered if AI is relatively easy to apply. Only the use of AI can guarantee sufficient use of a breeding bull in the commercial population to justify the investment in a progeny test. AI also helps to create progeny of one sire at a number of locations.

Which traits?

The traits to be measured are determined by the breeding objective. Preferably, breeding objective traits should be measured. Other traits could be measured additionally when it is difficult to obtain high accuracy for breeding objective traits. This is the case when BO traits have low heritability or when they are measured later in life. Measuring additional traits to include as selection criteria is only useful when they are highly heritable and have a high correlation with the breeding objective. Other traits could also be measured instead on BO traits when they are much easier (and cheaper) to measure. Decisions on whether a trait should be measured or not can be made in the selection index context. The evaluation criteria are increased accuracy (of estimating total genetic merit) and expected response per generation. For some examples and further information, we refer here to the Guidelines on Breeding Objectives and Trait Measurement.

Breeding cooperatives should design and plan a measurement strategy. A coordinating office to design and manage performance and pedigree recording systems needs to be established. Private breeding organizations could set up such recording systems themselves. They either record within their own nucleus or they need to seek cooperation with farmers to organize their trait recording. In a cooperative system, it might be easier to gain farmers' cooperation in recording and later in distribution of breeding stock. However, decisions in the selection need to be to the point and rigorous, which is often easier achieved in private breeding organizations.

Use of reproductive techniques

Artificial insemination mainly creates faster dissemination of genetic superiority to the commercial population. The effect on the rate of genetic improvement is mainly:
- more selection intensity on the male side;
- more accurate estimation of breeding value across herds;
- more accurate selection of males, based on progeny tests.

Use of reproductive techniques on the female side are generally more expensive and logistically more difficult to achieve. Increasing reproductive rate, e.g. by multiple ovulation and embryo transfer, is useful for species with low reproductive rates, such as cattle and sheep. Using MOET, the number of calves of breeding cows could increase from one to around ten per year. The benefits are:
- more selection intensity on the female side;
- more accurate estimation of breeding value, as family sizes are larger and animals will have more information on sibs. A possible result is that animals can have an estimated breeding value with a reasonable accuracy earlier, therefore making it easier to select young animals as a nucleus parent. This could typically decrease generation interval, with relatively less decrease in selection accuracy. A potential danger is an increased rate of inbreeding. With high reproductive capacity in males and females, it is advisable to apply selection rules that not only increase merit, but also restrict average co-ancestry of selected individuals.

The logistic challenge with MOET is that at the time of embryo transfer, a group of recipient cows needs to be available and synchronised. In a centralised nucleus, the application of MOET is well feasible under many circumstances, as all activities can take place at one location.

If technically and logistically, reproductive techniques as AI and MOET are achievable, then their application is generally cost-effective as increased genetic improvement can be passed on to many individuals in the population.

Genetic evaluation

Performance records jointly with pedigree records form the basic input for a BLUP breeding value estimation procedure. BLUP breeding values ensure a fair comparison of potential breeding animals across herds and age classes. BLUP requires pedigree recording and genetic links between herds and years. If the conditions for such genetic evaluations cannot be met, phenotypic selection within herds is an alternative. This is considerably less efficient than BLUP selection but for high heritable traits it may be a good and cheap alternative to BLUP.

The investment in genetic evaluation consists of a central office where all recorded information is stored in a central database. Genetic evaluation software is relatively easily available but for specific applications, some customisation might be needed (see further Guidelines on Genetic Evaluation). The quality of the EBVs can be partly evaluated based on computed accuracies. However, accuracies do not reflect biases and lack of links between different herds, years or locations.

Regular 'quality control checks' can evaluate the quality of the genetic evaluation system. An important quality control is a check on changes of sequential EBVs on the same animal over time. The change of an animal's EBV in subsequent evaluations (years) depends on its accuracy and the additional information used. The largest concern should be a consistent change in EBV over time, when more data appear. Consistent and directional changes may indicate bias in genetic evaluation. For example, animals that are preferentially treated will have high EBVs initially, but as information on progeny emerges the EBV will decrease.

Mate Selection

The process of selection of breeding animals based on their estimated breeding value and determining their matings, is indicated as mate selection. The selection part refers to the creation of selection differential (difference between selected animals and their contemporary group). Basically, as few animals as possible should be selected for breeding purposes, with the only restriction being the number of animals required for a minimum population size and the number needed for reproductive purposes. Minimising co-ancestry among selected individuals can more formally optimise the minimum population size and restrict inbreeding. Mate allocation can also prevent short-term inbreeding and to some extent, long-term inbreeding. Mate allocation can be particularly useful at the commercial level, by matching AI sires to individual cows for the purpose of avoiding birth problems. In general, traits that have an optimum value are candidates to apply corrective mating to. Also, combinations of traits can lead to 'profit heterosis' (see example).

Example of 'profit heterosis' in mate selection

An example here is protein yield per lactation viewed as the product of yield and percentage of protein. In the example below, the latter two traits are assumed to have fully additive inheritance, but corrective mating would slightly increase total yield.

Example:	Population mean	3 000	3%
	Bull A, Cow A	+300, -.2%	
	Bull B, Cow B	-200, +.3%	

AxA gives +92.4 AxB gives +93.0
BxB gives +92.4

Annex 1. Basic elements of genetic improvement

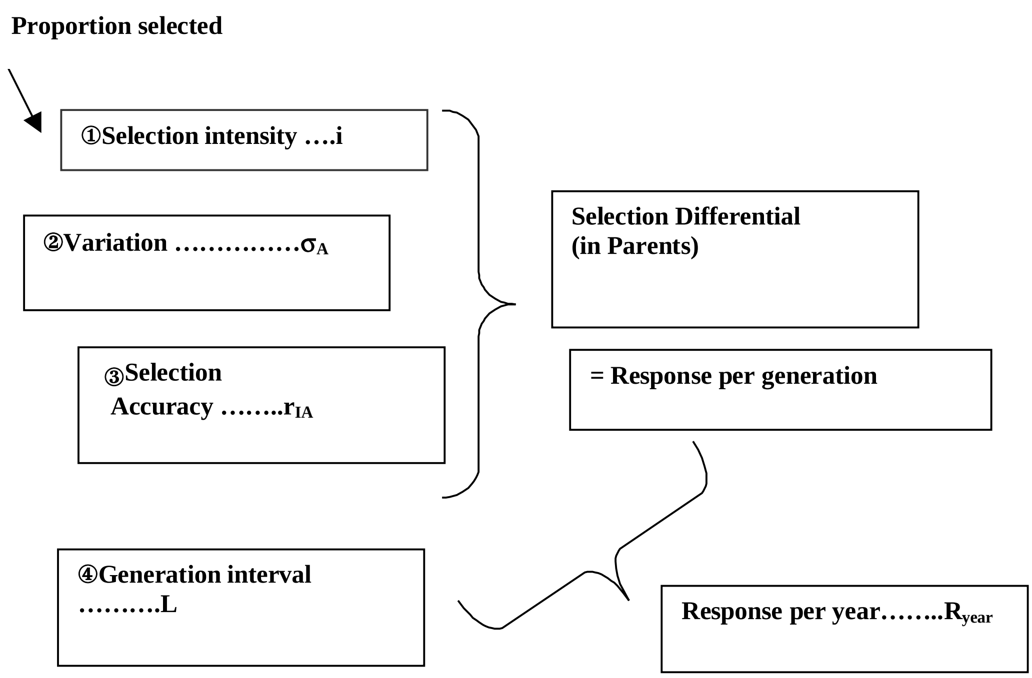
The amount of genetic improvement that can be made depends on four key factors:

- Variation
  The best animals will stand out more if there is more variation in the trait measured, i.e. they will be relatively more above the mean.

- Selection Intensity
  The selection intensity is the superiority of a selected group (in standard normal units). The larger the proportion selected the larger selection intensity. We may expect that the average of the very best animals (say top five percent) to be higher (on average) than the average of, for example, the best 50 percent.

- Accuracy of selection
  The better we are able to asses true genetic merit of animals, the more of what we see as 'good' in the selected parents will be passed on to the next generation.

- Generation interval
  The longer it takes for good animals to drop their progeny, the less progress can be made on an annual basis.



1.1. Selection accuracy

All of the differences between animals at the phenotypic level will not be passed on to their progeny, as it is not all due to their genes.

> The estimated breeding value (EBV) gives the part of observed differences that we believe is due to additive genetic effects.
>
> Half of the EBV of each animal will be passed on to progeny as an animal gives only 50 percent of its genes.
>
> In the process of genetic evaluation, genetic parameters are needed such as heritability for each of the traits and genetic and phenotypic correlations between the traits. Genetic parameters together with the amount of information on an animal determine accuracy of EBV and therefore accuracy of selection.

The accuracy of selection tells us how sure we know that a particular good animal has also a good breeding value. With no information, the accuracy of an EBV is zero and with full information it is one. As most traits have heritability considerably lower than one, there is always error in estimating a breeding value from phenotypic observations. Only a progeny test based on a large number of progeny can give an almost perfect accurate EBV.

The accuracy of selection depends on the heritability of the trait selected. It is equal to h ($=\sqrt{(h^2)}$) if selection is based on individual phenotypic performance only.

Furthermore, if information from parents, sibs or progeny is used, the accuracy will increase, the more so for traits with low heritability. Therefore, if family information is used, it becomes less important whether a trait has low heritability or not.
Using family information is more effective when heritabilities are low. Data from tropical countries tend to show low to moderate heritabilities, suggesting that using information from relatives would be more useful. The expected increase in accuracy may be up to 50 percent for low heritable traits.

The accuracy of an EBV based on relatives' information can be calculated from the selection index theory. In routine genetic evaluations with BLUP, it is calculated (or approximated) from the mixed model equations. For a progeny test there is a simple formula to approximate accuracy:

$$\text{The accuracy of the progeny test is } = \sqrt{\frac{n}{n + a}}$$

This simple formula allows the quick determination of the accuracy, for a given progeny test based on n progeny, for a trait with heritability h^2 (where

$a = (4-h^2)/h^2$). Notice that n refers to the *effective number of progeny*. In a badly designed progeny test where progeny of the same sire are often compared with each other in the same management group, the effective number of progeny is lower than the actual number of progeny.

For an individual record: $n_{effective} = 1-(1/N)$ where N is the number of individuals in the contemporary group.

For n progeny of a sire : $n_{effective} = n_{sire}-(n_{sire}/N)$ where N is the total in a contemporary group.

The formula for the effective number of records shows that the information content of a record reduces to zero if there are no other animals (or progeny from other sires) to be compared to the same contemporary group.

Selection based on repeated records on the same animal increases accuracy, because the 'heritability' of a mean of repeated records is higher than that of single records, the more so if repeatability is low.

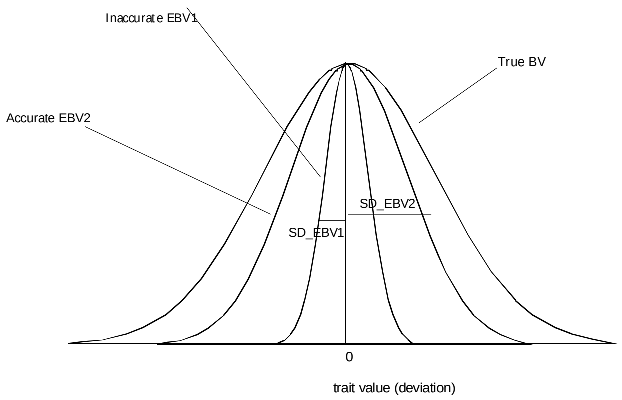
Some examples of accuracy

	accuracy	
Information used	$h^2 = 0.10$	$h^2 = 0.30$
1) Own information only	0.32	0.55
2) Mean of 5 full sibs	0.32	0.48
3) Mean of 10 half sibs	0.23	0.33
4) 1 + 2 + 3	0.43	0.65
5) Mean of 1 000 half sibs	0.49	0.50
6) Mean of 1 000 full sibs	0.70	0.71
7) Mean of 5 progeny	0.34	0.54
8) Mean of 10 progeny	0.45	0.67
9) Mean of 100 progeny	0.85	0.94
10) Mean of 2 repeated measurements		
Repeatability = 50%	0.37	0.63
Repeatability = 80%	0.33	0.58
11) Mean of 3 repeated measurements		
Repeatability = 50%	0.39	0.67
Repeatability = 80%	0.34	0.59

Estimated breeding value will be more spread out if they are more accurate.

The spread in EBVs (more formally: the standard deviation of EBVs) is determined by genetic variation and accuracy of breeding estimation. The more information used for estimating breeding values, the higher accuracy of EBVs, the more they are spread out.

In the extreme case where there is no information on animals, there will be no distinction: all EBVs would be at the value zero (i.e. no spread). With more information or higher heritability, the spread in EBVs will be closer to the spread in true breeding value. Therefore,



The standard deviation of Estimated Breeding Values is equal to the accuracy (of EBV) times the genetic standard deviation (SD(A)).

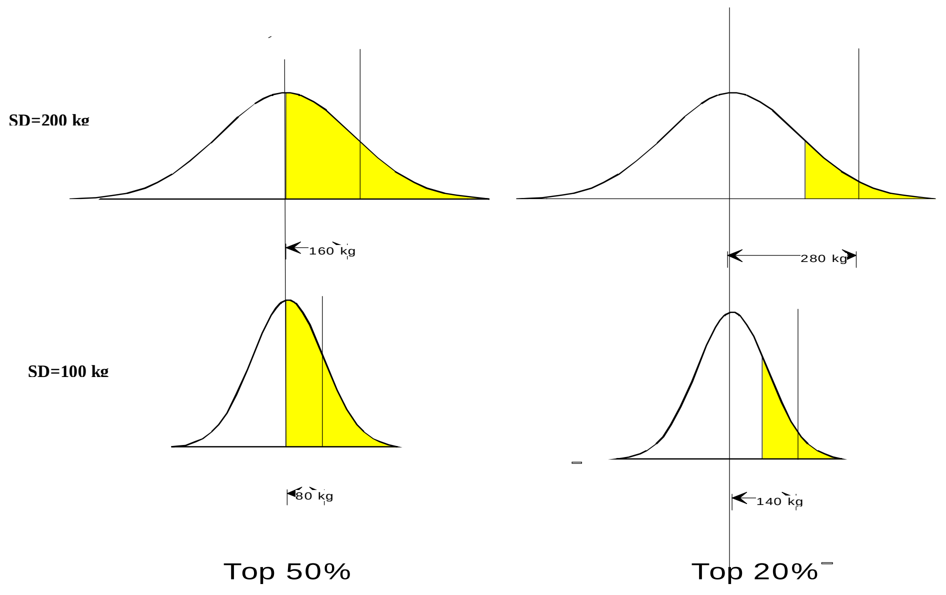
$$SD(EBV) = r_{IA} \cdot SD(A)$$

1.2 Selection intensity

The animals that we select as breeding animals have to be above average. This superiority of selected parents is often indicated by the term *selection differential*.

Selection differential is easy to measure for a given group of animals: it is the difference between average of the selected group and the average of the group they were selected from. Even if animals have not yet been measured, the superiority of selected parents can be predicted from the intensity of selection and variation of the selection criterion. The following illustrates this. The normal curve indicates how a population of animals is distributed for a certain trait-value. Selection differentials are indicated as the difference between the average of the selected animals (shaded area) and the average of all. The smaller the fraction of animals selected, the larger the selection intensity. Also, the more variation in the selection criterion (e.g. EBV!), the larger the superiority of the selected group.

Selection intensity is inversely related to the proportion selected.
The proportion selected is
- The number of animals selected as parents
- The number of animals considered for selection



Selection Intensity i is the number of standard deviation units that selected parents are superior to the mean. It allows us to predict the performance of a selected group of parents.

The relationship between proportion selected and selection intensity is

Proportion Selected p	Selection Intensity i
0.001	3.4
0.005	2.9
0.01	2.7
0.05	2.1
0.10	1.8
0.25	1.3
0.50	0.8
0.75	0.4
0.95	0.1

- Note the trend, fewer selected -----> more intensity
- Use Tables or sub-routines to find i given p (Falconer and MacKay, 1996)
- Selection intensities for males are mostly different from those of females. Due to their higher reproductive rate, less males are needed in breeding and males therefore usually have higher selection intensity.
- When the population selected from is small, selection intensities are slightly reduced. For example, the best out of ten will not be as good, on average, as the best ten percent of 1 000. The selection intensities are 1.75 and 1.52, respectively. There are special Tables (in Falconer & MacKay, 1996) or sub-routines used for small populations. Corrections become reasonably substantial if the population to select from is smaller than about 25.

The superiority of selected parents is often indicated by the term *selection differential.*

Selection differential = selection intensity * SD (selection criterion)

If selection is on phenotype, we can use the phenotypic SD and predict the phenotypic superiority of the selected group.

If selection is on estimated breeding value we can predict the superiority of the selected group in genetic value. Half of this will be passed on to offspring.

Selection differential = selection intensity * SD (EBV)

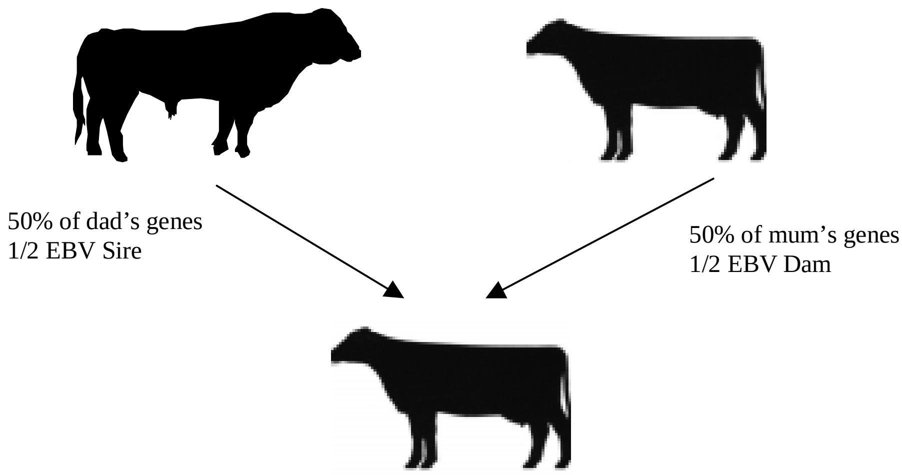
= selection intensity * selection accuracy * SD(true breeding values)

Wool production in sheep. Population mean 2 Kg , SD = 0.5 Kg

In a closed flock of 100 ewes, 100 lambs may be born annually and 60 percent can make it to reproductive age. Therefore, we have 30 young males and 30 young females that could be maintained in the flock as breeding animals. The 30 young females may be all needed for replacement of ewes. This makes the proportion of females selected equal to 100 percent and selection intensity for females equal to zero.

We may want to select four out of the young males as breeding rams. The proportion selected would be 4/30= 13 percent and the selection intensity for males is 1.63. If the males could be selected based on their wool yield at one year of age, we expect the average of the selected males to be 2 + 1.63*0.5 = 2.8 kg

The expected genetic value of the next generation is equal to the average EBV of selected parents. More accurate EBV as well as higher selection intensity will have a direct effect on genetic improvement.



Expected Value of progeny = 1/2 EBV_{sire} + 1/2 EBV_{dam}

- Generation intervals should be short.

1.3 Generation interval

For an efficient genetic improvement programme, the rate of genetic change *per year* is important. Hence, we are more interested in the genetic improvement we can make on an annual basis. In planning a selection programme, account has to be made for how quickly we can 'turn over' a generation. We use the concept of *generation interval*. This is the average age of the parents at the birth of their progeny. The longer it takes before the selected parents drop their progeny, the slower the response per year. The response per year is simply the response per generation, divided by the generation interval.

> The generation interval is determined by the age of the parents. As we keep breeding animals longer in the herd, the longer the generation interval, the less genetic improvement per year.

Generation intervals usually differ between males and females. Since less males are needed as females, males can be replaced earlier, so there is more potential to have short generation intervals on the male side. Most young females usually need to be retained as replacements, as female reproductive rates are usually low (at least for sheep and cattle). This leads not only to low selection intensity on the female side, but also to long generation intervals, as females are kept for the length of their productive life.

Notice in the following that generation intervals of both males and females are important. Even if females are not selected, their generation interval contributes to the annual rate of genetic improvement.

1.4 Prediction of the annual rate of genetic improvement (R_{yr})

$$R_{yr} = \frac{i_m * r_{TI\_m} + i_f * r_{TI\_f}}{L_m + L_f} * \sigma_A$$

with: Intensity of selection = i
Accuracy of selection (accuracy of EBV)= r_{TI}
Genetic Standard Deviation = σ_A
The generation interval = L
Note that males and females (can) have different selection intensity, a different accuracy of breeding value and a different generation interval.

Example. Selection for fleece weight in sheep: prediction of rate of genetic change.

Herd and age structure:

Consider a 100 ewe flock. There is one breeding cycle per year and the weaning rate for females is 80 percent. Each year, 24 new replacement females are added to the flock. The ewes remain a maximum of six breeding seasons around (until the age of seven years). Due to some culling and mortality (about 15 percent per year), the number of ewes per age class decreases with increase in age.
The number of ewes joined per ram is 25. Rams are kept for one breeding season.

- Age structure

Age at drop of progeny:	2	3	4	5	6	7	TOTAL
No. of Rams:	4	-	-	-	-	-	4
No. of Ewes:	24	21	17	15	13	10	100

- Generation intervals

Males: L_m = two years = average age of rams 'dropping' progeny.

Females: $$L_f = \frac{24*2+21*3+17*4+15*5+13*6+10*7}{100} = 4.2 \text{ years}$$

- Selection intensities

100 ewes give 0.8 x 100 = 80 progeny, 40 male and 40 female.

Males: Proportion selected: four young rams selected out of 40 available = 4/40 = 0.10

giving i_m = 1.786 = male selection intensity

Females: Proportion selected = 24/40 = 0.60 giving

i_f = 0.644 = female selection intensity

- Selection accuracy

Assume selection is based on own performance
Heritability (h^2) = 0.30
Phenotypic standard deviation = 0.4 kg
Genetic standard deviation (σ_A) = √(0.30)*0.4 = 0.22 kg
Accuracy of selection (r_{TI}) based on own performance = √(h^2)= √(.30)= 0.547

- Response

$$R_{yr} = \frac{i_m * r_{TI\_m} + i_f * r_{TI\_f}}{L_m + L_f} * \sigma_A = \frac{1.786*0.547+0.644*0.547}{2+4.2} * 0.22 = 0.047 \text{ kg}$$

R_{year} = 0.047 kg increase in fleece weight predicted per year.

Alternative: Keep one ram for two matings: This decreases selected proportion to 3/40; im is increased to 1.887 and generation interval in males (Lm) is increased to 2.25. Response = 0.050 kg

1.5 Genetic merit in the 4-pathways structure

A numerical example will give some more idea of a 4-pathway breeding structure, with dairy as an example. Notice that reproductive rates of males and females are important variables in designing such a structure.

Selection Intensities

Assume a commercial dairy cow population of one million animals. Assuming an average herd life of a dairy cow of four lactations implies that 25 percent of the cows needs to be replaced annually. With a female reproductive rate of one calf per year, this implies that at least 50 percent of all new-born females need to be kept as herd replacements. Allowing some loss in the rearing period (including birth), this number may be taken a bit higher, e.g. 70 percent. Hence, for the DD selection path, we need at least 70 percent of the commercial cows to breed their replacements and selection intensity cannot be very high.

To inseminate one million cows, we need about 50 breeding bulls (a rough figure, also given that there is usually quite a large variation in number of inseminations per breeding bull. In order to produce so many breeding bulls, we might want to test about 500 young bulls. This gives a selected proportion in the SD path of ten percent. This number is somewhat arbitrary. It can be optimised depending on expected gain (more selection intensity if more tested) and cost of testing.

The 500 young bulls have to be generated by test matings. We need at least 1 000 births, but allowing for some deaths and early culling of young males, we plan 2 000 elite matings. Hence we need to select 2 000 elite cows. This gives extremely high selection intensity in the DS path, as there is a very large cow population available. Suppose that 30 percent of the cows is found suitable as elite dam based on reasons other than milk productivity (e.g. type traits, legs, udder, mastitis history, etc), then effectively 2 000 out of 300 000 could be selected based on milk production criteria (=0.7 percent). We could all do 2 000 elite matings with one top breeding bull. However, this would quickly give too much inbreeding. A number of five sires selected for elite matings may be suitable. The selected proportion for the SS path then becomes 5 / 500= one percent.

Selection accuracies

Selection of males is based on a progeny test. The number of progeny tested per young bull depends on the total number of bulls tested and the number of cows made available for test matings. Let 20 percent of the population be used for test matings, i.e. 200 000 cows. This gives 400 progeny born per sire but with some loss, only 100 of those will be cows completing a first lactation. We obtain therefore selection accuracies of males of 0.87 (based on tests of 100 progeny with heritability equal to 0.25) and females of 0.50 (based on own performance). The last figure is an average, as some cows have more known lactation records at the time of selection than others.

Generation intervals

The average generation interval for cows to breed cows is assumed to be 4.5 years. We assume the same is true for elite cows. Bulls are selected after a progeny test and their average age will be 6.5 years when their progeny have produced the first milk lactation record.

The following Table can be constructed:

Table 1.2. Genetic contribution and its components for each of the four selection paths in a dairy cattle breeding programme.

Selection path	Selected proportion	Selection intensity	Generation Interval	Selection accuracy	% contribution to genetic gain
SS	5/500	2.65	6.5	0.87	45
DS	2 000/300 000	2.79	4.5	0.50	24
SD	50/500	1.76	6.5	0.87	27
DD	70%	0.47	4.5	0.50	5

The formula for genetic gain in a 4-pathway breeding structure is an extension of the earlier version for 2-pathways (with sBO being the SD of the breeding objective, i.e. genetic standard deviation). This formula is known as the formula of Rendel and Robertson (1950).

$$\delta G_{year} = \frac{\sum_{i=1}^{nr\_of\_paths} intensity * accuracy * \sigma_{BO}}{\sum_{i=1}^{nr\_of\_paths} generation\_interval}$$

$$= \frac{(i_{SS}.r_{SS} + i_{DS}.r_{DS} + i_{SD}.r_{SD} + i_{DD}.r_{DD}) * \sigma_{BO}}{L_{SS} + L_{DS} + L_{SD} + L_{DD}}$$

$$= \frac{(2.65*0.87 + 2.79*0.5 + 1.76*0.87 + 0.47*0.5)*\sigma_{BO}}{6.5 + 4.5 + 6.5 + 4.5} = 0.235\sigma_{BO}$$

Hence, we may expect an annual genetic improvement equal to about one quarter of a genetic standard deviation (σ_{BO}). This is equal to about 1.24 percent of the mean (given that $\sigma_{BO} = h*\sigma_P$, $h^2 = 0.25$ and σ_P (phenotypic standard deviation) is ten percent of the mean.

Notice that each part contributes to the sum of generation intervals over paths. Hence, even if we would not select cows for producing within herd replacements, they would still contribute to the sum of the generation intervals. The reason is that genes have to pass through this pathway in order to end up in commercial cows. If we would only keep calves from older cows, it would take longer before improved genetics flow on to future generations, whether we select these cows or not. The contribution of each pathway to the total genetic gain can be calculated by multiplying selection intensity and selection accuracy in each pathway (Table 1.2).

The numerical example used here contains many simplifications. For example, in order to test 500 young bulls and aiming at about 100 progeny records for each of them, we need to inseminate at least 200 000 cows with semen from unselected test bulls. This is 20 percent of the cow population being inseminated by untested young bulls rather than selected proven bulls. Calling test inseminations a fifth 'selection path' (YB for young bulls) we can adapt the formula (assuming tested young bulls are unselected males from elite matings and having a generation interval of 3.5 years

$$= \frac{(i_{ss}.r_{ss} + i_{DS}.r_{DS} + 0.80(i_{SD}.r_{SD}) + 0.20(i_{YB}.r_{YB}) + i_{DD}.r_{DD}) * \sigma_{BO}}{L_{SS} + L_{DS} + 0.80L_{SD} + 0.20L_{YB} + L_{DD}}$$

$$= \frac{(2.65*0.87 + 2.79*0.5 + 0.80*(1.76*0.87) + 0.20*(0) + 0.47*0.5)*\sigma_{BO}}{6.5 + 4.5 + 0.80*6.5 + 0.20*3.5 + 4.5} = 0.241\sigma_{BO}$$

hence, the correction for the use of some unselected test bulls has only a small effect on the annual gain. In fact, the gain is somewhat increased. Apparently, the loss from using some unselected young bulls on part of the population selection is partly recovered by the reduction of the generation interval. It should be noted that although they are not progeny tested and therefore unselected, young bulls are on average better than the generation from which the proven bulls are selected from as they descend from a younger generation of elite parents. Young bulls could therefore be quite competitive to proven bulls. However, there is some more risk involved in using them, as the EBVs are not known very accurately.

1.6 Realised and expected response

The example in this Chapter has shown that even for a more complicated breeding programme, such as the 4-pathway-structure in dairy, the response can be predicted relatively simply. The predicted response as worked out in the example is a reasonable prediction of the genetic improvement that could be achieved in a breeding programme. The realised response, however, is generally lower. Realised response predicted for dairy breeding programmes such as in this example were around 0.7 percent to one percent of the mean, about 30 percent lower than predicted here. The main reasons why realised responses are lower than expected are:

- there is some variation in the outcome of the breeding programme as it is the result of many random processes;
- the model to predict response is a bit simplified and contains some errors;
- the actual selection policies are sub-optimal.

Variation in response

At the level of an individual and considering inheritance at one locus, we know that the inheritance process is stochastic: one could inherit either the good allele or the bad allele from a heterozygous parent. Similarly, for quantitative traits, there is genetic variation within families as full sibs have not all the same genotype. On top of genotype, the environment and other random effects create additional unpredictable variation in the observed phenotype. Hence, we may expect a certain outcome of a breeding process, but there will be some variation around this outcome. Breeders or breeding organizations all do their best in generating good bulls, but breeding the number one bull is partly a matter of chance. Obviously, the occurrence of occasional topper in a breeding programme will have an impact on overall genetic improvement. The dairy bull 'Sunny Boy', bred in The Netherlands in the late eighties, managed to have over one million offspring worldwide!

The outcome of the whole breeding programme varies less if the breeding population is larger, since the effect on individuals will become smaller. Hence, the population size is a relevant parameter to determine variation in response. Population size depends on the number of males and females effectively used in the population, which is also used to predict inbreeding. In the example described here, it is mostly the number of sires that determines effective population size. A breeding programme using sufficient sires will have higher effective population size, leading to less inbreeding, but, also less variation in response. Hence, a breeding programme design that avoids inbreeding will also be less prone to risk. Note that it is not only the number of sires and dams used, but also the extent to which they are used that is important. In most dairy breeding programmes similar to the example, a number of 50 breeding bulls is not unrealistic, leading to about 20 000 inseminations from each bull. However, the very best bulls which are used may have close to a 100 000 progeny, while the worst may have not more than a few thousand.

Simplifications and errors in the prediction formula

Predicting genetic response in a breeding programme is based on a whole lot of assumptions concerning biological and genetic models. Biological parameters are related to mortality and culling due to disease or infertility, average productive life, etc. The genetic model is based on a very large ('infinite') number of loci. Although it is unlikely that this genetic model is realistic, it most probably produces reasonably accurate prediction of selection, even if there are some loci with larger effect. Possible interactions between environment and genotype could be important for certain specific cases, but are less likely for bulls that are both tested and used over a larger range of environments (herds) and regions.

The number of offspring of each breeding animal is assumed equal, but in reality, the best bulls will have more offspring and they will also have more offspring tested. Furthermore, the prediction formula does not account for some loss of variation due to selection nor does it take into account effects of inbreeding. Selection candidates are also assumed to be unrelated, but in reality, they may be half or full sibs, therefore decreasing somewhat the selection intensity. On the other hand, selection of bulls can be optimised over age classes, as an occasional good bull may be used for elite matings for a number of years and this somewhat increases the realised gains.

Errors may be the result of using incorrect heritability or genetic correlations in breeding value estimation and there may be registration errors in recording of performance or pedigree. An estimate for the degree of pedigree errors has been as high as ten percent in some countries. Furthermore, EBVs could be biased due to preferential treatments or due to unequal variances in different herds. A common problem in dairy cattle breeding is that progeny tests from young bulls turn out to be lower than expected based on the parental average. It is mostly the dam's EBV that is expected to be biased and over-predicted. This is partly due to the fact that dams EBVs are less accurate, as they have no progeny test and partly due to preferential treatment, as farmers may want to pamper their best cows in order to get a lucrative bull dam contract. Another possible explanation could be that the genetic evaluation system might be somewhat sub-optimal in the extremities. As only a very small fraction of cows is selected as bull dam, those animals can deviate several standard deviations from the mean. It is not unreasonable to assume that in the extremes, somewhat more of the differences may be due to extreme environment, giving over-predicted EBVs. Dairy breeders tend not to fully rely on EBVs of commercially tested bull dams. This is also one of the reasons why some dairy breeding organizations have moved to central test herds for elite cows, with the idea of obtaining less biased bull dam EBVs.

Some of the simplifications used in the prediction of rate of genetic change could be avoided with more complicated modelling, as has been done in a number of studies. Overall, simplifications and errors may over-estimate the realised genetic response up to 20 percent and is therefore not the only reason for the discrepancy between realised and predicted response. Furthermore, the simple formula gives a reasonable approximation for ranking of alternative breeding programmes. For example, the change of response with a smaller number of young bulls tested, or smaller number of test progeny per young bull can be easily assessed. The prediction of genetic change may be optimistic, but the ranking of a different breeding programme is likely to be more robust toward the assumptions made.

Annex 2. Limiting the rate of inbreeding

The rate of inbreeding in a population depends on effective population size. In practice, a sufficient number of males should be used in each generation.

Inbreeding occurs more frequently in small populations. The reason is that in a small population there is a large chance for an individual to mate with a related individual. Inbreeding therefore depends on population size. If males have a lot more offspring than females, we only need a few males to breed the next generation. So, even if the actual population is reasonably large, there can be a high chance of mating a relative if only a very few males were sires of a current generation. Therefore, population size is measured by how many parents are used *in each of the sexes*. Inbreeding depends on *effective population size* rather than actual population size.

Effective population size is equal to true population size if an equal number of males and females are used for reproduction in equal amounts. However, the number of males used is much smaller and in that case, the effective population size is mainly determined by the number of males used.

Effective population size: N_e $$N_e = \frac{4N_m N_f}{N_m + N_f}$$

where N_f and N_m are the number of males and females used as parents in each generation.
This formula gives much more weight to the lesser represented sex. Note that if $N_m = N_f$ then $N_e = N_m + N_f$ as you might expect.

Example:

nr males per generation	2	2	5	20
nr females per generation	2	200	200	200
Effective Population Size (N_e)	4	7.9	19.5	72.7

The average inbreeding co-efficient at ***generation*** t:

$$F_t = 1 - [1 - \frac{1}{2N_e}]^t$$

and the relative increase of inbreeding in each generation, is *the Rate of Inbreeding*:

$$\Delta F = \frac{1}{2N_e}$$

Note that it is assumed here that all males are unrelated to each other. If the males used in a nucleus population (or village herd) are related to each other, effectively the population size is smaller. Software exists to optimise the number of males selected, given the genetic relationships of the selection candidates.

Annex 3. Best linear unbiased prediction

BLUP is used to give EBVs for commercially important traits. It has the same capabilities as the selection index, plus a lot more. Whereas the selection index uses information from defined sources (e.g. fleece weight on self, fibre diameter on self, fleece weight on sibs), BLUP uses all available information.

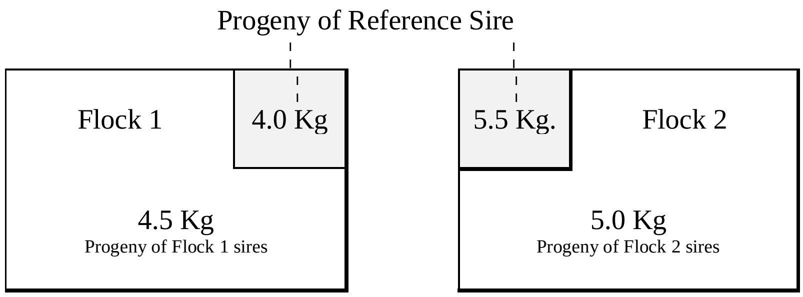
1. BLUP makes full use of information from all relatives.

BLUP does not have to give separate attention to sib testing, progeny testing, own performance, etc. Use of information from all relatives (even those long dead) is simultaneously handled. This gives more accurate EBVs and more selection response.

2. BLUP accounts for fixed environmental effects (management group, herd, season, year, etc).

This means that animals can be compared across groups, giving wider scope for selection. For example, comparing across age groups means that older animals have to prove their competitiveness at every round of selection.

As a different example, consider two flocks with mean fleece weights of 4.5 and 5.0 Kg. Is the second flock 0.5 Kg better ***genetically***? This depends on the flock environmental conditions. Using a reference sire with random mate allocation helps:



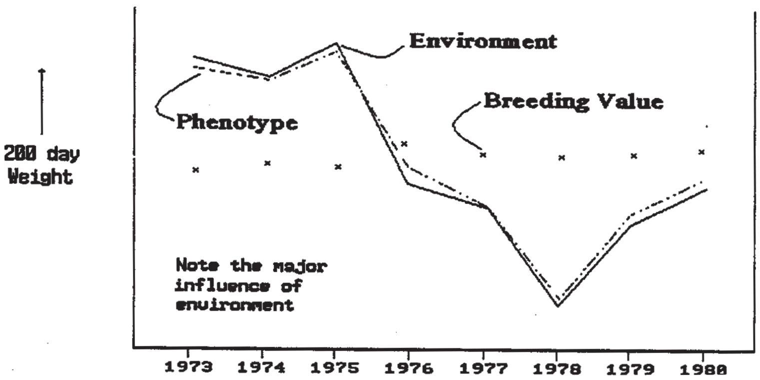
The reference sire is inferior in the 4.5 kg flock and superior in the 5.0 kg flock, so the 4.5 kg flock must be better genetically.

By How much? In Flock 1, the reference sire progeny is worse than Flock 1 sire progeny by 0.5 Kg. Assuming many progeny, the reference sire breeding value inferiority must be twice this, because of the diluting effect of ewe mates of equal merit. So the reference sire is 1 Kg genetically inferior to Flock 1 sires and by a similar argument, he must be 1 Kg genetically superior to Flock 2 sires. Thus, if the flock sires are representative of their flocks (or if they are equally selected) then Flock 1 is 2 Kg genetically superior to Flock 2. Given the observed average merit of the flocks, the Flock 1 environmental effect must be 2.5 Kg below that of Flock 2.

BLUP can both calculate and use this information automatically whenever there are such genetic linkages available, i.e. whenever relatives are spread across different groups.

3. BLUP gives genetic trends.

The approach used in the last example could be used to test the genetic differences between animals born in different years, instead of different flocks. This ability to compare the EBVs of animals born and measured in different years means that year mean EBVs can be calculated and genetic trends reported.



4. BLUP can handle unbalanced designs easily:

a selection index using sib information faces the problem that each candidate does not have the same number of sibs (n):

One solution is to construct an index for each number of sibs involved but if progeny information is available the same problem exists. BLUP handles this imbalance automatically by constructing a custom selection index for each animal. However, it only needs to report the EBVs and not the index weights.

5. BLUP can cater for non-random mating:

such that males can be compared via their progeny even if some had been allocated better mates. This can only be done where the mates were allocated on the basis of their recorded performance, such that BLUP can account for their EBVs when evaluating the males concerned.

6. BLUP can account for selection bias:

e.g. consider ranking bulls on the first two lactations of their daughters. The worse bulls, who had worse daughters, will have benefited more from culling of daughters on first lactation performance.

7. BLUP relies on good genetic parameters:

as with the selection index, BLUP assumes that the estimates of genetic parameters it uses are valid (i.e. reasonably close to the truth) and that the genetic model we use is valid (e.g. that the variance due to sires is $\frac{1}{4}V_A$).

8. USING BLUP.

BLUP gives estimates of breeding value (EBVs or s) for the traits of interest. The breeder only needs to weigh these by economic weights to provide an index which s/he can select on:

$$\text{Index} = a_{11} + a_{22} + a_{33} + \ldots$$

Annex 4. Optimising progeny testing across herds

Assume progeny testing of ten sires, each with ten progeny and the test capacity is in ten herds.

Comparing the efficiency of progeny testing (measured by accuracy of the EBV of the sire) of different strategies:

- one sire per herd;
- pairs of herds, each with two sires, with a sire five progeny in each of two herds;
- sires are used in two herds (five progeny/herd), but each time compared with another sire: sire one in one and two, sire two in two/three, etc.
- each sire one progeny in each herd.

In the following the 'design' matrix represents the number of progeny of each sire (rows) in each herd (columns)

10	0	0	0	0	0	0	0	0	0
0	10	0	0	0	0	0	0	0	0
0	0	10	0	0	0	0	0	0	0
0	0	0	10	0	0	0	0	0	0
0	0	0	0	10	0	0	0	0	0
0	0	0	0	0	10	0	0	0	0
0	0	0	0	0	0	10	0	0	0
0	0	0	0	0	0	0	10	0	0
0	0	0	0	0	0	0	0	10	0
0	0	0	0	0	0	0	0	0	10

Sires are used in one herd only and in none of the herds can we compare progeny of two sires.

Accuracy of each bull = 0.00

5	5	0	0	0	0	0	0	0	0
5	5	0	0	0	0	0	0	0	0
0	0	5	5	0	0	0	0	0	0
0	0	5	5	0	0	0	0	0	0
0	0	0	0	5	5	0	0	0	0
0	0	0	0	5	5	0	0	0	0
0	0	0	0	0	0	5	5	0	0
0	0	0	0	0	0	5	5	0	0
0	0	0	0	0	0	0	0	5	5
0	0	0	0	0	0	0	0	5	5

Sires are compared pairwise, each pair in two herds only. There is some accuracy, but a lot less than possible.

Accuracy of each bull = 0.447

Note that bulls from different pairs cannot be compared. The average EBV of each pair will be zero. A bull has bad luck if he happens to be in a pair with a very good bull.

5	5	0	0	0	0	0	0	0	0
0	5	5	0	0	0	0	0	0	0
0	0	5	5	0	0	0	0	0	0
0	0	0	5	5	0	0	0	0	0
0	0	0	0	5	5	0	0	0	0
0	0	0	0	0	5	5	0	0	0
0	0	0	0	0	0	5	5	0	0
0	0	0	0	0	0	0	5	5	0
0	0	0	0	0	0	0	0	5	5
5	0	0	0	0	0	0	0	0	5

Bulls pairwise connected within a herd, but different pairs in each herd such that they are all connected. EBVs of bulls are now comparable across herds. However, still a loss in accuracy, as within a herd, each progeny of a bull is compared to progeny of only one other bull (and to other progeny of the same bull, which is not providing information about the bulls' EBV)

Accuracy of each bull = 0.475

1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1

Perfect distribution

Accuracy of each bull = 0.60

Note that the accuracy is smaller than SQRT[n / (n+15)] = 0.63 with 15 = alpha for h2 = 0.25. This 'theoretical' accuracy would hold if bulls were compared to a very large number of other bulls.

Developing cross-breeding structures for extensive grazing systems, utilising only indigenous animal genetic resources

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1. Introduction

Not more than a third of a century ago, a comprehensive theory of systematic cross-breeding in farm animals was fully developed (Smith, 1974; Moav, 1966; Dickerson, 1969; Dickerson, 1973). Since then many experiments have been conducted to provide information about the effect of crossing breeds or strains within farm animal species. Based on these results, efficient industry cross-breeding enterprises have been developed in poultry and pigs. In grazing species, however, even in developed countries, cross-breeding is still a matter of individual farmers who differ very much in their judgement of appropriate mating systems and breeds to be involved.

This paper presents an introductory overview of systems of breed utilisation and of the benefits that can be drawn from various mating systems. Secondly, characteristics of grazing systems, herd management and indigenous genetic resources in the tropics are briefly discussed. The last part deals with the conditions and prerequisites for the application of various cross-breeding systems for grazing livestock in the tropics when only indigenous breeds are to be used. It tries to develop guidelines which may be helpful to recognise, assess and perhaps overcome the constraints in the conditions of developing countries.

2. Systems of breed utilisation

2.1. Benefits from cross-breeding compared to pure-breeding

The major benefits from cross-breeding compared to pure-breeding can be summarised as follows:

- use of complementary breed differences;
- avoiding antagonistic genetic relationships between traits;
- use of heterosis;
- improving within breed selection response;
- adaptation of specialised breeds to different environments.

Complementary breed differences may be the most important reason for switching from pure-breeding to cross-breeding, at least in meat producing animals. Moav (1966) first discussed this effect which occurs without heterosis for single traits. He called it “sire-dam heterosis”. The efficiency of meat production is greatly increased when dams of a breed that produces offspring with less cost are mated to sires of a breed specialised in superior growth and carcass traits. In other words, the traits or trait groups in the different genotypes complement each other in their contribution to meat production. Sellier (1976) pointed out that complementary breed differences are mainly due to differences in maternal traits. In addition to differences in adaptation of dams to the environment, these differences can either arise from different performance in the number of offspring reared per dam (e.g. in sheep) or from different maintenance requirements of dams due to their body size (e.g. in cattle). Extreme examples are mating sires of the Texel or Suffolk breed to dams of Finnish Landrace or Romanov in sheep or mating Charolais bulls to Jersey cows.

Antagonistic relationships between traits are most common in animal breeding. Genetic antagonism between meat and egg production traits was the main reason for the strict differentiation between the laying hen and broiler industry in poultry. The incompatibility of stress resistance, prolificacy and meat quality on one hand with superior carcass conformation and muscling on the other is claimed to be one of the major reasons for cross-breeding in the continental pig industry of Europe. Many investigations have shown that similar antagonisms are also prevalent in grazing species. Breeds with high performance in maternal ability such as fertility and milk yield are seldom sufficient in producing carcasses of high quality. The last decades have shown that the dairy industry based on cattle moves in a direction comparable to that in poultry. Breeds which were formerly known and used as dual purpose breeds have now been transformed into single purpose breeds. Poor meat production of dairy breeds is tolerated and one tries to compensate this insufficiency by crossing beef bulls to surplus cows in the dairy herd.

Heterosis is the superiority of cross-bred animals when compared to the mean of their parents. It is expected to be proportionally related to the degree of heterozygosity. Cross-breeding increases heterozygosity whenever inbreeding has led to a higher frequency of homozygote loci than expected from Hardy/Weinberg equilibrium. More importantly, heterozygosity is increased whenever there is a difference in gene frequencies between the parental breeds. Heterosis occurs on an individual (direct) level when the performance of cross-bred offspring is compared to that of pure-bred offspring, i.e. individual heterosis is measured on F_1 animals after the first cross of two pure-breeds. Maternal heterosis is measured when dams of the F_1 generation, mated to any breed of sire, are compared to dams of the parental pure-breeds mated to the same type of sire. In other words, maternal heterosis appears after a secondary cross-bred generation such as the F_2 (*inter se* mating of F_1 animals), the back-cross to F_1 dams or three-way crosses. Less important, but commercially used in four-way crosses, there can be paternal heterosis when mating to F_1 sires leads to superiority compared to mating with pure-bred sires.

Improved selection response is expected whenever parental lines are specialised. When production is based on a pure-bred or multi-purpose population, all traits in a general breeding objective are to be improved simultaneously. In the specialised line, however, selection can be concentrated on a reduced number of traits. Thus, for example, in a terminal sire line (from which sires are used to produce cross-bred products which are all slaughtered), all traits related to female reproduction can be widely ignored. The lower the number of traits in the breeding objective, the higher is the expected selection response for single traits. Thus, the genetic response realised in cross-bred animals is increased as they get half of their genes from each of the parental lines.

Adaptation of specialised breeds to different environments is used in stratified crossing systems such as that with sheep in Great Britain. Hill breeds specialised in hardiness are kept in harsh environmental conditions on top of the stratification. “Draft ewes” of these breeds (e.g. Scottish Blackface, Swaledale or Welsh Mountain) being advanced in age are transferred to uplands to be mated to sires of Longwool breeds (Bluefaced Leicester, Border Leicester or Teeswater) to produce a first cross generation. F_1 females reared in these conditions are genetically improved for maternal traits and are transferred to intensive downland areas where they are kept as ewes to produce terminal slaughter lambs after being mated to a terminal sire line (primarily Suffolk). There are various modifications of this “standard stratification”. F_1 ewes determined for terminal crossing in lowlands can be produced directly in the hill flocks, draft pure-bred ewes are put to the lowlands (leading to two-way terminal crosses) or Suffolk rams are placed in the position of Longwool sires (leading to terminal back-crosses). A good example for stratification in subtropical conditions is the three-tiered prime lamb industry structure in Australia. Here, Merinos stand in the position of the hill breed, the F_1 ewe is a Border Leicester cross and the terminal sire is mainly Poll Dorset.

In cattle, a similar kind of stratification leading to three-way crosses is used in the British dairy and beef industry. Friesian dairy cows not required for replacement are mated to beef bulls of medium sized breeds such as Hereford. Female cross-breds are used as replacements for cows in beef herds in less intensive conditions where they may be mated to bulls of a third beef breed such as Charolais. Opposite to sheep, here the intensive environment with high-producing dairy cows is on top of the stratification and the terminal product is generated in extensive conditions.

2.2. Detrimental effect of epistatic gene recombination

Dickerson (1973) stressed the importance of recombination loss in secondary cross-bred generations. Any selection in pure-bred populations is assumed to have accumulated favourable additive epistatic gene combinations. These are partly disarranged after crossing so that the genetic source of heterosis in the F_1 generation can be considered as a mixture of (usually favourable) dominant and (unfavourable) epistatic effects. Of course general results show that advantageous dominance exceeds detrimental epistasis in the F_1 generation. Secondary cross-bred generations have a reduced expected heterozygosity so that the heterosis retained can be predicted from the relative degree of heterozygosity. However, the performance of secondary cross-bred generations predicted through the expected drop of heterosis can be substantially over-estimated when recombination loss in parental gametes is neglected. Various cross-bred generations differ in the amount of expected recombination loss. Most disadvantageous from that point of view are cross-bred generations in which both sires and dams are cross-bred animals. This holds mainly for generations such as the F_2 and composite breeds.

2.3. Mating systems

Systems of breed utilisation can be characterised according to their characteristics when considered as production systems. Production is either based on one breed only or on the utilisation of more than one breed. Production with one breed occurs either on a breed kept pure without any introgression of genes from another breed or when production is based on a composite breed. Production with more than one breed can be some form of “static” terminal crosses where the terminal product is not used for replacement. A second group of production systems with more than one breeds is that of rotational systems. In rotational systems there is no typical terminal product; females of cross-bred generations are further used for reproduction. The systems of breed utilisation are listed in Table 1.

If there is no genetic drift or inbreeding after formation of a composite breed, the heterosis retained in a synthetic is expected to be $1\text{-E}p_i^2$ where p_i is the gene proportion of the breed i. This is true for each of the various levels, i.e. direct, maternal and paternal. Heterosis can be used most in a four-way terminal cross, a three-way cross misses paternal heterosis and in a two-way cross both maternal and paternal heterosis cannot be used. In rotational crosses the utilisation of heterosis is intermediate. Terminal crosses enable the differentiation between specialised sire and dam breeds and thus benefit from complementarity, from avoiding genetic antagonisms and from improved selection response due to specialisation. They also allow optimal breed adaptation in a stratified cross-breeding scheme but suffer from the need to replace the cross-bred females from pure-bred parents which makes self replacement difficult. This can be avoided by rotational cross-breeding which, however, can have the disadvantage of variable genotypes from generation to generation, both as dams and as finishing products. The advantages of using specialised breeds can be used in modified systems of rotation. The terminal rotation

Table 1. Systems of breed utilisation[1]

Mating system	Symbol	Heterosis Dir.	Heterosis Mat.	Heterosis Pat.	Recomb.loss Dir.	Recomb.loss Mat.	Compl.	Breed adaptation	Uniformity of products	Self re-placement
Production with one population										
Pure-breeding		-	-	-	-	-	-	-	+++	Yes
Synthetics; two breeds, balanced	$(AB)_{Syn}$	1/2	1/2	1/2	½	1/2	-	-	++	Yes
Synthetics; three breeds, balanced	$(ABC)_{Syn}$	2/3	2/3	2/3	2/3	2/3	-	-	++	Yes
Terminal cross-breeding										
Two-way cross	B*A	1	-	-	-	-	+++	+++	+++	Yes [2]
Two-way cross, synthetic dam line	$C*(AB)_{Syn}$	1	1/2	-	¼	-	+++	+++	++	Yes [2]
Three-way cross	C*BA	1	1	-	¼	-	+++	+++	++	No
Four-way cross	CD*BA	1	1	1	¼	-	+++	+++	++	No
Back-cross	B*BA	1/2	1	-	¼	-	+	+	++	No
Rotational cross-breeding, controlled mating										
Two breeds; balanced	$(AB)_{Rot}$	2/3	2/3	-	2/9	2/9	-	-	-	Yes
Three breeds; balanced	$(ABC)_{Rot}$	6/7	6/7	-	2/7	2/7	-	-	-	Yes
Terminal rotation	$C*(AB)_{Rot}$	1	2/3	-	2/9	2/9	+++	+++	+	Yes
Two breeds; breed preference	$(AAB)_{Rot}$	4/7	4/7	-	2/11	2/11	-	-	-	Yes
Two breeds; generation preference	$(AB)_{Rot}$	2/3	2/3	-	2/9	2/9	+	(+)	(+)	Yes
Rotational cross-breeding, uncontrolled mating										
With dam identification		>1/2	2/3	-	2/9	2/9	-	-	-	Yes
Without dam identification		>1/2	>1/2	-	>2/9	>2/9	-	-	-	Yes

[1]The number of + symbols indicates the degree of use.
[2]Self replacement difficult in small herds/flocks.

or criss-out-cross allows mating a part of rotational dams to sires of a terminal sire breed. In a rotation with generation preference one of the breeds involved can be a specialised sire breed and the production is mainly based on dams of that generation which contends the least gene percentage of the sire breed. There are also rotations where controlled mating or breed of sire identification are not feasible.

When recombination loss is expected, this is most harmful for composite breeds. More details about the different cross-breeding systems will be discussed later in the context of their application to grazing livestock in developing countries.

3. Grazing systems and herd management

3.1. Grazing systems

Grazing of animals occurs in various conditions, ranging from some form of roadside grazing in small units to large-scale ranch management systems. In this paper extensive grazing systems will be considered under the aspect of access to controlled mating which is a prerequisite for the realisation of systematic cross-breeding. One criterion of access to controlled mating is herd / flock size and management and thus the grazing systems will be classified into four categories as shown in Table 2 (Williams, 1981).

Table 2. Grazing systems and constraints to controlled mating and identification (CM/I).

System of grazing	Area of predominance	Access to CM / I[1]
Nomadic	Developing countries (DC)	(+)
Semi-sedentary	DC	(+)
Transhumance	DC and temperate countries	++
Sedentary		
• Smallholder	DC	+++
• Village herds	DC	(+)
• Ranching	DC and temperate countries	+++

[1]The number of + symbols indicates the degree of access.

According to the evolution of the relationships between man and grazing species, the ***true nomadic system*** may be mentioned first. It is becoming more and more uncommon for a variety of reasons. Nomadic tribal groups operating in this system do not have a built home base. Herds, flocks and people move within a tribal territory following the rains to areas with sufficient plant growth. Usually the herd in the system contains a mixture of various species, predominantly cattle, sheep and goats.

Second, s***emi-sedentary systems*** are based on a built village permanently occupied by the women and children. The herds are absent for extended periods and usually attended by men and boys such as in the Maasai tribe of eastern Africa.

<u>Transhumance</u> systems are applied in developing as well as in developed countries. They differ from semi-sedentary systems in that the trek is cyclical. In Mediterranean countries, for example, it begins at the end of winter with the flocks and herds moving to the mountain pastures. The shepherds or herders bring the animals back to the lowlands at the end of summer.

As a last group of systems in this classification, the ***<u>sedentary systems</u>*** include the majority of the world's livestock. There are three basic types with a variety of modifications. First there is the <u>smallholder section</u>. Ruminants are kept in a low external input system, fed partly on a mixture of crop residues and more or less extensive grazing. A rather old and traditional system concerns <u>village herds</u> or flocks herded on surrounding common or private lands and taken into yards, corrals, folds or byres during the night. The last one took its rise as a consequence of developing industries in the last two centuries. This is the open range or <u>ranching system</u>, originally developed in North America, Australia, New Zealand and parts of South America. This system still has a growing tendency. It is characterised through sub-divisional fencing, provision of water and with very few exceptions, no housing in winter. Buildings are limited to shearing and machinery sheds as well as animal handling facilities such as yards and dips.

Typical grasslands with extensive grazing are steppes, veld (South Africa), pampas (South America), plains and prairies (Northern America, Australia). These are the areas where nomadism, semi-sedentary systems and ranching predominate. Transhumance occurs in areas with diversified altitudes such as river valleys and hills at near distances. In addition to nomadism and semi-sedentary systems, smallholder units and village herds prevail in developing countries. For all systems except ranching, there is generally low capital input and a medium to high labour input; ranching is usually high in technology and low in labour inputs but has heavy capital requirements. The division of the grassland into paddocks through fencing allows for the splitting of herds into various groups.

3.2. Constraints to controlled mating and identification

Admission to controlled mating and / or identification (CM / I) in a grazing system is most important for an appraisal of the possibilities to apply systematic cross-breeding in grazing ruminants (Table 2). At a first glance, fencing in the ranch management seems to be the main reason why controlled mating and identification are widely limited to this system. This, however, should not be so. Within the transhumance system, there are examples of intense breeding activities. Sheep and goat flocks in Switzerland and other alpine countries are kept in transhumance conditions. After being shepherded in large flocks for summer grazing in the mountains, the flocks are subdivided into small groups and confined in farmers´ sheds for the rest of the year. During that time, most of the mating and lambing occurs and thus such a system is very accessible to controlled mating, lamb identification and even recording.

CM / I should not be a problem in smallholder units, both with and without artificial inseminations. For nomadic, semi-sedentary and village herds / flocks, however, the practicability of CM / I depends primarily on the qualification of personnel and its motivation to do so. In many cases personnel qualification concerning the familiarity with individual animals in the herd / flock is extremely good. At least dam identification of new-born animals can be ensured by some sort of eartagging. Sire identification is much more difficult due to natural mating with more than one sire in the herd. It is not impossible, however, to manage controlled mating through some sort of periodic sire rotation. As in most circumstances, sires cannot be separated from the herd / flock, the use of harnesses for mate prevention could be arranged so that in a certain period the new-born offspring can be identified for paternal ancestry.

4. Characteristics of indigenous genetic resources

4.1. What are indigenous breeds?

A definition of what we refer to as indigenous breeds seems to be necessary. Criollo cattle in South America and Merino sheep in many semi-arid regions in the world have a pure European origin. Santa Gertrudis cattle and Dorper sheep have at least one half of their genes from indigenous non-European breeds and have lived in the tropics since the first decades of the 20th century. What is indigenous? In this paper, new breeds formed in the 20th century which have genes from improved temperate breeds from Europe or North America are referred to as non-indigenous. This includes e.g. Santa Gertrudis, Charbray and Droughtmaster cattle as well as Dorper sheep. Breeds or strains from Mediterranean countries will be considered non-temperate. Since both Criollos and Merinos originated from the Iberian peninsula and were also introduced in non-temperate countries long before the 20th century, there is no doubt we consider them as local breeds. So far the distinction is straightforward. A question arises concerning modern breeds selected in Mediterranean conditions and introduced and crossed in tropical countries, such as the fertile Chios sheep from Greece or the Lacaune dairy sheep from the south of France. Let us call them indigenous with a question mark.

In contrast to most countries in temperate zones, genetic resources in tropical livestock can rarely be considered as consolidated breeds with a certain uniformity and a common breeding goal. Only a few of these populations are managed genetically by a breed society that maintains a stud book and performance records. Symptomatically, breed names in many areas vary substantially and are quite often rather artificial. Reports from livestock populations in India are most honest when talking about “non-descript” breeds. As a result, unusually high levels of phenotypic variations can be observed in these populations which led Timon (1993) to the suspicion that major genes with significant effects on production traits may be segregating in these populations. Here a rough characterisation of breed groups is presented according to their suitability for utilisation in cross-breeding. Furthermore, a brief description of the few outstanding breeds which have systematically been selected will be given.

4.2. Breed groups in cattle

Many *Bos taurus* and all *Bos indicus* cattle strains can be characterised as indigenous breeds with a long history of adaptation to tropical conditions (Table 3). For many centuries, taurine breeds have settled in Western Africa and widely adapted to trypanosomosis in the tse-tse fly areas. In the humid climate the size of these breeds remained small. An outstanding breed due to its trypanotolerance is the N'Dama breed. Since the 16th century, European settlers brought cattle from the Iberian Peninsula to Latin America which were then called Criollos. They have been adapted to tropical and subtropical conditions, but due to the overwhelming imports of European and improved Zebu breeds there was nearly no organized selection of any breed. Taurindicus strains (Sanga) were kept by African tribes, mostly in East and South Africa, long before the new composite breeds between *Bos taurus* and *Bos indicus* were formed in the 20th century. The most well-known breed selected for beef (originally draught) is the Africander breed of South Africa. More recently, breeds from Zimbabwe and Botswana such as the Tuli, have received attention because of their beef performance.

Bos indicus cattle were brought to Africa many centuries ago and also to South and North America since the 19th century. In southern states of the USA, the Brahman breed has been selected as a beef breed for tropical conditions. Zebus in India are of miscellaneous size and quality due to its multipurpose use for draught, milk and manure. Zebus in Africa are mostly of small size except the Boran which has been developed for beef by a breed society in East Africa. Zebu beef breeds have also been selected by breeders in Latin America who formed breeds such as Nellore and Indo-Brazil. Less efforts have been devoted to developing dairy strains from the Zebu gene pool, e.g. from Sahiwal and Red Sindhi.

4.3. Breed groups in sheep and goats

As cattle, sheep and goat populations in the tropics should be considered from the viewpoint of their suitability for milk and meat production. Wool, pelt and skin may either be considered as by-products of dual purpose breeds or if specialised in a specific market, confined to special pure-bred populations such as Merino strains or Karakul in sheep and Angora or Cashmere strains in goats. In both species there are a variety of populations which differ in many aspects. Size and weight are considered to be most important as they are the major criteria concerning the suitability for meat and to a lesser extent, also for milk production.

Mason (1991) classified sheep breeds according to fleece and tail type. There are a variety of large, medium and small-sized breeds either

Table 3. Classification of indigenous breed groups in ruminant species.

Species and groups	Main characteristics	Superior breeds
Cattle		
• West African taurine breeds	Trypanotolerant, small	N'Dama
• Latin American taurine breeds (Criollos)	Miscellaneous sizes	-
• African taurindicus (Sanga) breeds	East and South Africa	Africander, Tuli
• Small Zebu breeds	e.g. East Africa	-
• Large Zebu breeds	India, Africa, America	Brahman, Boran, Nellore Sahiwal, Red Sindhi
Sheep		
- Large sheep breeds	Mainly wool sheep	Somali, Awassi, Chios?, Lacaune?
- Small sheep breeds	Hair and wool sheep	-
- Prolific sheep in the tropics	Polygenic inheritance	D'man, Barbados Blackbelly
	Major gene responsible	Booroola, Javanese Thin-tail
Goats		
1) Large goat breeds	Arid or semi-arid areas	Boer, Damascus, Jamnapari
2) Small goat breeds	Humid areas	-

short-tailed, thin-tailed, fat-tailed and fat-rumped within both fleeced and hair sheep breeds. Furthermore, there are breeds with outstanding prolificacy such as the Booroola Merino from Australia (Piper *et al.*, 1985), the D'man from Morocco (Lahlou-Kassi and Marie, 1985), the Javanese Thin-tailed breed from Indonesia (Bradford et al., 1986) and the Barbados Blackbelly hair sheep from the Caribbean (Rastogi, 1996). The prolific breeds Han and Hu have been reported from China (Feng et al., 1996) from which particularly Hu seems to be well adapted to subtropical conditions (Notter, 1996). Irrespective of whether there is polygenic inheritance of the trait or whether a single gene is responsible, these breeds provide potential indigenous resources for improving the maternal potential of native breeds in improved tropical conditions. DNA technology will facilitate the introgression of major high-fecundity genes.

An outstanding large breed of sheep for meat production has been developed on the basis of the black-headed Somali hair sheep in South Africa. The breeding society calls it Blackhead Persian and a derivation from this is also bred in Latin America under the name Brazilian Somali. Part of the widespread Awassi sheep in the Near East has been selected efficiently as a superior dairy breed. As already mentioned, dairy breeds developed in Mediterranean conditions may be suitable when the aim is to improve milk production from sheep in developing countries. While some information about crossing Chios with breeds in the Middle East (Aboul-Naga, 1996; Notter et al., 1996) exists, the suitability of the intensively selected French Lacaune breed for subtropical conditions has still to be proved.

Domestic goat breeds in tropical countries vary considerably in size and body weight. A speciality of goat breeds is that dwarfism has not revealed to be a handicap for goat husbandry in many conditions. Particularly in Africa where goats are primarily used for meat production and seldom milked, there are many extremely small breeds. Like in cattle, it is the small breeds which are kept in tse-tse-fly infested areas and thus have developed trypanotolerance. On the other hand, there are a few large breeds specialised in milk or meat. In minor improved husbandry conditions, indigenous dairy goat breeds can hardly compete with cross-breds that are improved by introgression of genes from European breeds. However, native dairy breeds with some superiority, e.g. the Damascus goat from the Middle East and the Jamnapari from India, may be important in less favourable conditions. An exceptional local breed systematically selected for meat production is the Boer goat from South Africa.

5. Suitability of various cross-breeding systems

The intention of a synthesising / upgrading programme is to create a new breed by introducing genes of a foreign indigenous breed. Various prerequisites are required when this is to be established and are described as follows.

5.1. Composite breed formation and upgrading

a. The programme should be a cooperative enterprise.
Based on animals of a local breed, a new breed is to be created. That means, in the long run any mating and selection will be realised within this new population. The population to be changed should not be too small. It is obvious that with an increasing population size the risk of inbreeding depression declines and the probability of genetic improvement through selection increases. In other words, before starting the programme, there should be a certain probability that enough farmers / stockholders are willing to join the scheme.

b. There is an agreement about the concept of a new breed.
The members of the cooperative agree that selection within their own breed takes an unacceptable long time compared to the progress that can be obtained through introduction of genes of another breed. There is also an agreement about the foreign breed from which genetic material should be introduced. Although there are usually no figures about the real superiority of the foreign breed, they have a common idea of the genetic constitution of the new breed, but do not know what the optimal proportion of foreign genes should be.

c. There is a central organization of the process.
The introgression of foreign genetic material is to be managed efficiently. Most reasonable seems to be the creation of a central station for sires that carry the genes of the desired foreign breed. If artificial insemination is possible, there can be a central deposition of semen doses. The station can be run by a state farm, a cooperative or a private unit. A minimum of educated technical personnel is required to manage the service of the station, supply the clients with the genetic material, collect and analyse some data and to take care of mutual information between the station and the participants.

d. Sires of the foreign breed should be carefully selected.
In contrast to the introduction of genetic material from temperate breeds in developed countries, knowledge about characteristics of another indigenous breed is usually scarce. With few exceptions, these breeds are not genetically structured as temperate breeds and there are normally no breeding values of single males. It is expected that phenotypic variance in these breeds is very high which complicates the assessment of the genetic merit of individual animals. Furthermore, there are usually insufficient records about measures of disease control in these breeds and the danger of introducing infectious diseases is quite high. In a first step, the number of sires selected should not be lower than between five and ten. For several reasons, an introduction of embryos or females of the foreign breed is considered not to be cost-effective.

e. First crosses are accompanied by the installation of an information system.

In a first step, pure-bred sires of the foreign breed are mated to dams of the local breed in order to produce F_1 animals. This first step of gene introduction is to be accompanied by a minimum of recording and information. Initial information should be collected about survival, growth and other characters of interest in the growing F_1 animals. Sire identification is to be insured for both the farmer and the staff of the central station. After a first round of cross-bred matings, a meeting should be arranged where preliminary results and experiences are exchanged.

f. The central station takes care of providing sires to mate F_1 females.

From the first batch of F_1 cross-breds, young males are selected by the station personnel and bought or rented for rearing in the station. To avoid risk of inbreeding and genetic drift, rearing of about two sons per sire is recommended. If the first meeting has demonstrated a positive reaction, about one half of the F_1 females are mated by F_1 sires to produce animals of an F_2 generation. Another half is back-crossed to pure-bred sires of the foreign breed. The mating of sires with their half-sibs (in case of F_1 *inter se* matings) or with their daughters (in case of back-crosses) are to be prevented. As in the F_1 generation, a sire identification of new-born F_2 and back-cross animals is to be insured. F_1xF_1 and back-cross matings are followed by collection of information and data about the maternal performance of F_1 dams (e.g. dystocia, fertility, suckling or milk performance) and juvenile traits of their offspring (e.g. survival and growth). After a second meeting with exchange of this information, first decisions about the further choice of sires will be made.

g. A further strategy based on F_2 and back-cross information is organized.

After rearing F_2 and back-cross animals and first assessments of maternal characteristics, the results of a third meeting and the conclusions to be drawn may be as follows:

Results	Conclusions
• All cross-breds are inferior to pure-breds	• Further matings with sires of the local breed and the upgrading scheme are abandoned
• F_2 generation is better than back-crosses	• The station keeps and produces F_1 sires for further matings; a part of cross-bred females are mated to local sires
• Back-crosses are superior to the F_2 generation	• The station rears back-cross sires for further mating and tests a next step of back-crossing to the foreign breed

In the second case (F_2 superior to back-crosses) it should be checked whether a lower gene percentage of the foreign breed would have been enough. Therefore, a part of the F_1 and F_2 animals is back-crossed to pure-bred sires of the local breed. If the F_2 maintains its superiority, a continuous selection and supply of F_1 sires as proposed by Cunningham and Syrstad (1987) should be organized by the central station. F_1 sires are produced by a steady selection of sires or semen from the foreign breed and by mating them to the best cows of the F_2, F_3 and further generations. This ensures that inbreeding will be minimised and if there is an efficient selection programme in the foreign breed, guarantees that the new population benefits from the continuous genetic improvement in this breed. In Case 3 (back-crosses superior to F_2) the same benefits can be drawn from a continuous supply of selected sires of the foreign breed.

h. The station initiates a recording and selection scheme.

Any new breed formation or upgrading is useless if prerequisites of further selection are not available. A by-product of the upgrading scheme was the initiation of an information system and the introduction of common decision-making. Data and observations were collected and analysed and meetings were organized. During this process it is quite likely that some of the participating farmers have shown to be most interested and active. They should be stimulated to continue their activity and form the nucleus for further breeding policy. They should be the basis for a continuous and slowly extended recording scheme. The staff of the station are responsible for data collection and will be educated in computerised estimation of breeding values. Regulations for a further breeding strategy and the creation of a breeding society should be negotiated and realised.

5.2 Terminal two-way crossing

In contrast to cross-breeding for new breed formation, terminal crosses of two pure-breeds can usually be managed on a single farm level. Motivation, conditions and prerequisites for changing from producing with pure-bred animals to single two-way crosses may be the following.

a. The farmer is interested in improving meat performance.

Except in egg production where the terminal product is the laying hen, terminal two-way crosses are particularly important for meat producing systems with farm animals. Dams of a breed sufficient for maternal traits are mated to sires of a specialised meat breed with superior growth and carcass performance. In nearly all production and marketing systems with ruminants, the farmer can profit from animals with genetically improved meat performance. Exceptions may be very specialised systems of pelt or fibre production in extreme conditions (e.g. Karakul pelts, mohair or cashmere wool) or dairy production with cattle in most parts of India where beef is not consumed.

b. The environment allows the exploitation of genetically improved meat performance.

Very often the dams of the local breed are best adapted to the harsh conditions of the farm and the farmer is willing to continue keeping these dams. For the surplus offspring determined for slaughter, however, feed and husbandry conditions can be provided which are sufficient for animals with a potential for meat production higher than that needed for pure-bred offspring of the local breed.

c. There are indigenous breeds with a higher potential for meat production.

In many tropical conditions the adaptation process was accompanied by a reduction of body size and weight. Examples may be Criollo strains in high altitudes of Latin America or small Zebu strains in Africa which, over the centuries, ended up with smaller body sizes than their ancestries of the Iberian peninsula or of India. Furthermore, adaptation also seems to occur with a reduction of fleshiness, meat proportion and conformation. There is no doubt that for many small and "bony" breeds in the tropics, there are indigenous breeds with a higher meat performance. Examples have been mentioned in Chapter 4.

d. There is continuous availability of sires from superior meat breeds.

One of the reasons for the poor application of two-way cross-breeding may be that there is no steady, uniform and cheap supply of sires from superior meat breeds. A prerequisite for continuity and uniformity would be a genetically structured breed of that type. The structure should guarantee the existence of a nucleus level of breeders who are ready to supply sires with reliable quality, uniformity and price. Furthermore, the distance to the breeder should not be too far due to transport costs. It should be mentioned that the use of semen instead of sires for natural service seems highly impracticable in present conditions of developing countries. This is particularly true in our case where both the recipient of semen doses (the one who crosses) and the donator (the breeder of the indigenous sire breed) should have access to an AI service which is hardly thinkable. Even in a large dairy herd applying AI, the meat sire may be preferred to be used in a "clean-up" natural service instead of as a semen dose.

e. The sires of the meat breed can be kept cheaply and in good breeding conditions.

Keeping sires of a second breed depends on the size of the farm and on facilities to guarantee an appropriate environment for maintaining its breeding conditions. A large cattle herd or sheep flock always uses more than one sire. For a sustained breeding condition and long productive lifetime it may be sufficient to separate it from time to time and feed it in improved conditions. Small herds / flocks may keep either one or, in most cases, no sire at all. They rely on a village, communal or private sire station. Under these circumstances it should be easy to keep sires of more than one breed. A prerequisite for a cheap supply is that the small farmer shares the sire with other farmers.

f. The use of a second sire breed does not impair a continuous female replacement.

Self-replacement of females is essential for the majority of livestock owners in developing countries. This is particularly true for smallholders with a high degree of self-sufficiency where the loss of a cow, ewe or doe means a substantial jeopardy of the family's welfare and security. If the smallholder is not willing or unable (e.g. due to lack of cash) to buy replacement dams, there is almost no chance of using two-way terminal crossing. In small herds or flocks the risk of an insufficient own dam replacement is tremendous. If, for example, the average cow gives birth to four calves during her lifetime, a farmer not willing to buy missing replacements should have a herd size higher than about 15 cows (Gerhardy, 1986). If he has a very large number of dams, or if he is prepared to buy any missing own replacement, the maximal capacity for terminal crossing is 1-2 / n, where n is the average number of live offspring reared per dam and suitable for breeding. For n=2, 3, 4, 5 or 6 this means a proportion of 0, 33, 50, 60 or 67 percent of cross-bred matings.

g. Controlled mating and individual identification are useful.

An optimal procedure would be to take the genetically best females for replacement through pure-bred matings and cross the rest to sires of the meat breed. If dystocia from mating meat sires is a problem, young dams should be used for replacement and the older ones can be crossed. For both of these targets, controlled mating would be required. Where this is not feasible, at least breed of sire identification for new-born offspring were useful, e.g. through using harnesses (marking mated dams, periodic exchange of breed of sire) or simple genetic colour marking of the two genotypes.

h. The reproductive performance should not be too low for extra cross-bred matings.

There may be specific situations where the number of offspring reared and suitable for replacement is not higher than the number of replacements required. This means that n (in paragraph f) is near 2.

Heterosis is not essential for the efficiency of terminal two-way crosses to improve meat production. The main reason for its use is the sire-dam complementation. In most conditions with tropical breeds and environments, the reason for complementarity will be breed differences in size rather than in reproduction performance. Mating dams of a small breed with low maintenance requirement to sires of a large breed means that the proportion of feed directed to growing animals is increased. Of course, the size of the dam breed should not be too small for dystocia to be a problem.

Any interest in terminal cross-breeding will depend on the socio-economic constraints that keep the farmer away from a more market-oriented animal husbandry. So far the majority of livestock in developing countries is kept as multipurpose animals. They have to provide the farmer or family first with milk and meat and secondly, with draught power, manure, fibres, hides and skin. Farms with any market-oriented specialisation are rare. As long as a certain degree of specialisation with stock exchange between farms is not reached, any interest in terminal crossing will be poor.

A first stimulation for cross-breeding could arise if some farms specialise in fattening meat animals or if there are organizations interested in establishing some kind of feedlots. These should find other farmers who are prepared to renounce keeping their surplus offspring up to slaughter age and who can expand the number of dams instead. Feed and husbandry conditions in the fattening units will be managed differently from those in the farms which keep the dams so that the issue mentioned in paragraph b) will be accomplished. A second but more unrealistic encouragement to use cross-breeding could arise if stratification of production is further expanded so that not only fattening and dam-offspring enterprises are separated in different units, but also the dams are replaced at different locations. Under these circumstances, the concern discussed in paragraph f will not be a problem.

A brief look at the situation in more advanced livestock industries in developed countries may be helpful to assess the chance of more terminal cross-breeding in tropical conditions. Sometimes the issue c) (no better meat breed available) may not be true in a herd or flock. This is only possible if the animals belong to a breed that has all characters of a typical terminal sire breed. However, meat production with this breed can hardly be competitive as genetic antagonisms will prevent the breed from having satisfactory maternal characteristics. A farmer with such a type of animal will therefore try to sell sires which are used for terminal crossing in another breed. In other words, he will be a breeder within a cross-breeding system rather than running a typical commercial herd or flock. Another example without terminal crossing is the majority of dairy farms in temperate livestock enterprises. Dairy farming is mainly based on pure-bred cows that are extremely specialised in milk and quite insufficient in growth and carcass traits. That means, the issue in paragraph c) is more than realised. However, the average number of lactations in e.g. Holstein herds is usually lower than three. Under these circumstances it is paragraph g) which is responsible for producing with pure-bred cows without any terminal crossing.

5.3. Stratified terminal cross-breeding

Advanced production systems for white meat species (e.g. pigs and poultry) are mainly based on terminal crossing using F_1 dams. The pig and poultry industries are hierarchically stratified. Multipliers cross parental pure-breds to produce F_1 replacement females for commercial units where the terminal slaughter products are reared and transferred to commercial finishing units. A terminal sire is mated to the F_1 females to exploit complementarity and direct heterosis in addition to maternal heterosis in the dam. Sometimes the terminal sire itself is a cross-bred animal contributing paternal heterosis. The number of breeding animals in the pure-bred parental lines involved in the system is very low. The genetic improvement of these lines lies in the hands of internationally operating companies. The lines are selected differently according to their specific position in the cross-breeding system.

Although the livestock industry of grazing animals in developed countries is also highly specialised and market-oriented, there are no organized cross-breeding strategies in ruminants similar to those in pigs and poultry. The reason is not that genetic effects used in cross-bred animals such as heterosis and complementarity were smaller (Nitter, 1978; Gregory and Cundiff, 1980), but simply the much lower reproductive performance of ruminants. To maintain a cross-breeding system based on F_1 dams, the number of pure-bred animals should be very large. As specialised lines by definition have a lower overall performance, their inferiority would more than offset the benefits from hybrid F_1 dams.

If a cross-breeding system based on F_1 dams should work in grazing species, the participating pure-breeds should *per se* be specialised and should be self-contained independently from a special task in a cross-breeding scheme. Specialisation of breeds has always occurred when they had to adapt to special environmental or production conditions. Examples of specialised breeds and their use in stratified cross-breeding systems have been mentioned previously (see Chapter 2.1). We will show various conditions and prerequisites for the realisation of stratified crossing and discuss it with regard to conditions in developing countries. These are the following:

a. There is a market with both a demand and an offer of female breeding stock.
Production with and replacement of F_1 dams in one farm or unit is considered to be impossible as three different genotypes of dams should be kept simultaneously and under complete controlled mating. Therefore, more than in a terminal two-way crossing, certain stockholders should be willing and able to buy their female replacements from outside (recipient units). On the other hand, there should be herds or flocks which are specialised in selling replacement females (donor units).

b. Recipient and donor units have different environments.
Theoretically, in a unique environment there is only one optimal genotype of dam. Due to maternal heterosis this is most likely an F_1 dam. To produce this animal, however, a high amount of pure-bred females is required. These are expected to be worse than F_1 dams and

thus are an unjustifiable burden for the system. This burden disappears if donor units produce in a different environment where a genotype different from the F_1 is adapted. Most likely this would be a harsh environment with an adapted hardy breed, whereas F_1 dams are kept in better conditions.

c. The donor unit separates or sells surplus dams for cross-bred matings.
For various reasons, the stockholder in harsh conditions may hardly be able to separate the herd or flock into two mating groups, i.e. one for pure-bred replacements and one for the generation of F_1 dams. It may be convenient for him, however, to focus on keeping as young dams as possible and transfer older and more vulnerable dams to a "sub-unit" with less hard conditions. Younger dams are expected to cope much better with the harsh environment, whereas older dams can survive and reproduce for another two or three years in the better conditions of the sub-unit. This is operated as a multiplier unit as the dams there will be exclusively mated to sires of a second breed to produce F_1 dams.

d. A specially selected sire breed is used in the multiplier unit.
Whereas the breed on top of the stratification is fixed due to its adaptation, the sire breed used in the multiplier unit should be carefully chosen. It is expected to transmit genetic improvement according to the special demands of the recipient unit. These may predominantly be maternal traits such as fertility, prolificacy and milk yield. In sheep, for example, the high fertility breeds mentioned earlier (Chapter 4.3) may be most interesting.

e. The dams in the recipient unit are exclusively mated to terminal sires.
As the recipient unit renounces own replacement, its mating strategy is most easy. Sires of a meat breed are purchased which improve growth and carcass traits according to the market demands and as far as feeding and husbandry conditions allow its genetic exploitation. All offspring born are destined for slaughter.

f. Continuous organizational activities of the recipient unit are most important.
Contracts of participants in a cooperative scheme can highly facilitate its conduct. A focal position in the scheme has the recipient unit. It knows the market requirement and its own environmental constraints. It is thus best informed about the optimal genetic qualities of the terminal sire and also of the sire to be used in the multiplier unit. Furthermore, it is most sensitive to the discontinuous supply of healthy replacement ewes with high genetic merit. Thus, it is evident that it is the recipient unit which is expected to take responsibilities and activities in the operational course of the scheme. It will be well recommended

to make contracts with owners of donor units or, if possible, run a multiplier unit on its own.

The scenario of a three-tier stratified cross-breeding system as outlined above is very similar to the stratification in the British sheep industry. As in two-way terminal crossing, heterosis is no prerequisite for the application of such a scheme. In contrast to stratified systems in pigs and poultry, there is no centrally organized operation of the system. As if supervised and managed by an “invisible hand”, the cooperation of the participants in the various tiers of the British sheep industry has been operating for two centuries. One of the reasons for its success may be the simplicity of the mating policy within flocks. In the hill breeds, i.e. on top of the stratification, there are only pure-bred matings for own replacements. The multiplier upland flocks as well as the commercial F_1 down flocks are both “flying flocks”; that means, all replacements are generated from outside and all ewes are exclusively mated to one breed of sire. In none of the tiers, except in flocks of seedstock producers, is controlled mating required to run the system. Another advantage of the system is the higher price that a hill farmer gets for a draft ewe sold for further use than for a ewe culled for slaughter. So far transformation of the system to the livestock industry in tropical or subtropical countries sounds reasonable and easy.

The most severe obstacle to the encouragement of such a system in developing countries is most certainly the high degree of specialisation required. The breeds involved in the system are no more the typical multipurpose animals that have so far been a guarantee for economic security and for avoiding risks. Instead, at least the breeds producing the sires used in the second (multipliers) and in the third stage (F_1 dam units) will be more and more specialised for their tasks in the system. Thus, a specialisation in a framework of collaborating farmers will be inevitable. The necessity of collaboration is still a barrier hard to be passed, even in the advanced livestock industry of developed countries and it is hard to believe that the establishment of a stratified cross-breeding system in conditions of the developing world will be easier.

How could we imagine a source from where cooperative stratified animal production could commence? It is easy to believe that an impulse can come from increased urbanisation with growing prosperity of the urban population. This induces demands for animal products such as meat with continuous supply and quality standards. This would stimulate livestock enterprises around the cities to specialise in satisfying the growing demands. Depending on the price relationship between meat and feed concentrates, it may be economical to intensify feeding and husbandry conditions. The shorter the distance to a city, the more interesting it is to specialise in producing the terminal products and leaving reproduction and replacement of females to more distant units with less intensive conditions. If the price / cost ratio becomes more favourable, there may be capital investment in the livestock industry and some livestock enterprises may expand to a size which allows them to control and manipulate the genetic material to be selected and used for the generation of both the end products and their mothers.

So far the discussion has circulated around the classical three-way cross within a stratified system of production. A second option, the use of a cross-bred instead of a pure-bred sire in the terminal position (four-way crosses) seems to be of pure academic interest as it may be hard enough to find at least one indigenous breed which is superior in meat production and fulfils the conditions d) in Chapter 5.2 (continuous availability of sires). More interesting is the option that the sires used in the second and third stage of the system come from the same breed. This would turn out to be a stratified back-crossing. In regions with small adapted breeds, a large indigenous breed may be found which is better in both, maternal traits and meat characteristics but lacks some hardiness. A pure-bred dam of this breed may be less economical than using an F_1 female which gets half of its genes from this breed and the other half from a small and hardy breed. In addition to heterosis and an increase in hardiness, the use of such a cross-bred female benefits from reduced maintenance requirement. A third option may be a two-tier stratification. On top there are still stockholders who like to sell surplus dams with an older age for further production in a better environment. This environment, however, can be one of the herds or flocks keeping dams of the terminal produce. The surplus dams are transferred there and directly mated to terminal sires; in this case we deal with a two-way cross.

In all options so far discussed, an adapted hardy breed is assumed to stand on top of the stratification. More than a terminal two-way crossing, stratified terminal cross-breeding thus enables low producing but well adapted breeds to play an important role in the domestic livestock industry. Otherwise endangered breeds can thus be prevented from extinction and contribute to strategies for sustainable development of animal agriculture in developing countries.

A stratification where a dairy cattle herd could be involved seems to be far from reality in a developing country. We should, however, stick to the discussion of opportunities to use stratified crossing for meat production in ruminants. Which grazing system could be most suitable to take part in such a system? Extensive grazing systems in the tropics such as nomadism, transhumance, village herds or ranching, suffer frequently from periods with low feed supply due to drought. An important strategy to cope with drought in these conditions is to keep the stock size variable. In periods with low feed supply surplus females are sold in order to save the rest of the flock or herd. These will most likely be older dams. This means that traditional extensive grazing systems seem to be predetermined for the top position in a stratified cross-breeding system. Let us assume that there are potential multiplier units which are ready to take these surplus dams to produce F_1 dams. These, however, are forced to guarantee a continuous supply of F_1 replacements for the third tier. In other words, the multiplier stock of dams should be stable in size and not dependent on an insecure supply of surplus dams from its potential donors. The erratic availability of surplus indigenous animals may thus be a crucial point in the system. Use of extensive grazing areas with adapted indigenous breeds in the tropics and simultaneously, a continuous culling policy in the herd or flock seem to be unsurpassable contrasts for which we hardly find solutions.

5.4. Rotational cross-breeding

In contrast to static terminal cross-breeding schemes, systematic rotational crossing is much less widespread. A critical look at claimed applications of rotational cross-breeding quite often may turn out to be conducted by stockholders who change their mind about the best breed from time to time. Much more than in a two-way cross, systematic rotation is appropriate when there is a need or desire that replacements should be generated in the own herd or flock. However, as they are produced by cross-bred dams instead of pure-breds, maternal heterosis is used in addition to direct heterosis. In species with a low reproduction performance such as ruminants, a continuous replacement of cross-bred dams from cross-breds themselves seems to be most useful. This avoids the need to keep a large number of pure-bred dams for the replacement of cross-bred dams as has been the case in systems based on F_1 females. On the other hand, conventional "balanced" systems as described in most textbooks, do not allow the use of complementarity. The breeds or lines involved should not be specialised like those for terminal systems since animals are expected to be suited for both, to be good mothers or milkers and to produce good offspring for growth and carcass production. On the other hand, these requirements together with the need of no large variation between the rotational cross-bred generations, are longing for breeds which are not so different from each other. This, however, leads to the dilemma that heterosis, the original cause for rotation, may not be as high as it could be when crossing breeds with large differences in their gene frequencies. It is no wonder that conventional systems of rotation have never reached a large distribution.

A first useful alternative for conventional balanced rotation is to use rotational cross-breds as dams and mate those not needed for female replacement to sires of a terminal meat breed. This terminal rotation allows to fully exploit complementarity and direct heterosis and the final produce differs much less from generation to generation. To some degree, a similar effect can also be obtained when two breeds with some specialisation as sire and dam breeds are rotated, but different cross-bred dam generations are kept in unequal numbers, i.e. they are not "balanced". The cross-bred generation with a higher gene proportion of the foundation sire breed is kept in a small number of dams, just the size required to sustain the replacement of the other generation. Then the majority of females in the herd or flock are those with the higher gene proportion of the foundation dam breed. This also means that most of the offspring destined for slaughter are those with a higher gene proportion of the foundation sire line. In other words, such an approach uses complementarity to some extent. Let us call this "rotation with generation preference". A third modification of conventional rotation may be called "rotation with breed preference". This is an unequal use of sire breeds in a regular sequence allowing for increased expression of additive effects of one breed (the one with the best overall performance) at the expense of reduced utilisation of heterosis (Bennett, 1987a).

So far, all options of rotational cross-breeding cause tremendous management problems in extensive grazing systems of livestock. These are the identification of individual dam' sire-breed pedigree and due to overlapping generations in the herd or flock, controlled mating through the concurrent use of more than one sire breed. Controlled mating, i.e. the mating of a defined cross-bred dam group to sires of a specific breed, may be the major constraint. Management inputs are much less when only one sire breed is used during a certain mating period ignoring the different sire-breed pedigrees of dams from overlapping generations. Let us assume that this is possible. A slight relaxation of management input may then be a dam identification for its sire-breed, e.g. by simple ear-marking. Only those female offspring are then kept for replacement which belong to the "correct matings". In an $(AB)_{Rot}$ criss-cross, for example, after mating sires of breed A only female offspring from ($^1/_3$A $^2/_3$B) dams will be identified and kept for replacement and all offspring from ($^2/_3$A $^1/_3$B) dams will be slaughtered. Let us call this "uncontrolled mating with dam identification". In these circumstances, the same amount of maternal heterosis can be maintained as in a regular two-breed rotation with controlled mating. A rotational system with the least management input is one that uses only one sire breed per mating period and without dam identification. Such an "uncontrolled mating without dam identification" was called "sire-breed rotation" by Bennett (1987b). He showed that, depending on the number of consecutive mating periods a sire breed is used and on age structure of females, an amount of heterosis higher than in a composite breed with equal gene proportions could be maintained.

The feasibility of controlled mating and dam identification in various grazing systems has already been discussed (see Chapter 3.2). As in the other systems of cross-breeding, we will step by step consider the conditions and prerequisites for the realisation of rotational cross-breeding in developing countries.

a. **Direct and maternal heterosis can be used by crossing indigenous breeds.**
   Information about heterosis for cross-breds where indigenous breeds are involved, is almost exclusively limited to crosses of indigenous with modern temperate breeds. For milk traits in dairy cattle there are substantial heterosis estimates between exotic and tropical breeds (Rege,

1998) and there have been recommendations to use these through rotational cross-breeding (Gregory and Trail, 1981; Thorpe *et al*., 1993). Rotations are most interesting for dairy cattle as these generally have the lower reproduction performance. Except for some cross-breds among Criollo (taurine breeds) and *Bos indicus* breeds in Latin America (Plasse, 1988), we know very little about heterosis in crosses among indigenous breeds. We can only speculate that they should be lower in crosses among *Bos indicus* breeds which contribute the majority of indigenous cattle in the tropics.

b. The sires used for rotation guarantee persistent heterosis.
Within breed variation of livestock in developing countries is usually much higher than in temperate breeds. If heterosis is found in cross-breeding experiments among specific indigenous breeds, we should be sure that these can be repeated. The breeds involved should be structured so that herds or flocks are available from which sires with high genetic merits and a reliable genetic uniformity can be selected.

c. Controlled mating and dam identification are required to apply systematic rotation.
Optimal use of additive breed and heterosis effect is hard to achieve in extensive livestock grazing systems. This is even difficult in most husbandry conditions of advanced livestock industries in developed countries. Systematic rotation should guarantee that e.g. sires of breed A should be mated to a dam ($^1/_3$A $^2/_3$B) in a two-breed rotation and to dam ($^1/_7$A $^2/_7$B $^4/_7$C) in a three-breed rotation.

d. If controlled mating is not possible, breeds of sire should be mated periodically.
Periodic mating of sires means that in each mating period or in consecutive mating periods only one breed of sire is mated to the cross-bred females. Then dams should be marked according to their sire. This indicates the gene fractions of sire breeds in each dam. The sires in a given mating period, say those of breed A, will then mate two groups of dam, namely ($^1/_3$A $^2/_3$B) and ($^2/_3$A $^1/_3$B) in a two-breed rotation and the three groups ($^1/_7$A $^2/_7$B $^4/_7$C), ($^1/_7$B $^2/_7$C $^4/_7$A) and ($^1/_7$C $^2/_7$A $^4/_7$B) in a three-breed rotation. Only offspring of those dams with the least gene proportion of breed A, namely of dams ($^1/_3$A $^2/_3$B) and ($^1/_7$A $^2/_7$B $^4/_7$C) will be the correct ones for replacement, i.e. those with the highest heterosis. The others should be slaughtered. This guarantees the same maternal heterosis as in controlled matings. If dam identification is not possible, periodic mating of sires in consecutive years should still be applied because the majority of dams mated has a low gene proportion of the breed of sire due to the age structure of dams.

e. Terminal rotation seems advantageous but is hard to manage.
Terminal sires mated to dams from rotational cross-bred generations result in the utilisation of complementary and more direct heterosis.

Problems are the same as those discussed for terminal two-way crossing. The greatest handicap is the risk of replacement due to small herd / flock sizes. Furthermore, there should be sires of at least three breeds instead of two for which carefully controlled mating is required.

f. **Rotation with generation preference is very efficient if controlled mating is possible.**
The option of generation preference is most interesting for a two-breed rotation. If one of the breeds involved has a superior maternal performance (say breed A), the rotational cross-bred generation with the higher gene proportion from A should be preferred in size. With controlled mating, dams of this generation ($^2/_3$A $^1/_3$B) are mated to sires of breed B (assumed to be better in meat) so that complementarity can be used to a large extent. Replacement conditions are much better than in two-way crosses or in terminal rotation. Whereas there the maximal capacity for terminal crossing was 1-2 / n, here the maximal proportion of the better "dam generation" ($^2/_3$A $^1/_3$B) is 1-2 / (2+n). The figure n is the number of offspring reared per dam of the other generation ($^1/_3$A $^2/_3$B). For n = 2, 3, 4, 5 or 6 this means a proportion of 50, 60, 67, 71 and 75 percent, respectively.

g. **Rotations without controlled mating are not recommended if composite breed formation is possible.**
At a first glance, periodic sire rotation without controlled mating seems attractive for extensive grazing systems. It can be easily handled and applied in a single farm or unit whenever appropriate pure-bred sires of the breeds involved are available. A problem may be the cost of sires. As only one sire breed is mated each period or in consecutive mating periods, the sires of the other breed or breeds have to be kept inactive until the next season or sold after a limited time of use. The benefits from heterosis are not much higher than from blending the breeds involved in a synthetic breed. Once consolidated, the handling of a composite breed is much easier. The formation of composites, however, is a matter beyond the facilities of a single farm or unit. Whenever the conditions and prerequisites mentioned previously exist (see Chapter 5.1), cooperation in a composite breed formation programme is recommended.

6. Final remarks

This paper was intended to deal with opportunities of exploiting benefits from cross-breeding in low to medium input grazing systems. While we restricted to crossing among only indigenous breeds, there is no doubt that at least with a medium input environment, temperate breeds could be considered as partners as well. The inclusion of temperate breeds is the issue of another paper. The limitation to indigenous genetic resources means lower risk since indigenous breeds are assumed to have the bonus of some adaptation to the various stress factors of the tropics.

In the social, economic, infrastructural and institutional framework of livestock production in developing countries, there are many obstacles to the introduction of any breeding strategy. The importance of risk prevention is one of them, the frequent lack of cash economy and market-orientation is another. Although it is certain that a great variety in the genetic value of indigenous genetic resources exists, this is hard to exploit through cross-breeding. In contrast to temperate breeds, so-called breeds in the tropics are genetically not consolidated, they are usually not recorded, not structured and seedstock producers such as in temperate breeds who could guarantee quality and uniformity of genetic material are not available. There are seldom breeding societies or other institutions responsible for genetic and administrational activities for a breed and properly educated personnel are not available or cannot be paid.

The availability of superior indigenous breeds, at least for special traits, is a prerequisite of utilising genetic variety through cross-breeding. Therefore, there is an urgent need for an international programme for coordinated genetic evaluation, testing and preparation of designed germplasm and animals from superior indigenous breeds for special needs and environments in the tropics.

Independent of the situation in developing countries, controlled mating in grazing herds or flocks is generally hard to manage. This automatically excludes some of the systematic cross-breeding systems. Generally, there may be arguments against all of the cross-breeding systems discussed in this paper. The formation of composites requires a certain size and may thus not be flexible enough as even small geographic areas will include stockholders with widely different environmental conditions. The other systems are free of this disadvantage. They can be used and managed according to the specific needs of the individual herd or flock but they require an owner or manager with a high amount of operational skills. The most interesting seem to be stratified cross-breeding systems. They can best include the use of low-input requiring and highly adapted pure-breeds and thus contribute to maintain sustainable agriculture. Mating within the herds/flocks participating in the stratification is easy but the system requires a degree of readiness for cooperation between units which is hard to be realised. Rotational systems will generally fail due to the need for controlled mating. Rotation without controlled mating might be interesting in certain conditions, but the use of cross-breeding effects is only marginally superior to those of a composite breed.

7. References

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Developing straight-breeding and cross-breeding structures for extensive grazing systems which utilise exotic animal genetic resources

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Introduction

In this chapter we consider how exotic germplasm can be evaluated and then incorporated into cross-breeding programmes. We define exotic as meaning any breed or strain that is not native to the country or region in consideration. The general principles of how to design and operate cross-breeding systems or create new synthetic populations based on indigenous genetic resources are dealt with in the previous chapter and are not repeated here. Here, we deal with what needs to be modified when exotic germplasm is being considered. We also consider the possibility of using exotic germplasm as pure-breds.

When considering the use of exotic germplasm, the following key questions need to be answered:

1. How can one decide what characteristics should be sought in exotic germplasm?
2. How should one choose between pure-breeding versus creation of a new synthetic versus alternative cross-breeding structures for utilising exotic germplasm?
3. How should choices be made among sources of exotic germplasm for possible importation and testing in the country or region of interest?
4. How should exotic germplasm be imported?
5. How should exotic germplasm be evaluated in local conditions?
6. How should exotic germplasm be incorporated into local cross-breeding systems?

Answers to these questions are not independent of each other and while the above forms a logical sequence for the questions, to obtain a final answer a certain amount of iteration is required. We will deal with each of these questions in turn and then suggest a decision tree for design and implementation of cross-breeding systems based on exotic germplasm.

1. What characteristics are sought in exotic germplasm?

In all cases exotic germplasm will be sought to increase one or more aspects of the economic and / or social value of the livestock production system. This will mean increasing the off-take of animal products from the system and / or the number of animals maintained. For either of these goals to be achieved, there must be resources available that the current livestock are not utilising.

These extra resources might be found by improving the efficiency of utilisation of existing resources. It is a general observation, however, that animals with high genetic potential for production generally have higher maintenance requirements and lower ability to thrive on poor nutrients. Thus, in most cases, exotic germplasm is unlikely to find extra resources through improved efficiency. Exotic germplasm might achieve more efficient utilisation of resources if it has higher tolerance of environmental stress, parasites and disease, thereby reducing losses and allowing more resources to flow into production of products or maintenance of larger populations.

If more efficient utilisation of resources is not possible through increased stress tolerance, surplus resources for livestock production must be available if use of exotic germplasm is to be considered. It is therefore important to first document the nature and stability of these resources, before going on to assess what type of genetic changes might be utilised. An integral part of this process is a simultaneous assessment of how the indigenous livestock utilises the resources available and what limits their productivity in that environment.

It is a general observation that high production genotypes also have high maintenance requirements for nutrients and very often, high requirements for management inputs such as shelter and prophylactic protection against parasites and disease. This can make high production genotypes very susceptible to loss of resource inputs. It is a frequent characteristic of low to medium input environments that they are also variable environments. An integral part of the assessment of what type of genotype would improve the current production system is the assessment of impacts of fluctuations in resource supply, brought about by climate fluctuations, long-term trends in physical environments, social and political unrest, changes in local or global commodity prices and war.

While increased productivity is generally desirable, in many situations livestock is extremely important as a form of economic and social capital. There will be situations in which increased productivity in the long-term is obtained at the expense of increased variance in survival. Such increased variance may lead to a proportion of families losing their livestock. The negative impact on social and economic structures may more than outweigh any gains in the long-term rate of production.

A preliminary decision tree is provided in Appendix 1 to assist the assessment of what type of germplasm should be sought for a given situation. Notes on the various steps in the decision tree are given in Appendix 2

2. Choosing between pure-breeding and various cross-breeding systems

The general principles of cross-breeding have been dealt with in the previous chapter and therefore, the details are not repeated here. Many of these details are implicit in our accompanying decision tree, which could also be used when examining the potential use of indigenous germplasm. Additional considerations when examining exotics are whether or not the exotic might be used as a pure-bred and if used in cross-breeding, is it feasible or desirable to maintain a pure-bred exotic population as part of that cross-breeding programme?

Other important considerations are how the exotic germplasm, as pure-bred or cross-bred, will be evaluated. That is dealt with later, but decisions there may impact decisions here. The decision tree suggested here is used to assess likely end uses of hypothetical exotics with identified characteristics based on the assessments of the production environment in Section 1. The process should be repeated once a specific exotic source has been identified and characterised to make sure that the original decisions on the breeding programme still make sense.

We have worked with many of the same assumptions as in the preceding chapter. We do not believe that cross-breeding programmes that involve maintenance of pure-bred stock, either for terminal crossing or rotational crossing have any likelihood of success where any or several of the following apply: a) livestock is an important part of economic and social capital; b) production is by small holders with little infrastructure support; c) marketing and distribution networks for sale of livestock products are not highly developed; d) the lifetime reproduction rate is below three to four progeny per female; e) it is expensive or impossible to maintain pure-bred stock because of lack of adaptation to the local environment. In addition, it is probably not sensible to consider such cross-breeding structures if social, political or climatic fluctuations or the risk of war might periodically disrupt infrastructure support and marketing and production structures.

The above restrictions mean that in the vast majority of cases of low input systems and probably in most medium input systems, the choice will be between the use of the exotic as a pure-bred or in creation of a new composite or synthetic stock. Complementarity of breeds is not relevant when considering synthetics, so the problem is to determine the expected performance of the synthetic based on expected heterosis and proportion of genes from each breed source and then comparing that to the pure-bred performance.

When assessing performance, the breeding objective needs to have been defined clearly. Thus, apart from the various performance measures, such as milk yield, growth rate, egg production, etc., there must be an overall definition of economic value within the social, economic and management system in which the new germplasm is to be used. In low to medium input systems, fitness traits such as survival and reproduction rate will often be the key determinants of overall economic value. These traits are often much more difficult to measure than standard performance traits, but they cannot, as is too often the case, be ignored because of that. The problem of assessing fitness traits will be more fully dealt with in Section 5.

In low to medium input environments it is unlikely to be worth the expense and risk of trying to capture heterosis of an exotic cross, unless performance is increased by at least 20 percent. The body of evidence shows that substantial heterosis can generally be expected only for traits closely related to fitness, such as reproduction, stress tolerance and resistance to parasites and disease. The worse the environment, the greater the importance of fitness traits and the greater the heterosis that can be expected. In very stressful environments, substantial heterosis will be observed for production traits such as growth and milk or egg production, because heterosis for fitness traits creates a healthier, stronger animal that is then more able to express its genetic potential for production. This has implications for an efficient testing of germplasm (see Section 4). It also means that if an exotic has sufficient fitness to resist disease, survive stress and reproduce well in the local environment, it is unlikely that a synthetic would do better than a pure-bred exotic (see Appendix 3 for an illustration of the impact of fitness traits).

The degree of heterosis maintained in a synthetic will depend on the cause of the heterosis. Apart from the usual considerations of dominance versus epistasis as the cause (see previous chapter), heterosis due to only one or two genes may cause problems. It is possible that some instances of disease or parasite resistance may be due to a single gene. In many (probably most) cases the gene for resistance can be expected to be dominant, so that the F_1 with an exotic not carrying the gene will exhibit good resistance (and thereby heterosis for production and survival). One quarter of the F_2 will be homozygous susceptible and will exhibit very low, perhaps zero fitness. Production of remaining animals would therefore have to be more than 33 percent higher than the indigenous pure-bred before any gain is made. Such problems would be less severe where resistance is polygenic, as all animals in the F_2 would be expected to have at least some level of resistance. Thus, at this stage of evaluation, some thought needs to be given to the likelihood that one or more key fitness characteristics of the indigenous stock might be controlled by only one or two genes.

3. How to choose among alternative sources of exotic germplasm

Having identified the characteristics desired of exotic germplasm, decisions must be taken on which of the many possible sources of exotic germplasm should be imported and tested. The principal criteria for such decisions will be: a) the likelihood that a given exotic has the desired genetic characteristics; and b) the logistical difficulties of obtaining and importing that exotic. The natural tendency is to consider the logistical difficulties first and then examine genetic characteristics of exotics that would be easy to access. However, a greater chance of genetic improvement will come from first producing a list of potentially useful exotics based on genetic characteristics. Final choices among exotics can then be made based on logistical difficulties. Stocks with the greatest potential will be worth taking more trouble to obtain and import than lower ranking stocks.

3.1 Evaluating genetic potential of exotic stocks

Assessment of genetic potential ideally should be based on information that is *sufficient*, *relevant* and *reliable*.

3.1.1 Sufficiency of information. For information to be sufficient, it should encompass all characteristics that will determine the value of the stock. This means having information on all performance and fitness traits that will contribute to economic and social value. In general that requires very detailed experiments, trials or performance and life history recording programmes to be in place.

3.1.2 Relevance of information. Relevance here is the need for information to be available on performance of the stock in environment and management conditions that match those of the importing country. For information to be fully relevant, all important aspects of the environment and management should match that in the importing country. In most cases, the information available will be only partially relevant, with not all components of the environment and management matching that of the importing country.

3.1.3 Reliability of information. Reliability of the information is determined by the statistical accuracy of the experiments, trials, surveys or reports from which information on genetic potential is derived. It is also determined by the credibility of the sources of the information, the methods used to collect the information and how well described are the conditions in which the information was collected. The degree of reliability required will depend on the size of differences between stocks that are expected to be useful. Thus, for example, if one is looking for increases of performance of 100 to 200 percent, information can have relatively low accuracy and yet remain certain that a large difference does exist. If one is looking for improvements of, say, 20 percent, the information will need to be very accurate (see Appendices 5.1 and 5.2, for more detailed statistical arguments on accuracy of estimates of performance characteristics).

It is clear that only very rarely will existing information meet all criteria for sufficiency, relevance and reliability. Stocks in commercial production in developed countries will often have reliable information available and in some cases also sufficient information. However, in most cases the production systems will differ markedly from the low to medium input systems of the importing country, so that the information will only rarely be fully relevant. Conversely, most stocks in low to medium input systems occur in underdeveloped countries, so that while information on such stocks might often be relevant it will rarely be fully sufficient or reliable.

3.2 Sources of information

Appendix 4 lists the possible sources of information on genetic potential of exotic stocks. In general, electronic access to the research literature is improving rapidly and this provides much more rapid and efficient screening of the information available. A limitation is that electronic access to literature will generally exclude the early literature. Few electronic databases go back beyond the early 1970s and many only go back to the mid-1980s or even later.

An important point is that only a small proportion of the world's sources of livestock germplasm has been properly evaluated. There is a serious bias in the published literature because a publication on one promising breed or stock will spur other groups to study the same breed. Similarly stocks that are already common are more likely to be studied than rare stocks. The result is that a small proportion of the world's germplasm sources dominates the published literature. Thus, while the published literature is a very powerful resource in the search for suitable germplasm, ignoring more anecdotal sources of information would cause exclusion of the majority of germplasm from consideration. Unsubstantiated reports should probably be given much less weight than fully documented assessments of performance, but very promising stocks should be examined more closely, whatever the first source of information.

4. How to import germplasm

We have not included a decision tree here, but have summarised a variety of options that are available, some logistical considerations for each and some advantages and disadvantages. From this it should be possible to determine the most viable option in each case.

4.1 Import live animals

This may be a viable option when a pure-bred stock is required on site as a foundation for cross-breeding. The **advantages** of this approach are: a) it is technically fairly easy; not requiring advanced reproductive technologies; b) it can be relatively cheap for very small species such as chickens and rabbits, especially if they can be transported when very young, as is the case with chickens; c) if pure-bred females are imported, a pure-bred herd can be established immediately. There are serious **disadvantages** with this option: a) it will be moderately to very expensive for large animals such as pigs, goats, sheep and cattle; b) it can sometimes be logistically difficult to guarantee the feed and water supplies of live animals in transit; c) if disease is a problem, imported animals will have no opportunity to acquire immunity and may well succumb. Even where vaccines and/or prophylactic treatments are available for major diseases, a variety of less well characterised and often sub-clinical infections may severely debilitate newly imported exotics; d) animals reared in benign conditions in their home country may not thrive when moved to harsh conditions. A period of careful acclimation may be necessary for imported animals; e) imported animals may be carriers of exotic diseases or parasites and thereby put indigenous livestock at risk; and f) veterinary health laws may prohibit such imports.

4.2 Import fertilised eggs

A reasonable option for poultry at relatively low cost and fairly low risk of disease if purchased from a reputable company or other agency, but substantial disease risk otherwise. Nevertheless, for poultry this will very often be the least expensive, lowest risk option.

4.3 Import oocytes

In some species it is technically feasible to consider importing oocytes and then fertilising them *in vitro*, culturing the embryos and subsequently transferring to recipient females. Using this approach one could produce either pure-bred progeny or cross-bred progeny. In the former case, however, it seems preferable to import embryos and in the latter case semen, since these technologies are easier they are generally cheaper than oocyte technologies. At current cost rates, success and technical difficulty, it is difficult to see that import of oocytes would be the desired option.

4.4 Import embryos

Import of embryos is a viable option for bringing in pure-bred exotics of cattle, sheep, goats, pigs and rabbits. There are several **advantages** of importing embryos: a) transport costs are low; b) disease risk can often be substantially reduced when compared to live animal imports by use of embryo washing procedures; c) progeny are born to indigenous dams and will acquire immunity to some local diseases via colostrum and opportunity for infection leading to immunity in early life; and d) being born into harsh conditions provides a better opportunity for adaptation than being imported in later life. There are also several **disadvantages** of importing embryos: a) it requires embryo transfer technology to be available in both the exporting and importing country. These technologies require a certain minimum infrastructure to be present, although that infrastructure need only be temporary if a one-time import is made; and b) veterinary health laws may prevent such imports in some cases. Provided that technical and disease problems can be overcome, this will often be the import method of choice for large ruminants and possibly also for pigs and rabbits.

4.5 Import frozen semen

Import of frozen semen is a viable option for most ruminants and rabbits. It may also be viable for pigs but success rates may be low. The **advantages** of this approach are: a) transport costs are very low; b) collection is relatively easy; c) delivery is fairly easy; d) disease risks are minimised; and d) progeny will be born to indigenous dams and will acquire immunity to local diseases through colostrum and early life infection leading to immunity. There are some **disadvantages:** a) the progeny will be cross-bred, which will mean that several generations of importation and crossing will be required if a nearly pure-bred exotic population is required. If non-genetic adaptations to disease or environment, or lack or embryo transfer technologies are issued, import of frozen semen may nevertheless be the best way of establishing a (nearly) pure-bred population; b) a certain level of expertise and infrastructure is required, although this can be imported if a one time import is made; c) disease risk is not eliminated; and e) fertility may be lower than with natural mating or use of fresh semen.

4.6 Import of fresh semen

Import of fresh semen will usually be an option for any species for which frozen semen is an option and can be considerably more successful for some species, such as pigs. The **advantages** of this approach are essentially the same as for frozen semen, plus increased fertility in several species. The **disadvantages** are also similar to those for frozen semen, plus the need to deliver semen from the source to the recipient female within the normal shelf life (a few days for most species), plus the need to keep semen in carefully controlled conditions with minimal temperature fluctuations whilst being shipped. Where the technology for frozen semen is available, frozen semen will generally be preferred over fresh semen because of the extended life of the sample and the less stringent handling conditions

5. How to test exotic germplasm in local conditions

The optimum design of a testing programme depends on factors such as: a) the most likely end use of the exotic; b) the principal traits to be evaluated; c) the number of sources of exotic to be tested; and d) the time, financial and technical resources available for testing.

A) The most likely end use of the exotic will generally be dictated by knowledge of the social, economic and production environment and will have been determined before testing begins. In most low input systems, the goal will be some form of synthetic population or replacement with a well adapted exotic, so that testing needs to focus on performance of the synthetic in comparison to existing stock and / or the well-adapted exotic pure-bred. In higher input systems with reasonable infrastructure, terminal (or very rarely, rotational) cross-breeding systems may be feasible and testing will need to be decided between this and a synthetic or a pure-bred indigenous stock or adapted pure-bred exotic.

B) In all cases the testing needs to evaluate the complete economic and social value of the stock in the relevant environment. The limiting factor in such testing will be the low accuracy of evaluating fitness traits with low heritability, such as fertility, reproduction rate, survival and disease resistance. In low input systems, such traits will often be the principal determinants of the value of alternative germplasm and accurate assessment of these traits cannot be avoided (see Appendix 3 for an example of the impact of fitness traits on overall value). It will often prove very difficult to operate large-scale trials in such conditions. In medium to high input systems, fitness traits may be less of an issue and testing can focus more on production traits, which is generally far cheaper and easier. The risk is that there is a serious fitness problem that is not detected if smaller trials are run. This risk will generally decrease as the input level goes up and the disease problem goes down.

C) In some cases, choice of exotic will not be obvious before testing commences and it will be desirable, if resources and time permit, to test several exotic stocks. In such cases a hierarchical design should be considered, where several stocks are initially tested at relatively low accuracy, with the poorest performing being sequentially eliminated until one remaining stock is adequately tested.

D) The time available for testing may have a major impact on design. Crisis situations, such as repopulating after civil war or drought, may allow no time for testing, whereas systems that are currently functioning well will require long and careful testing of alternatives before decisions to introduce new stock are taken. The actual resources available for testing will impact the ability to run trials of adequate size and to record appropriate traits with appropriate accuracy. Where few resources are available, only fairly crude trials may be possible and these will require more cautious interpretation before any decisions are taken. The larger and more detailed the trial, the more confidence can be put in the final decision taking. This principally means that smaller differences will lead to decisions to import exotics into the production system than when only crude trials are possible. This may well determine whether a trial is worthwhile when few resources are available for the trial.

5.1 Simple designs

A summary of basic design sufficient for most uses is given here. More details can be found in Appendices 5.1, 5.2 and 5.3, which contains copies of reports by E.P. Cunningham and O. Syrstad (1987) and J. James (1977).

5.1.1 Testing pure-breds and F_1

We follow the views of Cunningham and Syrstad (*1987, FAO Animal Health and Production Paper 68*) that it will not be technically feasible to test all possible cross-breeding systems to discover which is the best for any given environment. Rather, it makes more sense to evaluate the additive difference (A) and heterosis (H) between an exotic and an indigenous stock. Once A and H are estimated, the performance of different types and degree of cross-breeding can be predicted. These predictions may be faulty if a large amount of epistasis contributes to heterosis, but errors are unlikely to be large. Moreover, it is expected that the cross that is predicted to be most suitable for the environment will be tested before being launched into widespread application.

The simplest design for estimating A and H involves testing the two parental strains (the exotic and the indigenous stock) and their F_1. The optimum design is to allocate 34.5 percent of animals to each parent strain and 31.5 percent of animals to the F_1; but an equal allocation of animals among the two parents and the F_1 will have nearly the same power. The number of animals required in total to achieve a given accuracy of estimation of A and H are given in the table below. The co-efficient of variation of the trait and the standard error of the estimate of A and H are measured as a percentage of the mid-parent performance. The number of animals required are given for various combinations of co-efficient of variation of the trait and the desired standard error of A and H.

Standard error of A or H	Co-efficient of variation 25%		35%		45%	
	A	H	A	H	A	H
2.5	579	468	1 135	918	1 876	1 517
5	145	117	284	229	469	379
10	36	29	71	57	117	95
15	16	13	32	25	52	42
20	9	7	18	14	29	24

Traits will need to be ranked in terms of importance and the size of the standard error that will be required for evaluation. The most important traits will determine the size of the trial. In low input environments, fitness traits will generally be the most important and these will have high co-efficients of variation. The size of the standard error required will depend on the size of differences that are considered important. The exotic pure-bred or cross will generally need to be at least 20 percent superior to the indigenous stock in terms of overall economic merit before replacement is worthwhile. At this lower end, A and H for key traits might be less than 10 percent of the mid-parent mean, requiring small standard errors for accurate assessment. In many cases, however, the expected differences of F_1 and exotic from the indigenous stock will be much larger, allowing somewhat larger estimates of standard errors to be tolerated (see also Appendix 5.3).

In species with low reproduction rates, relatively small differences in survival and reproduction rates will have a large effect on overall value of the stock. In such cases it will often be more efficient to first test an exotic stock for performance traits. Performance traits generally have low co-efficients of variation and in many cases, large expected differences allowing relatively large standard errors to be tolerated. Thus, a preliminary trial of performance traits might require only about 30 to 40 animals. Only if the exotic stock was suitably based on performance traits would a much larger trial for evaluating fitness traits be considered. The second phase trial would probably involve from 500 to several thousand animals.

An important design criterion is that the exotic pure-bred must have had the chance to become fully adapted to the local conditions. This means that they must have been born in the local environment, preferably to dams who themselves were fully adapted. This means testing grand-progeny of live imported animals, or testing pure-breds born after embryo transfer into indigenous locally adapted females. Waiting for production of grand-progeny will be too long a time for large ruminants, but might be acceptable for pigs and poultry, where only a two year delay would be involved.

5.1.2 Testing when the pure-bred exotic is not available.

In many situations the pure-bred exotic will not be available for evaluation. This may be because the exotic does not survive, or fails to thrive, in the local environment. Alternatively, a strategic decision may be taken that it is not worth the expense and difficulty to import, establish and then test the pure-bred exotic if it is unlikely that the pure-bred exotic would be required as part of the cross-breeding programme. In such cases, A and H can still be estimated by including F_2 and backcross animals in the design. To obtain the same standard errors of estimates, from 2.5 to 8.3 more animals will be required than when testing both pure-bred parents and the F_1 (see Appendix 5.1 for more details).

5.1.3 Testing pure-breds only

In some cases one would not be interested in cross-breeding and the evaluation trial would include only the pure-bred exotic and indigenous stocks. In that case the difference between the stocks is 2A. The number of animals required will be 2/3 of the number given in the above table for the appropriate value of A (see also Appendix 5.2 for more details of testing pure-breds).

5.2 Hierarchical designs

It was noted in 5.1 that it will often be sensible to first confirm the utility of an exotic for performance traits before testing fitness traits. A similar design can also be used to perform a preliminary screen of a number of possible exotic stocks for general performance characteristics and then test the best one or two stocks for fitness traits. In this case it may be possible to reduce even further the number of animals required for phase one testing, because relatively small differences among exotic stocks are unlikely to matter greatly.

No calculations have been performed, but an efficient design might look something like the following:

Phase 1: Evaluate performance traits on approximately 30 animals from each of the several exotic stocks.
Phase 2: Evaluate the top two or three exotic stocks for fitness traits plus production based on about 400 animals.
Phase 3: Obtain more accurate estimates of fitness traits on best exotic stock based on about 1 500 animals

Phase 3 might be replaced by a direct test of the synthetic or other cross-bred thought to be the best option based on results in Phases 1 and 2.

5.3 More complex designs

Based on Larry Cundiff's/MARC experience

6. How should the final cross-breeding system be put together and operated?

Most of the issues relating to constructing and maintaining a cross-breeding programme have been dealt with in the previous chapter. The only novel problem posed by exotics is if the maintenance of a pure-bred population is required and pure-bred animals do not thrive in the local environment. In most cases a pure-bred exotic population would be used to supply males for use in cross-breeding. Thus at the very least the males must be able to survive and breed successfully in the local environment or the use of AI must be a feasible option. In the former case, the exotic can be treated as any other pure-bred population, albeit with potentially more expense and greater difficulty involved. In the latter case, the population might be maintained in a more benign environment with semen shipped into the production environment. Alternatively, the choice might be to continuously import semen from another country, with its attendant disadvantage of continuous expenditure of foreign exchange. In low input environments, however, use of AI is very unlikely to be feasible, so that any cross-breeding system that requires use of poorly adapted pure-bred exotic males in the main production system will also not be feasible.

Appendices and attachments

Appendix 1 Decision Tree 1: Identifying likely role of an exotic.
Appendix 2 Notes to Decision Tree 1.
Appendix 3 Example of effect of fitness on decisions among pure-breds and cross-breds.
Appendix 4 Sources of information on exotic stock characteristics.
Appendix 5.1 Cunningham and Syrstad FAO chapter.
Appendix 5.2 John James' report of testing groups.
Appendix 5.3 John James' arguments on size of differences needed.

Appendix 1.1 Decision tree for deciding on requirements for and broad uses of exotics

Assessment	Decision
1: Is there a need for improved ability to survive a harsh environment that might realistically be found in exotic germplasm (e.g., improved heat and drought tolerance or disease resistance)?	**Yes**: go to 13 **No**: go to 2
2: Are there extra nutrition and / or management resources available to sustain production above current levels?	**Yes**: Go to 3 **No:** Go to 4
3: Are the extra resources available at all times or are there periods when there are no or very little extra resources (e.g. periodic drought, erratic supply of supplements due to poor infrastructure or political and economic instability.	**Constant supply:** go to 5 **Erratic supply**: go to 6
4: Do not seek exotic germplasm. Examine possibilities of a within breed selection programme or cross-breeding programme based on indigenous stocks.	
5: Define the expected level of production that could be supported with the extra resources available in an average year. Express as a percentage of current production levels.	**>200%:** got to 9 **120–200%:** go to 10 **< 120%:** go to 4
6: Define the worst case scenario for resource inputs. Are animals with a production potential which is higher than that of the current animals likely to survive and then recover from the worst case scenario better or worse than current animals? Define survival and recovery as greater than or less than that of current stock.	**Greater than:** go to 5 **Less than**: go to 7
7: Does this species have major importance as a form of economic and social capital?	**Yes:** go to 9 **No:** go to 8
8: Based on the reproductive capacity of the species and the production potential when extra resources are available and on projected frequency of episodes of low resource availability, calculate the long-term production of the exotic as a proportion of the current stock.	**>200%:** got to 10 **120–200%:** go to 11 **< 120%:** go to 4
9: Is there a substantial risk of much lower survival of exotic germplasm such that either the mean of long-term economic and / or social capital might be substantially reduced or its variance substantially increased.	**Yes:** go to 4 **No:** go to 8
10: Does the local environment require environmental and / or disease stress tolerance already available in indigenous germplasm?	**Yes:** go to 11 **No:** go to 12

(To be continued...)

(...To be continued)

11: Seek a moderate production exotic germplasm with potential for adaptation to the local production environment and use as a pure-bred or high percentage (75 percent exotic genes) cross or synthetic. Or, seek a high production exotic germplasm with some potential for adaptation for use in a moderate to low percentage (<= 50 percent exotic genes) cross.	Go to decision tree 2
12: Seek high production exotic germplasm with the potential for adaptation to the local production environment and use as pure-bred or a ¾ or higher cross or synthetic.	Go to decision tree 2
13: Go to 2 and determine how much room there is for improved production assuming that the exotic would bring existing levels of survival to the local environment at times when extra resources are available. You should end up at box 4, 11 or 12.	**If box 4:** go to 14 **If box 11:** got to 15 **If box 12:** got to 15
14: Seek exotic germplasm with moderate to low production capability and higher ability to thrive in the local environment than existing stock.	Go to decision tree 2
15: Determine whether a cross-bred of indigenous stock to exotic germplasm with high production potential could have higher production than an exotic germplasm with high stress tolerance used as a pure-bred or as a cross-bred with indigenous stock. Express result in terms of the production potential in the local environment of the high production versus the high stress tolerant exotic germplasm.	**Higher:** go to 11 **Similar:** go to 11 and 14 **Lower:** go to 14

Appendix 2. Notes on decision tree for deciding on requirements for and broad uses of exotics

Numbers refer to decision item in the table. Subscripts (a or b) to numbers refer to a) the basis of the decision; or b) the actual cut-offs used.

General notes: In these decision trees, exotic refers to any source of germplasm that is not indigenous to the region in consideration. The evaluations here are intended to define the limits of production capability and lead to broad definitions of what type of exotic germplasm might be sought. The same decision tree could, however, be used when a specific exotic or indigenous stock is being considered.

2a: Production in any system can only increase over the current production levels if extra nutritional resources are available or can be made available for the livestock. These resources might be available through increased efficiency of utilisation of a new stock, but differences between stocks will generally be fairly small and will tend to favour genotypes with high stress tolerance and low productivity. Thus, if importation of new germplasm is to be considered, there will need to be additional feed resources not currently being utilised. In order to access these feed resources, additional management resources may be required. These might be as varied as the manpower or transportation to bring crop residues to the livestock, the development of a complex infrastructure to produce crops specifically for livestock production, the use of prophylactics to protect against disease, the provision of water and shelter in harsh environments, or the development of marketing systems to allow surplus production to be sold.

3a: *A chain is only as strong as its weakest link.* Success in low to medium input livestock production systems is often less related to their ability to produce surpluses in times of plenty than their ability to survive times of scarcity. The production environment should therefore be evaluated in terms of both average resource availability and the frequency and severity of periods of low resource availability.

A characteristic of many low input environments is their variability over time, with periodic episodes of very low availability of feed and / or water, generally due to drought. Resource availability is often also compromised by human factors such as political and social upheaval, fluctuations in world commodity prices and war.

3b: Erratic here is defined as fluctuations in resource supply that would cause the lowest level of resource availability to be as low or lower than the average utilised by the current stock. The answer should be erratic if there is any likelihood of one or more episodes of such low resource availability in the foreseeable future (say 30 years).

5a: The calculations required here are theoretical. They require an assessment to be made of the nature and level of nutrients that could be utilised if a suitable genotype was found. These can then be compared to the estimates of current nutrient utilisation to determine the level of production that could be supported. When making such calculations allowance should be made for the observation that high output genotypes invariably have higher maintenance requirements than low output genotypes. This will have implications for both the average level of production and the ability of the genotype to thrive under low input episodes (this is relevant to question 6).

Provided that information is available on nutrient type and supply, approximate estimates of maximum production capacity can be made based on livestock nutrition guidelines such as those produced by the National Research Council of the USA and the Agriculture and Food Research Council of the UK, etc. Not all feedstuffs will be covered by such guidelines, but in most cases prediction formulae can readily be amended to deal with feedstuffs of different composition to those covered in the various guidelines. Note that the objective here is to obtain a rough guide to the level of production that might be possible rather than the highly accurate estimation that is usually sought in highly intensive production environments.

One key element in many tropical environments, not present in most temperate environments, is the presence of toxic plants that could have severe effects on production of livestock not adapted to local conditions. This should generally be ignored here when estimating production potential, but should be noted as a highly important criterion when evaluating the need for traits of adaptation to the local environment (question 10).

5b: The cut-off of 120 percent is relatively arbitrary, but it is deemed unlikely that it would be desirable to implement a programme for importing, testing and application of an exotic for less than a 20 percent gain in productivity. Getting to the application of an exotic has many costs involved and is never totally without risk of failure due to unforeseen circumstances when compared to a tried and trusted indigenous stock. In many cases the cut-off should probably be higher than 20 percent; it may be lower in cases where relatively high levels of input and infrastructure are available and fluctuations in resource availability are low.

6a: In general, animals with high production potential will also have high maintenance requirements and this will affect their ability to survive and reproduce in times of low resource availability. Similarly, high production genotypes may not have the same ability to digest high roughage/low nutrient density diets, which may compound the problem of requiring higher inputs for maintenance.

In some cases the extra resources that allow higher production will include such things as availability of prophylactic treatments to allow disease susceptible genotypes to thrive in the local environment or provision of water and housing to alter the physical environment. If any of this management support is unavailable in part or whole from time to time, the evaluation here should include what would happen to the high production germplasm if such support was removed.

The evaluation can be a fairly subjective assessment of whether or not it is likely that the exotic would suffer worse losses and take longer to recover than the current stock. The answer should err on the lower side of survival and recovery if there is any doubt, so that the decision tree goes on to an explicit evaluation of the impact of reduced survival and recovery. There are cases, however, where it might be expected that higher production genotype might suffer marginally worse losses than indigenous stock during low resource episodes but would be expected to rebuild population sizes more rapidly (because of high reproduction potential). In such cases their combined survival and recovery might be considered superior to that of the indigenous stock.

7a: The use of livestock as social and/or economic capital is extremely important in many societies. In such cases, the long-term production capability may be of less importance than ability to maintain or increase numbers of livestock maintained by family or other social groups. If a change in germplasm significantly alters the risk of some groups losing their capital holdings, this could lead to social change that would outweigh any benefits from increased long-term production potential of the livestock system.

8a: It can safely be assumed that for species such as cattle and sheep, reproductive rates in a low to medium input environment will be low and recovery from population reduction will be slow. Species such as pigs, poultry, ducks and geese will make much more rapid recoveries and can sustain more severe losses and still make rapid recovery to full population size and production levels when favourable conditions return. Calculations of expected net productivity of exotic versus current stock can be made based on the expected frequency and severity of periods of low resources in relation to the species reproductive rates and potential production levels during good years of the higher production genotype.

The following is a crude example of such a calculation that nevertheless may work well as a first approximation in many situations.

It is assumed that the current stock survives the low resource periods with no loss of population size, but neither does the current stock or the exotic produce any surplus (product) during the low resource period. The exotic also has no surplus while population size is being rebuilt to that required by the production system.

The long run production of the exotic expressed as a proportion of the current stock is,

$$\text{long run production of exotic} = y^*(T - t - n)/(T - t),$$

where y is the production of product (an identified single product or an aggregate net economic benefit) of the exotic in good years expressed as a proportion of the production of the current stock; T is the total cycle length (the period in years between episodes of low resource availability); t is the length in years of the average episode of low resource availability; n is the number of years it takes the exotic to recover its population size and is given by,

$$n = -\log(p)/\log(r)$$

p is the proportion of the original population that survives the period of low resource availability; and r is the annual rate of population growth of the exotic during periods of good resource availability.

The result of the production calculation is clear. Exotics will produce more than indigenous provided the rate of production is more than sufficient to overcome the years of lost production while population size recovers. This becomes more unlikely as the time between episodes of low resource availability goes down, the reduction in population size of the exotic becomes more severe and the reproductive rate and hence rate of population growth goes down. Species with high reproductive rates, such as pigs and poultry, have a much greater potential to bounce back from periods of low resource availability than species with low reproductive rates such as cattle and sheep.

The above estimate of production tends to favour the indigenous stock, because it does not account for products being produced by the exotic during the expansion of the population phase. It will be a disadvantage to the indigenous stock if they can produce products during periods when exotics produce nothing or are reducing in population size. More complex estimates of total production can be constructed that allow for these and many other more realistic assumptions.

It is important to note that the production calculation does not account for use of livestock as economic and / or social capital, where the existence of a live animal has substantial value irrespective of whether or not it is currently producing anything. In such cases the loss of some or all livestock owned by a proportion of families or other groups would cause a much larger economic loss than indicated above. Here we deal with that at a separate point in the decision tree, but it would be preferable to find a way of modifying the product calculation to include the concept of economic and social capital.

8b: see 5b

9a: A careful economic and social appraisal should be carried out where livestock form an important source of economic and social capital and where new germplasm might have lower survival than current stock during low resource episodes. The important question is whether the average long-term economic/social capital might be reduced, or if the variance might be increased and in either case by how much. Reduction in the average capital may be easier to understand and even estimate than the variance. In many cases the average reduction will be a simple, probably linear function of long-term average reduction in number of animals. The possibility that exotic germplasm might actually increase long-term capital should also be considered. Change in the variance of economic/social capital could well be more important than change in the mean. Increased variance would cause a proportion of livestock owners to lose their capital, leading to concentration of capital in fewer hands. This could have profound implications for social structure and distribution of wealth in rural communities.

The choice here is put in terms of substantial negative effect on economic/social capital versus little negative, null or positive effect on capital. If a substantial negative impact or substantial risk of such impact is anticipated, exotic germplasm with high production potential should not be considered. No explicit framework is proposed here for estimating these impacts on economic/social capital. Future versions should include such frameworks and might lead to a more objective balance being defined between long-term productivity and variance in social capital.

10a: Elements to be considered here include heat, parasite and disease tolerance, strong foraging ability, ability to digest toxic plants without severe ill effects and ability to survive periods of severe resource restriction.

Appendix 3. An example of the effect of fitness on value of and choice between pure-bred and cross-bred stock

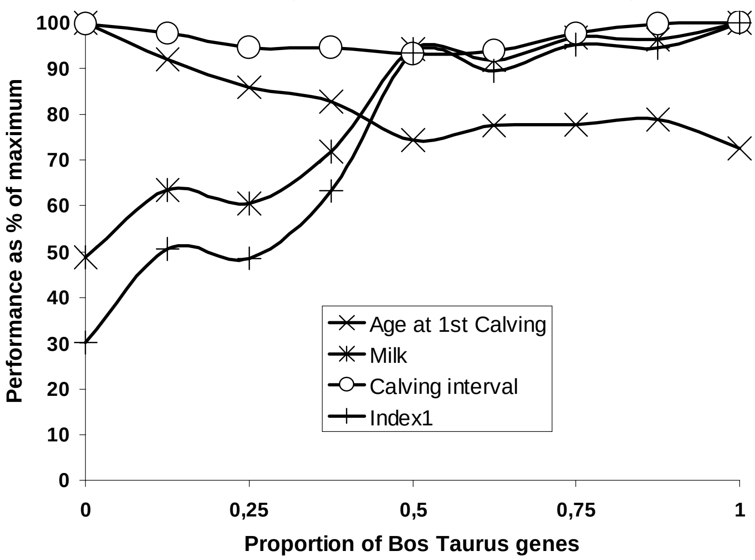
The impact of fitness, specifically survival, on the overall assessment of value of various cross-bred stock is given in the following figures. In both figures, age at first calving, calving interval and milk yield are plotted against proportion of *Bos taurus* genes. Data is the average of many global studies as summarised by Syrstad (1988). Values are expressed as a percentage of the maximum for the trait.

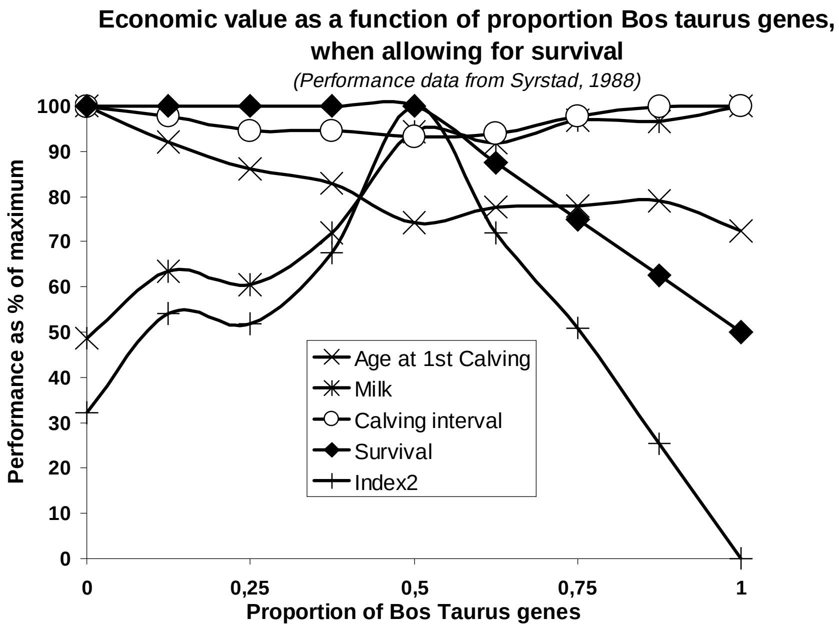
In the top figure, it is assumed that overall economic value can be derived as Index 1 = Milk - ¼ age at first calving - ¼ calving interval, with each trait expressed as a percentage. Index 1 is then also expressed as a percentage of its maximum value. In this hypothetical situation, there is little to choose between the F_1, the pure-bred *Bos taurus* and any degree of backcross to *Bos taurus*.

In the lower figure, values for survival have been added. Although these are hypothetical values in this case, they could easily represent something close to reality in a very harsh or disease prevalent environment. It is assumed that the system is not viable (has no value) when survival falls to 50 percent. Allowing for differences in survival, overall economic value is now expressed as Index 2. In this situation, there is a very clear advantage of the F_1 over all other cross-breds and pure-breds. This contrasts markedly with the situation in the upper figure, which implicitly assumes that survival of all genotypes is the same. The need to record fitness traits such as survival is clear and cannot be avoided just because it is difficult to do so.

Economic value as a function of proportion Bos taurus genes

(Performance data from Syrstad, 1988)





Economic value as a function of proportion Bos taurus genes, when allowing for survival
(Performance data from Syrstad, 1988)
Performance as % of maximum
100
90
80
70
60
50
40
30
20
10
0
0
0,25
0,5
0,75
1
Proportion of Bos Taurus genes
Age at 1st Calving
Milk
Calving interval
Survival
Index2

Appendix 4. Sources of information on characteristics and status of exotic germplasm

Research papers

Animal Breeding Abstracts, published by C.A.B. International provides by far the oldest and most comprehensive routes into the published literature on livestock genetics, including breed evaluation, comparisons and cross-breeding trials. Information in A.B.A from 1972 to the present can also be accessed electronically (see search engines below).

Publication Series

Bulletin of Animal Genetic Resources Information. Published free-of-charge by FAO, Viale delle Terme di Caracalla, I-00100 Rome, Italy. Also available in the Library of DAD-IS at URL http / www.fao.org / dad-is /

Books

Mason, I.L., 1996, A world dictionary of livestock breeds, types and varieties., 4th ed. C.A.B. International, Wallingford, Oxford, pp. 273.

Websites and other search engines

The FAO DADIS website, currently under construction, will eventually contain information on the majority of the world's livestock breeds, with search engines allowing rapid search for particular breeds, regions or traits. Located at http: / / dad.fao.org / dad-is /

The International Livestock Research Institute (http: / / www.cgiar.org / ilri) is also developing a Domestic Animals Genetic Resources Information database (DAGRID), but this, at the time of writing, was not yet available.

Most scientific literature databases now provide electronic search capabilities. The two most useful are AGRICOLA and the C.A.B. Animal Breeding Abstracts. These databases are accessible to paying subscribers, but most university libraries in developed countries will provide access for their staff, students and collaborators. The National Library of Agriculture of the USA also maintains a free access AGRICOLA database and search engine at http: / / www.nal.usda.gov / ag98 / ag98.html. Electronic access to CAB abstracts dating back to 1972 is provided by a number of different service providers (for a fee). Details can be found at http: / / www.cabi.org /

Publications dealing with animal disease resistance and susceptibility and most aspects of genomics and gene discovery are increasingly being covered by MEDLINE. Two good points of access are http: / / www.biomednet.com / db / medline / and http: / / www.ncbi.nlm.nih.gov / PubMed / The former site allows direct downloading of references into several electronic reference manager software packages that can be very useful for building databases on particular topics.

General web search engines such as Netscape Search (formerly Yahoo) at http://search.netscape.com/ will sometimes turn up useful information on specific breeds or traits that is not easily found through other means. Such information is rarely verified by independent review and is often placed by individuals or organizations with vested interests. Nevertheless an increasing amount of truly useful information can be found by this means.

Appendix 5.1

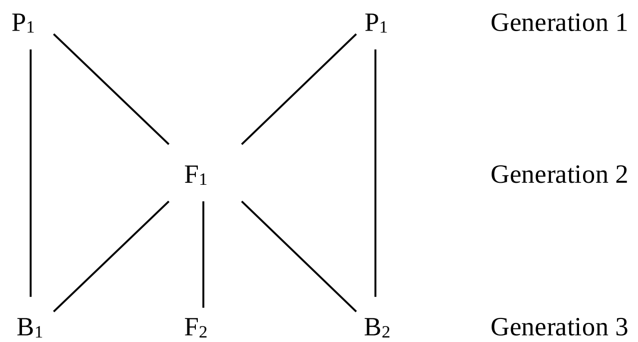
Chapter 6 of E.P. Cunningham and O. Syrstad, 1987. Cross-breeding *Bos indicus* and *Bos taurus* for milk production in the Tropics. FAO Animal Production and Health paper. No.68

The contemplation of cross-breeding with Bos taurus breeds in a *Bos indicus* population is based on the initial presumption that sufficient additive genetic difference (A) exists between the local and exotic breeds and / or sufficient heterosis (H) is exhibited in crosses between them, that some form of cross-bred animal will be more productive than the local breed. Unless these additive and heterotic effects can be accurately estimated in advance, there is great difficulty in deciding what the appropriate breeding strategy should be. Depending on the absolute and relative values of A and H, the best strategy may be any of the following: breed replacement, some form of synthetic, rotational crossing, or up-grading to half or three-quarter exotic.

It could be enormously expensive for a country to discover the correct strategy by trial and error. The time lost in pursuing inappropriate strategies could run into decades. The delay in achieving possible increases in productivity could be very serious economically. The scale of some animal populations and the ease with which inappropriate cross-breeding schemes can be introduced via AI, mean that very widespread disappointment, confusion and economic loss could result from unguided cross-breeding.

All of these considerations serve to strongly emphasise the necessity for well-planned trials at the beginning of such a cross-breeding programme and to provide an adequate information base on which to design the subsequent cross-breeding strategy. Considerable care and investment is justified in the design and conduct of these trials because of the scale, duration and economic impact of the breeding programmes which follow.

The primary purpose of any such cross-breeding trial is the estimation of A and H with sufficient accuracy and precision for subsequent plans to be developed with reasonable confidence. If such trials are to be conducted within the first two generations of crossing between the two breeds, they can involve any or all of six generation groups: the two parental breeds, the F1, F2 and the backcrosses of the two parental breeds. These six groups are as follows:



A and H can be estimated from the differences between these groups. It is assumed, of course, that the trial is conducted in such a way that the differences between the groups are not a reflection of environmental, time, location and nutritional or other non-genetic factors. In order to obtain estimates of both A and H, a minimum of three of these groups is required in the trial. Starting with the local population (P1), it is relatively easy to generate F1 offspring using imported semen or males. It may also be possible to provide some animals of the exotic breed (P2) for evaluation in the same environment. This combination of three groups (both parents and F1) is the most efficient set out of the six possible groups which could be used.

With this optimal set, what size of experiment is required to give an acceptable level of precision in the estimation of A and H? This is the basic question in the design of such trials. Precision is best measured as the standard error of the estimate of A or H. If, for example, the additive difference A is expected to be about 40 percent of the mid-parent mean, an estimate of this with a standard error equal to 10 percent of the mid-parent mean (e.g. one-quarter of the actual value estimated) might be regarded as adequate precision for the use of the estimate with confidence in the development of breeding plans. Similarly, if H was expected to be approximately 20 percent of mid-parent value, then a standard error of 5 percent (of mid-parent value) might be regarded as adequate precision. As the scale of the experiment goes up, the size of these standard errors of A and H comes down. It is then a matter of judgement as to what balance of precision versus scale is acceptable.

Table 1 shows the scale of experiment (with two parental groups and F1) required for given levels of precision for the estimation of A and H. Traits will differ in their inherent variability and this in turn will affect the relationship between precision and scale. Three levels of basic variability are therefore provided for: co-efficients of variation of 25, 35 and 45 percent. To achieve given levels of the standard error of A or H (2.5, 5, 10, 15, 20 percent), the number of animals required in the trial is indicated. In all cases, optimal allocation of numbers to the three groups is assumed.

The following example illustrates the use of the table. If the main trait of interest has a co-efficient of variation of 35 percent and the standard errors of A and H are each required to be no greater than 5 percent, then the experiment should contain 284 animals to give this level of precision for the estimation of A, while 229 animals will achieve the desired precision in the estimation of H. As the design is the same in all cases, H is always more precisely estimated than A (about 20 percent fewer animals being required to give the same precision).

Table 1. Number of animals required to give specified standard errors (SE) of A or H at different levels of variation. (SE and CV both measured as percent of mid-parent mean).

Sandard Error of A or H	Coefficent of variation					
	25		35		45	
	A	H	A	H	A	H
2.5	579	468	1 135	918	1 876	1 517
5	145	117	284	229	469	379
10	36	29	71	57	117	95
15	16	13	32	25	52	42
20	9	7	18	14	29	24

In these calculations, an optimum allocation of animals in the three groups is assumed. This is defined as an allocation of the total number of animals available in the three groups in such a way as to minimise the sum of the variances of A and H. In the case of this particular design (two parents and F_1), the optimum is achieved by allocating 34.5 percent of the animals respectively to the two parental groups and 31 percent to the F_1 group. In the example given above, therefore, the 284 animals in the experiment would be allocated 98 each to the two parental groups and 88 to the F_1 group.

The optimal set discussed above includes only the first two generations (both parents and F_1). In the next generation, three groups are possible: F_2 obtained by *inter se* mating of F_1; B_1 obtained by backcrossing F_1 to parent 1; B_2 obtained by backcrossing F_1 to parent 2. There can be difficulties in having these three groups comparable to the parental and F_1 groups because they are generated at a later point in time. However, it may be possible to generate further samples of the parental and F_1 groups to give valid comparisons.

Assuming that problems of this nature can be overcome and that all three of these additional groups can be made available, do they contribute to the value of the experiment? One way to respond to this question is to specify a fixed total number of animals in the trial and to reallocate a certain proportion of them from the parental and F_1 groups to the F_2 and backcross groups. We can then observe the effect on the actual standard errors of A and H obtained. The results of this calculation are given in Table 2.

Table 2. The effect on the standard errors of A and H of reallocating resources from parental and F_1 groups to backcrosses and F_2 groups.

Percent of animals reallocated from P_1, P_2 & F_1 to B_1, B_2 & F_2 groups	Relative Size of Standard Errors of A	H
0	100	100
10	104	105
20	109	110
30	114	117
40	120	125
50	127	136

It can be seen that for fixed total experimental resources, the inclusion of these extra three groups in all cases reduces the precision of the estimates of A and H. If half of the animals are reallocated, the standard errors of the resulting estimates of A and H are increased by 27 percent and 36 percent, respectively.

In the design of such experiments, it is not always possible to choose the best combination of groups (P_1, P_2, F_1). For example, where P_2 is an exotic breed, it may not be possible to include it for practical or financial reasons. However, semen can be readily imported, so that F_1 progeny are usually easy to produce. From the F_1 generation, it is of course easy to produce F_2. Backcrosses to the exotic breed can be generated by further semen importations, while backcrosses to the local breed can be produced either by mating F_1 cows to bulls of the local breed, or vice versa.

Table 3 shows the effect on the precision of estimation of A and H of using different combinations of the six possible breeding groups in the experiment. For each design, optimal allocation is again assumed, for example, a distribution of animals over the groups involved in such a way as to minimise the sum of the variances of A and H. The final column gives the relative scale of experiment (for example, number of total animals) required to give precision equal to that obtainable with the optimal design.

It can be seen that in all cases the optimal combination (P_1, P_2, F_1) is considerably more efficient than any other design. The next best design requires at least twice the resources to give the same precision.

Table 3. Comparison of the precision attainable with different combinations of P_1, P_2, F_1, B_1, B_2 and F_2 groups. Optimal allocation to groups minimised V(A) + V(H).

Optimal percent of total animals allocated to groups						Relative size of standard errors of		Relative number of animals needed for equal precision
P_1	P_2	F_1	B_1	F_2	B_2	A	H	
35	35	31	--	--	--	100	100	100
37	23	--	41	--	--	111	191	231
29	29	--	--	41	--	109	188	223
23	37	--	--	--	41	111	191	231
22	--	30	--	48	--	335	214	826
22	--	35	--	--	43	170	145	254
17	--	--	47	37	--	366	385	1 405
26	--	--	46	--	29	198	288	587
13	--	--	--	49	38	360	558	2 111
--	--	19	38	43	--	370	254	1 047
--	--	31	35	--	35	200	200	400
--	--	19	--	43	38	370	254	1 047
28	28	--	22	--	22	102	186	212
27	31	--	--	30	13	108	187	221

Acknowledgements

The collaboration of Dr. John Connolly in Chapter 6 is acknowledged.

Appendix 5.2. Detection of sire by location interaction and comparison of groups of sires

by J.W. James
University of New South Wales

Suppose an experiment is carried out as follows in order to detect genotype-environment interactions. A total of s sires each is tested in p locations, with n daughters per sire at each location. We assume sires are randomly chosen, but that specific locations are used. The analysis of the result will be as follows:

Source	D.F.	M.S.	E (M.S.)
Locations	p - 1	MSL	$\sigma^2 + n\sigma_{SL}^2 + ns\sigma_L^2$
Sires	s - 1	MSS	$\sigma^2 + np\sigma_S^2$
Interaction	(s - 1) (p - 1)	MSI	$\sigma^2 + n\sigma_{SL}^2$
Error	sp (n - 1)	MSE	σ

The interpretation of the variance components is obvious. The statistical test at the α significance level for the presence of interaction is

$$(MSI / MSE) > F_{(s-1)(p-1),\ sp(n-1),\ \alpha}$$

the α point of the appropriate variance ratio distribution. Now, under the assumption that the ratio MSI / MSE has the distribution of $\left(\sigma^2 + n\sigma_{SL}^2\right)/\sigma^2$ times $F_{(s-1)(p-1),\ sp(n-1),\alpha}$. Thus denoting σ_{SL}^2/σ^2 as 1 , the probability of obtaining a significant result at the α level is Prob $\left\{(1+n\Theta)F_{(s-1)(p-1),sp(n-1)} > F_{(s-1)(p-1),sp(n-1)},\alpha\right\}$. If we specify a value for this probability, which is known as the power of the test, then for a given experimental design we can find, from tables of the F distribution, the value of 1 which will give this specified power.

For instance, we may take p = 2 and consider the range of experimental designs with s = 10, 20, 40 using α = 0.05. We find the values of 1 which give powers of 75 percent and 90 percent for each design.

Working Paper No. 2. Prepared for the APC Expert Panel investigating the Introduction of New Dairy Cattle Genotypes into Australia. April 1975.

Minimum values of $\Theta = \sigma^2_{SL} / \sigma^2$ which will give significant interactions at the 5 percent level with the specified power

		n		
s	Power	10	20	40
10	75%	0.1953	0.0954	0.0473
	90%	0.3188	0.1552	0.0771
20	75%	0.1122	0.0555	0.0267
	90%	0.1673	0.0820	0.0398
40	75%	0.0704	0.0346	0.0148
	90%	0.0988	0.0480	0.0240

It is of interest to interpret these figures in terms of genetic correlations as follows. If r_G is the genetic correlation between performance in the two locations, h^2 is the heritability and σ^2_p is the phenotypic variance, then

$$\sigma^2 = \left(1 - \tfrac{1}{4}h^2\right)\sigma^2_p$$
$$\sigma^2_S = \tfrac{1}{4}h^2\sigma^2_p$$
$$\sigma^2_{SL} = \left(1 - r_G\right)\tfrac{1}{4}h^2\sigma^2_p$$

and hence

$$\Theta = \frac{\left(1 - r_G\right)h^2}{4 - h^2}$$

or

$$r_G = 1 - \frac{4 - h^2}{h^2}\Theta$$

For a known h^2, 1 values can then be converted to genetic correlations. We do this taking h^2 = ¼ so that r_G = 1 - 151. We then obtain the following table, which is simply the preceding one in a different form.

Maximum values of r_G when $h^2 = 0.25$ which will give significant interactions at the 5 percent level with specified power

		n		
s	Power	10	20	40
10	75%	-1.93	-0.43	0.29
	90%	-3.78	-1.33	-0.16
20	75%	-0.68	0.17	0.60
	90%	-1.51	-0.23	0.40
40	75%	-0.06	0.48	0.78
	90%	-0.48	0.28	0.64

Genetic correlations less than -1 are of course impossible, but the corresponding 1 values may be of some use when all of the conditions specified in deriving the results do not hold. It may be noted that for a given total number of daughters, a lesser degree of interaction may be detected by using many daughters of few sires than can be detected with few daughters of many sires. Thus, with 400 daughters per location, the use of ten sires each having 40 daughters enables interaction to be detected with 75 percent power if 1 is 0.0473, but 1 must be as large as 0.0704 if we use 40 sires each with ten daughters.

It is also worth noting that if only highly selected sires were used in such a trial, the power would be reduced. The reason is that Φ^2 would be unaffected, but σ_{SL}^2 would be reduced because there would be less variation between sires than when sires are randomly chosen. For the same reason, the power of the test for interaction could be increased by using a combination of very good and very bad bulls, though this may be an unattractive proposition.

Now suppose that in this experiment half of the sires are from one genetic group and half are from another and we wish to compare the two group means. We assume that either there is no sire by location interaction, or we are interested in the average genetic value over both locations.

The variance between sire means within a group is $\sigma_S^2 + \sigma^2/np$. There are ½*s* sires in each genetic group, so the variance of a group mean is $\frac{1}{\frac{1}{2}s}\left(\sigma_S^2 + \sigma^2/np\right)$ and the variance of the difference between group means is twice this or $\frac{4}{.s}\left(\sigma_S^2 + \sigma^2/np\right)$. With p = 2, this may be rewritten as $\sigma_p^2\left[\frac{h^2}{s} + \frac{2 - \frac{1}{2}h^2}{sn}\right]$.

Now a difference is significant at the 5 percent level if D > 1.96Φ_D, where D is the difference between means and Φ_D is its standard error. If μ denotes the true mean difference, the chances are 90 percent and 75 percent that D > μ -1.28Φ_D and D > μ -0.67Φ_D. Thus for powers of 75 percent and 90 percent, we need

$$\mu \geq (1.96 + 0.67)\Phi_D \quad \text{and} \quad \mu \geq (1.96 + 1.28)\Phi_D$$

or

$$\frac{\delta}{\sigma_p} \geq \begin{Bmatrix} 2.36 \\ or \\ 3.24 \end{Bmatrix} \sqrt{\frac{h^2}{s} + \frac{2 - \frac{1}{2}h^2}{sn}}$$

Minimum genetic differences between groups in standard deviation units which give significant differences at the 5 percent level with specified power

		n		
s	Power	10	20	40
10	75%	0.55	0.49	0.45
	90%	0.68	0.60	0.56
20	75%	0.39	0.34	0.32
	90%	0.48	0.42	0.39
40	75%	0.28	0.24	0.23
	90%	0.34	0.30	0.28

Again using the value $h^2 = 0.25$, we find the condition

$$\frac{\delta}{\sigma_p} \geq \begin{Bmatrix} 2.36 \\ or \\ 3.24 \end{Bmatrix} \sqrt{\frac{1}{4s} + \frac{15}{8sn}}$$

Values of this criterion have been calculated for the range of values of s and n used before and are shown in the table. Since the co-efficient of variation of milk production can be expected to be about 20 percent, these figures can be expressed as percentages of average milk production, as in the following table.

Minimum percentage differences in milk production which will be significant at the 5 percent level with specified power

		n		
s	Power	10	20	40
10	75%	11.0	9.8	9.0
	90%	13.6	12.0	11.2
20	75%	7.8	6.8	6.4
	90%	9.6	8.4	7.8
40	75%	5.6	4.8	4.6
	90%	6.8	6.0	5.6

Notice that in this context, for a total number of daughters given, it is more efficient to have many bulls each with few daughters than to have few bulls each with many daughters. This is in contrast to the situation for detecting interactions. Similarly, use of highly selected bulls (provided that matching of the two groups can be achieved) will, by reduction of the variance between bulls, reduce the experimental error and give a more powerful experiment. Again, the situation differs from that of detecting interaction. Optimum experimental design for one problem is thus incompatible with optimum design for the other problem.

Though these power calculations are valuable, there are other aspects which need to be considered. If it is taken that a new breed must have at least a 20 percent genetic superiority over a local breed to justify a large-scale replacement programme, a question requiring an answer is, what is the chance that a new breed having the required genetic superiority would fail the test and not be introduced? Suppose a preliminary test is to be carried out and if the new breed appears to be 15 percent or more superior to the local breed in this test, a more thorough comparison may be made. What is the chance that the observed difference in the test will be 5 percent or more, less than the true difference? There is also the chance that a new breed will appear 5 percent better than it actually is, or that a breed with 10 percent superiority will be further tested. In the notation used above, we want the probability that D - ∗ > 5 percent. Our assumptions give

$$\sigma_D = 20\%\sqrt{\frac{1}{4s} + \frac{15}{8sn}}$$

Thus, we require the probability that a standard normal deviate exceeds $5\% \Big/ \left[(20\%)\sqrt{4/s + 60/sn}\right]$. These have been calculated for the same range of designs and are shown in the following table.

Probability that a new breed will appear to be 5 percent worse (or better) than it really is

	n		
s	10	20	40
10	0.1587	0.1160	0.0888
20	0.0787	0.0455	0.0283
40	0.0228	0.0084	0.0035

From the results in this table, it would appear that a preliminary test of this kind using 40 sires, 20 from each of the local and new breeds, would have a very small chance of missing a breed which ought to be introduced or of suggesting further tests of a new breed which had only half of the required superiority.

Appendix 5.3. Genetic differences required for introduction of new genotypes to be worthwhile

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Exotic genotypes need to be imported only if they enable a desirable object to be attained either more cheaply or more rapidly than it can be achieved using only local genotypes. A rational decision can then be made by comparing the pattern of genetic change over time through introduction with the pattern produced by the use of local genetic resources. This raises the serious problem that since neither of the programmes to be compared is under single control, both patterns of genetic change are to a very considerable degree unpredictable. A breed replacement programme will proceed essentially by top-crossing bulls from the new breed. The rate of replacement will depend on the rate at which cows are replaced by cows with higher fractions of new genes. Faster replacement means that cows are culled after fewer lactations and so the cost of replacement will rise accordingly. On the other hand, the benefits of breed replacement are obtained earlier. A further problem is the extent of breed replacement, that is, what fraction of cow replacements are sired by foreign rather than local bulls. If this fraction is high, then the benefits are spread over larger numbers of cows than when only a small part of the population is involved in replacement. One would guess that in practice both the speed of replacement and the fraction of replacement would be greater for foreign breeds which were vastly superior to local cattle than for moderately superior breeds. Thus, in practice, it seems likely that the benefits of replacement would show a non-linear relation to differences in productivity and therefore would be much more difficult to quantify by "discounted gene-flow" methods than is an integrated programme under one direction. Similarly, in practice, we need also to evaluate progress arising from selection within the local population for comparison with progress through introduction. If selection in the local population is already efficient, there is not much difficulty, but when the local breeding programme is very inefficient, it may be necessary to obtain an assessment of likely changes in the system; both changes in efficiency and the time-scale in which such changes take place are involved.

Yet another factor requiring evaluation is the system by which foreign genotypes are tested. The larger the scale on which a new breed is tested, the greater the cost. However, the chance of making a good decision is also increased. Further, a very convincing test result may help to speed replacement. It should be noted that comparison of top-cross progeny of foreign bulls with local animals is likely to be biased in favour of the foreign bulls because of the occurrence of heterosis, which is likely to be of the order of two to five percent of productivity. This heterosis would be lost after breed replacement. Suppose a foreign breed is ten percent better than a local breed and shows five percent heterosis. Then the first progeny would show ten percent superiority (five percent breeding value, five

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percent heterosis). If heterosis were ignored, it would then be predicted that replacement would improve productivity by 20 percent rather than by the true value of ten percent. It is to avoid the problems of heterosis in genotype evaluation tests that the importation of pure-bred bulls and cows is useful, rather than in the provision of a nucleus for expansion. Expansion will be mainly by top-crossing or up-grading even when a pure-bred nucleus exists.

In view of the complexities and the parameters for which reasonable values are not available, it does not seem worthwhile to attempt a detailed analysis of the economic advantages of a breed replacement programme. However, E.P. Cunningham, in a paper presented at the Zeist Conference, considered breed replacement under the assumptions that both breed replacement and selection in the local population are carried out efficiently. He reached the conclusion that breed replacement was not “likely to be a real option unless the mean difference between the native and imported breeds exceeds 20 percent”. A difference of this magnitude should not be hard to detect as significant, so if the conclusion is correct, there is no need for elaborate testing programmes, at least in the first stages, since it should be possible to estimate fairly easily which foreign strains are serious candidates for replacement of local strains. Later work may need to be more accurate, though if differences between possible replacements are small, it may not matter much which is chosen.

Economic evaluation of straight- and cross-breeding programmes

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Introduction

This document is part of a comprehensive study dealing with different aspects of the development of livestock breeding system strategies for use in sustainable intensification of production system incorporations, the planning and establishment of animal breeding strategies. It is closely linked to the companion document on breeding goal definition prepared by Ab Groen. The material presented summarises chapters 5, 6, 7, 8 and 11 of *Economic Aspects of Animal Breeding* (Weller, 1994). The presentation has been simplified somewhat for a more general audience, with emphasis on practical application to actual commercial conditions in both developed and developing countries. A basic understanding of genetics and calculus is assumed.

1. The main elements of returns and costs

Any economic evaluation should begin by considering two classes of variables, returns and costs. Often the concepts of returns and products have been confused in the economic evaluation of animal production. In a multi-enterprise production system, the returns of one enterprise may be quite different from the products that the consumer buys. For example, in the production of poultry broilers, one enterprise might produce breeding stock, which is sold to a second enterprise in the form of chicks. These chicks are raised at a second enterprise, which might sell the progeny as either eggs or chicks to a third enterprise that actually raises the broilers, which are sold to the public. The same situation is common in beef production where one enterprise raises calves until weaning in range conditions and a second fattens the calves in feedlot conditions.

Of course, the costs will also be different for the different enterprises. Dickerson (1970) noted that the main costs of animal production for most species would be dependent on three main functions: 1) female production;

2) reproduction; and 3) growth of young. He excluded the costs related to male production because for nearly all economically important species, this cost will be negligible compared to the factors listed above. Thus, economic efficiency, E, can be expressed by the following general equation for most production systems:

$$E = \frac{R}{C} = \frac{R_d + R_o}{EF_d + I_d + EF_o + I_o} \qquad [1]$$

where R_d is return from female production, R_o is return from offspring production, EF_d and I_d are feed and non-feed costs per dam, respectively; EF_o and I_o are feed and non-feed costs of her progeny; and the other terms are as defined previously. Calculations will generally be made on an annual basis for all terms. Various studies have preferred to estimate economic trait values based on the inverse of economic efficiency, which we will define as E_i. If E_i is selected as the criterion for economic evaluation, then the goal will be to minimised E_i, as opposed to maximising profit or E.

Economic objectives will consist either of increasing returns or decreasing the costs of production. We will consider the main elements of costs and returns that can be affected by breeding.

1.1. Elements of female production

The main animal products consumed are meat, milk, eggs and wool. We will use the notation of Moav (1973) with slight modifications. In general, economic constants will be denoted with uppercase subscripted letters and biological variables with subscripted xs and other variables with other lowercase subscripted letters. The value of female production can be expressed by the following equation:

$$R_d = m_d x_D A_d \qquad [2]$$

where R_d is the yearly return per enterprise, due to female production, m_d is the number of females per enterprise, x_D is yearly volume of product/female and A_d is the value of product per unit volume. For example, assume a herd of 100 milk cows, each producing 8 000 kg milk/year, with a value of US$.25/kg. R_d will be equal to (100)(8 000)(0.25) = US$200 000. Generally speaking, breeding has attempted to increase return by increasing x_D, although from the point of view of the producer, R_d could also be increased by increasing m_d or A_d. However, increasing m_d merely means increasing the size of the enterprise and is therefore not relevant to breeding. A_d can be affected by changing the quality of the product. This is clearly important for most agricultural products, but in practice, much more emphasis has been put on increasing quantity, rather than quality of produce. There are two main reasons for this. First, measuring quality of a product is generally more difficult than measuring quantity. For example, a simple scale can score quantity of milk produced, while measuring protein concentration requires at least a spectrophotometer. Second, there will generally be an antagonistic genetic correlation between quantity and quality of product. Continuing the previous example, both fat and protein concentration have negative genetic correlations with milk production.

Although most economic evaluations of breeding objectives have been made based on equation [2], it is inadequate for many situations. How do you compare milk production by goats and cows, or even compare milk production by different breeds, which may differ markedly in size? To account for this factor it is sometimes useful to rewrite this equation as follows:

$$R_d = m_d x_{3d} x_{2d} A_d \qquad [3]$$

where x_{3d} is the mean weight of females and x_{2d} is production per unit female weight. It is now possible to consider whether the total enterprise consists of a few big animals or many small ones. Total production, as computed in the equation can be increased by increasing m_d, x_{2d} or x_{3d}. Various researchers have suggested that metabolic body should be used rather than body weight. Metabolic body size is generally estimated as $x_3^{0.75}$. This value has been shown to be accurate over a large range of species.

Just as increasing the number of animals per enterprise is irrelevant to breeding, increasing the size of the production unit (animal) may not in fact increase either profit or economic efficiency.

1.2. Evaluation of female reproduction rate

Female reproduction rates differ markedly among domestic animals. This is illustrated by the examples in Table 1, from Moav (1973). Weight of dam, number of marketable offspring / year, market weight per offspring and reproduction ratio are listed for six species of domestic vertebrates. Reproduction ratio is defined as: the ratio of total market weight of offspring per weight of dam. At one extreme are large mammals such as horses and cows with one progeny per year and the other extreme are fish and crustaceans with thousands of offspring per year.

Return from female reproduction can be evaluated by the following equation:

$$R_o = x_{1o} x_{2o} A_o \qquad [4]$$

where R_o is the return from offspring / year, x_{1o} is the number of offspring marketed / female / year, x_{2o} is the weight of offspring product and A_o is the value per unit offspring product.

Table 1. Dam weight, number of marketable offspring/year, marker weight of offspring, and reproduction ratio for different domestic species.

Species	Weight of dam (kg)	No. of marketable offspring / year	Market weight per offspring	Reproduction ratio
Cattle	600	1	500	0.8
Sheep	60	2	40	1.3
Swine	200	15	100	7.5
Poultry	3	70	1.5	35
Turkeys	7	40	9	51.4
Carp (fish)	5	100,000	1	20,000

Breeding can increase R_o by increasing x_{1o}, x_{2o}, or A_o. Although we have designated A_o as an economic constant, there is generally some differential pricing, based on the quality of product, which can be affected by breeding. Generally, the effect of breeding on R_o will be greatest by selecting for x_{2o}, rather than x_{1o} or A_o. The reasons are as follows: x_{2o} will generally be dependant on growth rate, which usually has high heritability and variance; while x_{1o} generally has low heritability and A_o has low phenotypic variance, is generally difficult to measure and as stated above, will be negatively correlated with x_{2o}. The number of offspring marketed is determined by several different genetically unrelated traits, such as interval between litters, number of offspring per litter and juvenile mortality rates. Since these traits are related to natural fitness, they generally have low heritabilities. Furthermore, selection for an index of several unrelated traits is inherently less efficient than selection for a single trait. In addition, as will be shown below, the economic importance of changes in x_{1o} decreases as the mean value of x_{1o} increases. Thus, for animals with low reproduction rates, slight changes in x_{1o} will be of major economic importance, while for high fertility species, the economic importance of changes in this variable will be negligible. However, for most domestic species, the coefficient of variation for x_{1o} increases with mean x_{1o}. Thus, those species with the lowest reproductive rates and therefore the highest economic value for this variable, have the lowest relative variance for this trait.

Despite these considerations, significant emphasis in selection has been devoted to increasing the reproductive rate in most species. Moav and Hill (1966) give two reasons for this. In most cases one enterprise (which we will denote the breeder) produces juveniles or eggs, which are then sold to a second enterprise (which we will denote the rearer) that raises the animals for slaughter. The rearer will generally purchase young animals or eggs on a per unit basis. Thus, the breeder will be primarily interested in the reproduction rate of his females. Although in theory the rearer should be willing to pay a premium price for a superior product, i.e. animals with a higher growth rate, in practice, it is often difficult to evaluate the animals bought. Thus, while a feedlot manager may be willing to pay a higher price for a Simmental calf than a Holstein, a one day old chick looks just like any other. The second reason has to do with the difference of estimation of profit for a constant versus an expanding market and is explained below.

1.3. Evaluation of feed costs

Feed costs can be divided into feed for the breeding female and feed for the offspring. For each individual, feed costs can further be divided into feed for maintenance and production. In the case of the breeding female, feed for production consists of the feed needed to produce offspring. Thus, total feed costs of an integrated enterprise can be expressed by the following equation:

$$F_a = C_d m_d[x_{3d}F_{Md} + x_{1o}(F_{Pd} + x_{3o}F_{Mo}D + F_{Po}x_{2o})] \qquad [5]$$

where F_a is the annual feed costs of the enterprise, C_d is the unit feed costs, x_{3d} is the metabolic body weight of the breeding female, F_{Md} is the maintenance feed required per unit metabolic body weight of the dam, F_{Pd} is the feed required by the dam per offspring produced, x_{3o} is the mean metabolic body weight of the offspring, F_{Mo} is the maintenance feed required / x_{3o} / day, D is the number of days from weaning to slaughter for the offspring, F_{Po} is the feed required per unit product and the other terms are as defined previously. In this equation, x_{3o} is considered a biological variable and D is considered a constant. This will be true for animals that are slaughtered at a constant age. However, if animals are slaughtered at a constant weight, then D will be a biological variable and x_{3o} will be the economic constant.

Assuming slaughter at a constant age, the only terms in equation [5] that can be significantly effected by breeding are x_{3d}, x_{1o}, x_{3o} and x_{2o} and increasing any of them will have a positive effect on F_a. Increasing m_d will have a proportional effect on both costs and returns. That is by changing m_d we merely change the size of the enterprise. The effect of changing x_{3d} will depend mainly on x_{1o} as illustrated in Table 1. For large domestic animals, x_{1o} is relatively small and changes in x_{3d} can have a significant effect on total feed costs. However, for more prolific species, feed for dams is negligible as compared to feed for progeny. The effect of changing x_{1o} will also depend on the mean of x_{1o}. Although from this equation, it would appear that breeding for reduction in mean offspring weight is a desirable goal, this is hardly ever done in practice. This is because there is generally a strong positive genetic correlation between x_{3o} and x_{2o}. This is of course evident when the main offspring product is meat, but is also true for most other important products, such as milk or wool. Finally, decreasing x_{2o} can reduce feed costs. However, since x_{2o} is directly proportional to returns, unless profit is negative, it is in the interest of the enterprise to increase x_{2o}.

1.4. The relationship between growth rate and feed efficiency

For most domestic animals raised for slaughter, the main trait under selection is growth rate. This is because growth rate is usually highly correlated with feed efficiency. This will be illustrated by considering two cases, rearing to a constant slaughter weight and rearing to a constant age. Assume that body weight increases linearly over time. This is approximately true for most domestic animals. Then x_{3o} will be equal to the mean of initial and final body weight. Since differences in initial body weight are minimal, x_{3o} will be equal to ½ final body weight, plus a constant. Rearing to a constant slaughter weight is illustrated in Figure 1. Body weight as a function of age is plotted for two growth weights. The integral of this curve will be equal to the product of x_{3o} and D. In this case, increasing growth rate decreases D, but does not effect either x_{3o} or x_{2o}. Thus, $x_{3o}D$ is decreased and feed efficiency is increased. This is the common situation for poultry production.

Figure 2 illustrates the situation of slaughter at a constant age for two different growth rates. In this case, D is constant, but both x_{3o} and x_{2o} increase with increase in growth rate. Assuming that the initial weight is negligible to the final weight, the relationship is that feed for maintenance is proportional to ½ final weight, while x_{2o} is proportional to final body weight. The importance of this relationship can be illustrated as follows: if the number of offspring are doubled, with all other factors constant, then both maintenance feed and the quantity of meat produced will be doubled. However, if growth rate is doubled and all other factors remain constant, then x_{2o} is still doubled, but maintenance feed increases only by 50 percent. Beef cattle are generally slaughtered at a constant age.

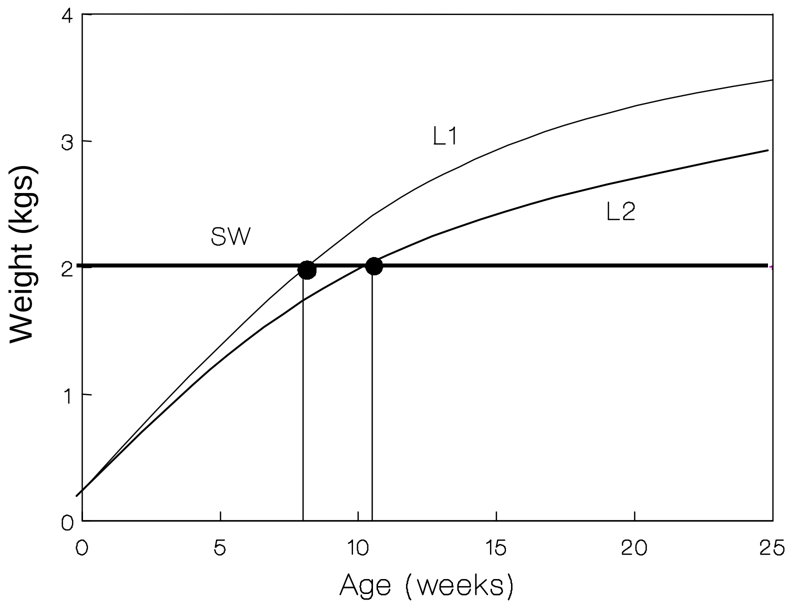

Figure 1. Effect of growth rate for slaughter at a constant weight. SW is slaughter weight. L1 and L2 are growth curves for two poultry strains.

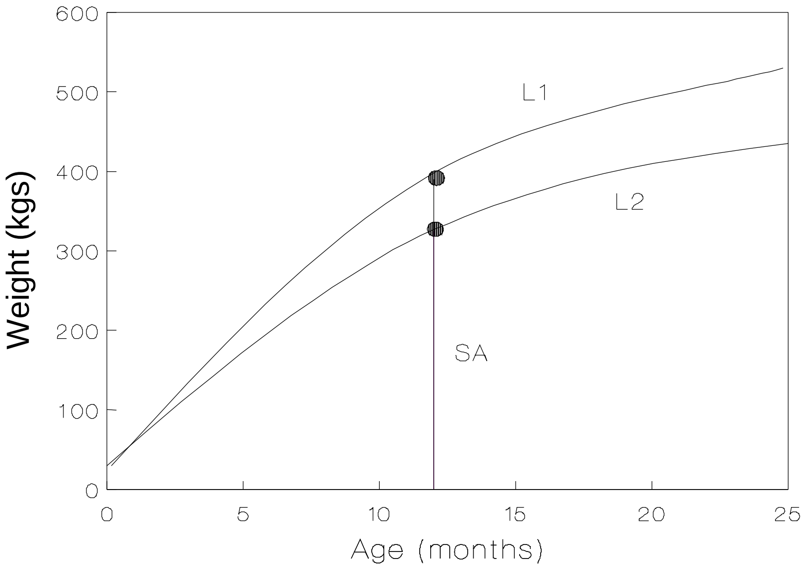

Figure 2. Effect of growth rate for slaughter at a constant age. SA is slaughter age. L1 and L2 are growth curves for two cattle strains.

It becomes apparent, that other factors being equal, there is an optimum slaughter age for all animals. Growth rates for most domestic animals are roughly linear until a given age and then decline. As animals approach maturity, growth rates decline and fat production, which requires more energy for production than muscle, also increases. The optimum slaughter time for beef calves is near the onset of sexual maturity. Extending the linear growth phase can therefore increase the economical efficiency of beef production. This is the main difference between large and small beef cattle breeds.

There is probably an economically important genetic variance for feed efficiency between individual animals after correction for differential growth rates. Although individual feed consumption has a high genetic correlation with growth rate, it is still less than unity. This relationship has been shown both for poultry and beef cattle. Furthermore, both traits have high heritability. However, selection for increased feed efficiency independent of growth rate, requires measuring individual feed intake and this is prohibitively expensive under commercial growth conditions for all domestic species.

1.5 Non feed costs of production

Although the major production costs will be feed related, there will also be significant non-feed costs. These can be divided into fixed costs per enterprise, per breeding female and per progeny. The major non-feed fixed costs were labour, rent, interest, buildings, veterinary costs and replacement breeding females. The only element of these costs that can be directly affected by breeding is veterinary costs. Even though disease related costs are significant, relatively little emphasis has been devoted to breeding animals for disease resistance, because of poor recording and generally low heritabilities. Although the other elements of non-feed costs can generally not be affected by breeding, we will see that they will affect the calculation of the economic evaluation of genetic differences. As is the case for feed costs, non-feed costs that are a function of the number of breeding females will be relatively more important for low fertility species.

2. Evaluation of genetic differences from profit equations

We will now explain how to evaluate differences between individuals or strains for traits of economic importance based on profit. In general terms this is accomplished by expressing profit as a function of the component traits. The economic values of the traits are then computed as the partial differentials of these traits with respect to profit. The notation and most of the examples will be based on Moav (1973). We will show that the estimation of marginal profit can be quite complex under certain circumstances and will depend both on the characteristics of the traits under selection and market constraints. Alternative criteria for evaluating genetic differences is discussed later.

2.1. The basis for evaluation of trait differences

In order to construct profit equations, it is necessary to first consider the unit of comparison. For example, we can consider profit per unit product, per production unit (animal), per unit animal weight, per enterprise (farm), or for the entire national economy. At a first glance, this question may not seem important. The reader may consider this analogous to asking whether a trait is measured in grams or pounds. In fact it will be demonstrated that radically different results can be obtained, depending on the unit selected as the basis of evaluation.

We will start with the example of egg production in poultry, assuming that the objective is to compute the economic value of a unit change in the number of eggs laid per hen. At the beginning it was assumed that all cost and returns from the layer mother are negligible compared to the costs and returns of the layer. Profit per unit of product, in this case profit per egg produced, is computed as follows:

$$P_1 = A_1 - F_1 - V(x_1) = K - V(x_1) \qquad [6]$$

where P_1 is profit / egg, A_1 is income / egg, F_1 is fixed costs / egg, x_1 is the number of eggs / hen and $V(x_1)$ is the variable costs of egg production. F_1 and $V(x_1)$ will include both feed and non-feed costs. $V(x_1)$ denotes that the variable costs of egg production are some function of x_1. Since both A_1 and F_1 are independent of x_1, they can be combined into a single constant denoted K in the right-hand-term of equation [6].

It has been explained that it is convenient to divide costs into feed and other costs. In equation [6] feed costs included in F_1 will be the feed required to produce eggs, while other feed costs will be included in $V(x_1)$. Similarly non-feed costs that are a direct function of the number of eggs produced, such as egg handling labour, will be included in F_1; while other non-feed costs will be included in $V(x_1)$.

In order to obtain a simple algebraic expression for $V(x_1)$, we will assume that all costs not included in F_1 are a direct function of the number of layers. Then equation [6] can be rewritten as follows:

$$P_1 = A_1 - F_1 - F_2 / x_1 = K - F_2 / x_1 \qquad [7]$$

where F_2 is the fixed costs per hen and the other terms are as defined above. In this equation profit is now expressed as an inverse function x_1. Increasing x_1 increases profit / egg by distributing the fixed costs per hen over a greater number of eggs.

The marginal change in profit / egg / hen (the a-value of the selection index) is computed by differentiating equation [7] with respect to x_1 as follows:

$$\frac{d(P_1)}{d(x_1)} = \frac{F_2}{(x_1)^2} \qquad [8]$$

We note first that as long as x_1 is positive, the change in profit per added egg / hen will be positive. However, the marginal increase in profit is *not* a constant, but rather a non-linear function of x_1. In fact, as the number of eggs / hen increases, that additional profit / egg decreases. This equation points out one of the main difficulties in application of selection index. Selection index assumes that the economic values of the traits under selection are constants. In reality the economic values are generally functions of the phenotypic trait values.

We will now rewrite equation [7] to evaluate profit per hen. This can be done by multiplying both sides of equation [7] by x_1:

$$P_2 = x_1(P_1) = K(x_1) - F_2 \qquad [9]$$

where P_2 is profit per hen and the other terms are as described above. Differentiating this equation with respect to x_1 yields:

$$\frac{d(P_1)}{d(x_1)} = K \qquad [10]$$

That is, profit / hen is a linear function of x_1 and the marginal change in profit is now a constant. Thus, the economic value of a unit change in the number of eggs per hen will be different if profit is computed per hen or per egg.

2.2. Multiple-trait economic evaluation

We will now consider the case of simultaneous economic evaluation of several traits. In the example given above, in addition to number of eggs / hen, mean weight of eggs and hen body weight will be important economic traits. Following the notation of Moav (1973) these two additional traits will be denoted x_2 and x_3, respectively. We will first assume that x_2 is constant and compute the economic value of the two remaining traits on profit. The fixed costs per hen can now be computed as follows:

$$F_2 = (K_4 + K_3x_3) \qquad [11]$$

where K_4 is the fixed cost per hen, K_3 is the fixed cost per unit weight of hen and the other terms are as defined previously. Substituting equation [11] into equation [9], profit per hen can now be expressed by the following equation:

$$P_2 = x_1[K - (K_4 + K_3x_3) / x_1] \qquad [12]$$

with all terms as defined above. Substituting equation [11] into equation [7], profit per egg can be computed as follows:

$$P_1 = P_2 / x_1 = K - (K_4 + K_3x_3) / x_1 \qquad [13]$$

Finally, we can also compute profit per gram hen, P_3, by dividing equation [12] by x_3 as follows:

$$P_3 = P_2 / x_3 = (x_1K) / x_3 - K_4 / x_3 + K_3 \qquad [14]$$

with all terms as defined above. The economic values of x_1 and x_3 are the partial differentials of these variables with respect to profit. These values are summarised in Table 2 for the three profit criteria in equations [12] through [14].

Table 2. Partial differentials of profit with respect to eggs/hen (x_1) and hen body weight (x_3).

Profit criteria	Partial derivatives	
	x_1	x_3
Per egg (P_1)	$[K_4 + K_3x_3] / x_1^2$	$-K_3 / x_1$
Per hen (P_2)	K	$-K_3$
Per gram hen (P_3)	K / x_3	$[K_4 - Kx_1] / x_3^2$

We first note that the economic values for both traits will be different for each of the three profit criteria. Under the assumptions that K, K_3 and K_4 are all positive and that x_1 and x_3 are greater than unity, then the economic value of x_1 will be greater if profit is computed per hen than if profit is computed per gram hen. Likewise, the absolute economic value of x_3 will be greater if profit is computed per hen, as opposed to per egg. We further note that the economic values are equal to constants only in the case of profit per hen. Thus, linear selection index cannot be directly applied for either of the other two profit criteria.

2.3. Choice of the appropriate profit criteria

Most studies that have attempted to evaluate genetic differences have done so by the criteria of profit per animal. This criterion is probably justifiable only under a very short-term profit horizon. For example, it may be difficult for a dairy farmer to significantly change the number of cows in his herd within a week, but there is no reason why he cannot appreciably change this number over a space of several months or years. Two alternative constraints which will apply both in the short- and long-term are constraints on production or constraints on investment. We will first consider the case of constraints on production.

In order that production does not exceed demand, most developed countries have imposed production quotas on many agricultural products. If each enterprise has a production quota, then production will be a fixed quantity for both the enterprise and the national economy. We will now compute profit per enterprise, P_E, as profit per animal, times m, the number of animals raised:

$$P_E = mP_2 = mx_1P_1 = Q(P_1) \qquad [15]$$

where Q, the quantity of the demand, is equal to m times x_1 and the other terms are previously defined. (We have designated the product of m and x_1 as "demand" rather than supply because it is demand that we assume to be fixed.)

With fixed Q, an increase in x_1 will cause a reduction in m. Thus, m can be computed as a function of x_1 and Q as follows:

$$m = Q/x_1 = (m_0x_{10})/x_1 \qquad [16]$$

where m_0 and x_{10} are the original values for m and x_1 prior to the change in x_1. Profit for fixed demand, P_Q can then be expressed as follows:

$$P_Q = m_0x_{10}P_1 = m_0X_{10}[K - (K_4 + K_3x_3)/x_1] \qquad [17]$$

Note that the only variables in this equation are x_1 and x_3. Therefore, since m_0x_{10} is a constant, the profit equation in [17] is proportional to profit per egg in equation [13]. Thus, the partial derivatives of this equation will be equal to the partial derivatives of equation, multiplied by the constant, m_0x_{10}.

We will now consider the other two possibilities of profit for a fixed number of animals (production units) and profit for a fixed total weight of animals. The latter alternative can be considered approximately equal to profit for fixed investment. Profit for a fixed number of animals, P_M, is computed as follows:

$$P_M = m_0P_2 = m_0x_1[K - (K_4 + K_3x_3)/x_1] \quad [18]$$

with all terms as defined previously. This is of course, profit per hen, multiplied by the constant, m_0. For the case of fixed investment, it is required that the total weight of hens be fixed. That is:

$$W = mx_3 = m_0x_{30} \quad [19]$$

where W is total weight of hens (investment), x_{30} is the initial hen weight and the other terms are as defined previously. From this equation we see that with fixed weight of hens, x_3 will be an inverse function of m. Profit with fixed investment, P_W, is computed as follows:

$$P_W = mx_3P_3 = m_0x_{30}x_1P_1/x_3 = m_0x_{30}[(x_1K)/x_3 - K_4/x_3 - K_3] \quad [20]$$

with all terms as previously defined. As in previous cases, P_W is equal to P_3 times m_0x_{30}, which is a constant.

Since the objective of breeding is to increase profit, we need to chiefly consider those situations that result in increased profit relative to the original situation, specifically $x_1 > x_{10}$ and $x_3 < x_{30}$. Within this parameter space we can then deduce the following inequality:

$$P_W > P_M > P_Q \quad [21]$$

This relationship can be explained as follows: for P_Q profit can be increased only be decreasing costs per unit product; for P_M, profit can also be increased by increased production; and for $P_{W,}$ it is possible to further increase profit by decreasing the production unit with fixed investment. The partial differentials for these three profit criteria are listed in Table 3. As should be clear from the previous discussion, the values for each row in Table 3 are proportional to the corresponding row in Table 2.

Table 3. Partial differentials of profit with respect to eggs/hen (x_1) and hen body weight (x_3) by three different enterprise criteria.

Profit criteria	Partial derivatives		
	x_1	x_3	ratio x_1:x_3
Fixed demand (P_Q)	$m_0x_{10}[K_4+K_3x_3]/x_1^2$	$-m_0x_{10}K_3/x_1$	$-[K_4+K_3x_3]/x_1k_3$
Fixed number of production units (P_M)	m_0K	$-m_0K_3$	$-K/K_3$
Fixed investment (P_W)	$m_0x_{30}K/x_3$	$m_0x_{30}[K_4-Kx_1]/x_3^2$	$-Kx_3/Kx_1-K_4$.

Multiplication of the vector of economic values by a constant is equivalent to changing the scale of measurement for the economic values. For example, if the economic values and index co-efficients are measured in US$/kg, multiplication of the index co-efficients by 2.2 changes the scale to US$/lb, but does not change the ratios among the economic values. Thus, the *ratios* among the economic weights is more important than their actual values. We have therefore also included the ratio of the partial derivatives in this table. These ratios are also different for the three profit criteria and except for P_M they are also functions of the trait values. In conclusion, the profit criterion can have a marked effect on the economic values of the traits included in a selection index.

2.4. Differential production quotas

We will now consider an example of profit computed as a function of three traits. In addition to the two previous traits of eggs/hen and hen weight, we will add a third trait of egg weight, x_2. If eggs are priced by weight, then this variable will affect both income and costs. Profit per hen can now be expressed as follows:

$$P_2 = K_1x_1x_2 - K_2x_1 - K_3x_3 - K_4 \qquad [22]$$

where K_1 is income per gram egg less fixed costs per gram egg, K_2 is fixed costs/egg and the other terms are as defined previously. As in the previous discussion, profit per egg can be computed by dividing equation [22] by x_1, while profit per gram hen can be computed by dividing this equation by x_3. In addition, it is now possible to define a fourth profit criteria, namely profit per gram egg, which can be computed by dividing equation [22] by x_1x_2. The co-efficients of the four constants K_1 - K_4 are summarised in Table 4.

Table 4. Coefficients of the economic constants with four different profit criteria.

Profit criteria	Coefficients			
	K_1	K_2	K_3	K_4
Per egg (P_1)	x_2	1	x_3/x_1	$1/x_1$
Per hen (P_2)	x_1x_2	x_1	x_3	1
Per gram hen (P_3)	x_1x_2/x_3	x_1/x_3	1	$1/x_3$
Per gram egg (P_4)	1	$1/x_2$	$x_3/(x_1x_2)$	$1/(x_1x_2)$

As in the previous example, the economic values of the three traits can be computed as the partial derivatives of each profit criteria with respect to each trait. These values are given in Table 5. As in the two-trait case, the partial differentials are quite different, depending on the profit criteria. Since the partial differentials for profit per egg and profit per gram egg are also different, which criteria is appropriate for conditions of fixed demand? The answer will depend on how fix demand is determined. For example, if each producer has a production quota computed in number of eggs, but is paid by egg weight, then the proper criteria would be profit per egg. Note that in this case the economic value of egg weight is K_1. That is with respect to weight of eggs, the producer is effectively in an unconstrained market and it will be to his advantage to put most of the emphasis of selection on increasing egg weight. However, if each farmer receives a quota in weight of eggs produced, or one considers the viewpoint of the national economy, then the proper criteria will be profit per weight of eggs produced.

Another example of this problem is calculating the economic weights for components of milk production. The economically important components of whole milk are butterfat, protein and lactose. Total milk produced and concentrations of milk components can be affected by both breeding and management. In many countries there is a price differential based on protein and fat concentration. In addition, the energy requirements to produce these components are not equal. It requires more energy to produce a gram of fat than a gram of protein, but production of protein requires ingestion of protein, which generally costs more than other feed components. If production quotas are in kg fluid milk, while a price differential is paid for protein and fat production, then the added profit for additional production of these components may be much greater than from additional milk production.

Table 5. Partial differentials of profit with respect to eggs/hen (x_1), egg weight (x_2) and hen body weight (x_3).

Profit criteria	Partial derivatives		
	x_1	x_2	x_3
Per egg (P_1)	$[K_3x_3 + K_4] / x_1^2$	K_1	$-K_3 / x_1$
Per hen (P_2)	$K_1x_2 - K_2$	K_1x_1	$-K_3$
Per gram hen (P_3)	$[K_1x_2 - K_2] / x_3$	K_1x_1 / x_3	$[K_2x_1+K_4-K_1x_1x_2] / x_3^2$
Per gram egg (P_4)	$[K_3x_3 + K_4] / [x_1^2x_2]$	$K_2 / x_2^2 + [K_3x_3 + K_4] / [x_1x_2^2]$	$-K_3 / x_1x_2$

2.5. Graphical representation of profit; reproductivity versus productivity

The relationships previously described can also be represented graphically by plotting one trait as a function of a second trait for a given profit level. If this function is plotted for a number of different profit levels, then this figure is denoted a "profit map" and the curves for the individual profit levels are denoted "profit contours". For example, x_3 in equations [17] or [20], can be plotted as a function of egg number and profit for fixed number of eggs (demand) or fixed weight of hens (investment). Solving for x_3 from these equations we obtain:

$$x_3 = \frac{1}{K_3}\left[\frac{x_1(m_0x_{10}K - P_Q)}{m_0x_{10}} - K_4\right] \qquad [23]$$

$$x_3 = \frac{m_0x_{30}(Kx_1 - K_4)}{P_W + m_0x_{30}K_3} \qquad [24]$$

Since the other terms are constants, x_3 is now expressed as a function of x_1 and profit.

The profit maps derived from equations [23] and [24] are plotted in Figure 3 for the constant values of Moav (1973). The solid lines represent the profit contours for fixed demand (fixed number of eggs) and the broken lines represent the profit contours for a fixed number of hens. Since profit is an inverse function of body weight, the scale of body weight is inverted. Thus, on this graph, profit is a maximum in the upper right-hand corner and a minimum in the lower left-hand corner. This convention will be followed throughout. By both criteria, x_3 is a linear function of x_1. Thus, the profit contours are straight lines by both profit criteria. However, the profit contours are not parallel. Furthermore, only the zero profit contour is congruent by both criteria. Thus, if individuals are ranked for selection based on their expected profit, the ranking will be different for different criteria.

Other things being equal, moving at right angles to the current profit contour will maximise profit. Since the profit contours for a given criteria are not parallel, the direction of maximum profit will change as profit increases. Furthermore, since the profit contours computed by the two criteria are also not parallel, except at zero profit, the direction of change for maximum profit at a given profit level will also depend on the profit criteria.

For most species, costs can be partitioned in costs of production and costs of female reproduction. To date, only the first element has been considered. In addition to the cost involved in keeping the laying hens, there will also be costs of keeping the mother hens that produce the laying hens. For an integrated enterprise that raises both mother hens and layers, profit can be expressed by the following equation:

$$P = K - V_2 - V_1 \qquad [25]$$

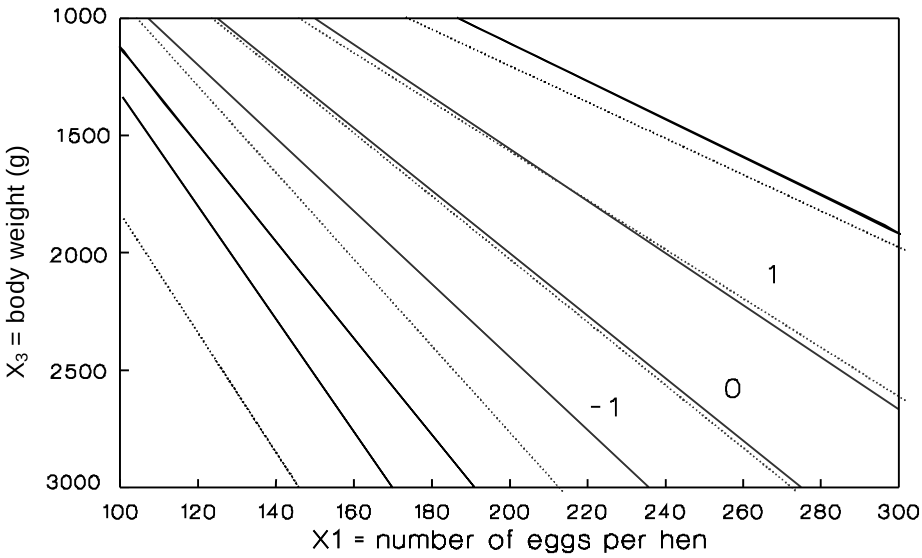

Figure 3. Profit map for laying hens. Body weight is a function of number of eggs per hen for the constant values of Moav (1973). The solid lines are the profit contours for fixed demand (fixed number of eggs) and the broken lines are the profit contours for a fixed number of hens. Since profit is an inverse function of body weight, the scale of body weight is inverted. Profit contour units are arbitrary monetary units.

where V_2 represents the variable costs of production, V_1 represents the variable costs of reproduction and K is return per unit production less fixed costs per unit production. We will now expand this equation following the specific example (Moav, 1973) of pig production in an integrated enterprise that raises both sows and pigs for slaughter :

$$P_1 = K_1 - K_2x_2 - K_3/x_1 \qquad [26]$$

where P_1 is profit per pig marketed, x_1 is number of pigs weaned per sow per year, x_2 is age to a fixed market weight, K_1 is income less costs independent of x_1 and x_2, K_2 is costs dependant on x_2 and K_3 are fixed costs (feed and non-feed) per sow. x_2 can also be defined as the food conversion ratio growth rate. In several previous equations, profit was also an inverse function of x_1. Note, however, the difference between this equation and equation [13]. The importance of this difference will become apparent shortly.

Increasing growth rate will also increase feed efficiency. In equation [26] we assume that pigs are marketed at a constant weight. Thus, increasing growth rate reduces expenses by decreasing the number of days that the pig must be fed prior to slaughter. For simplicity this function is assumed to be linear. Similar to the previous examples, we will now consider profit per fixed demand (pigs marketed), P_Q; and fixed number of production units (sows), P_M. These equations are derived in a parallel manner to equations [17] and [18]:

$$P_Q = m_0 x_{10} P_1 = m_0 x_{10}(K_1 - K_2 x_2 - K_3 / x_1) \qquad [27]$$

$$P_M = m_0 x_1 P_1 = m_0(K_1 x_1 - K_2 x_1 x_2 - K_3) \qquad [28]$$

where m_0 is the number of sows / enterprise, x_{10} is the original number of pigs / sow and the other terms are as defined previously. The profit contours can then be computed by solving for x_2 as a function of profit and x_1, as follows:

$$x_2 = \frac{1}{K_2}\left[K_1 - \frac{K_3}{x_1} - \frac{P_Q}{m_0 x_{10}}\right] \qquad [29]$$

$$x_2 = \frac{1}{K_2}\left[K_1 - \frac{K_3}{x_1} - \frac{P_M}{m_0 x_1}\right] \qquad [30]$$

with all terms as defined previously. The profit contours for these functions are given in Figure 4 for the constant values of Moav (1973) for a swine enterprise.

As in Figure 3, x_2 is plotted on a reverse scale, because of the negative relationship between x_2 and profit. Profit contours for fixed demand and fixed number of sows are denoted with solid and broken lines, respectively. Note first that in both equations, x_2 is an inverse function of x_1. Therefore, the profit contours are non-linear functions. As in Figure 3, the profit contours are congruent only when $P_M = P_Q = 0$. The profit contours with $P_M = P_Q$ cross at $x_1 = x_{10}$. That is, if the number of pigs per sow remains constant, then profit by both criteria will be equal for any value of x_2. As in the previous example, animals will be ranked differently by these two profit criteria.

The significance of the non-linearity will be two-fold. Firstly, we will consider the effect of changes in x_2 as a function of x_1. At any combination of values for x_1 and x_2, the effect on profit of a unit change in x_2 will be equal. However, for P_Q and a constant value for x_2, a unit change in x_1 will have a greater effect on profit at a lower number of pigs than at a higher number. This relationship is of course evident from the partial derivatives of equation [27]. Secondly, profit is increased most rapidly by progressing at right-angles to the profit contours. In the example in Figure 3 the direction of maximum increase in profit will be parallel for all points along

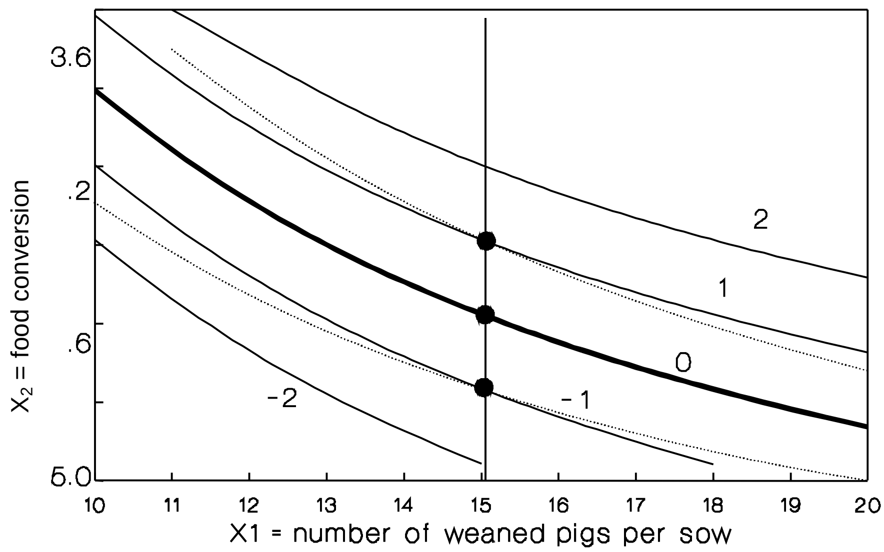

Figure 4. Profit map for a swine enterprise for the constant values of Moav (1973). x_2 is plotted on a reverse scale, because of the negative relationship between x_2 and profit. Profit contours for fixed demand and fixed number of sows are denoted with solid and broken lines, respectively. Profit contour units are arbitrary monetary units. The vertical line is the initial value for x_1.

a profit contour. In Figure 4, for points with equal profit, the direction of maximum increase in profit will be different.

3. Evaluation of genetic differences by alternate methods

There are several disadvantages of using maximisation of profit as the criteria for economic evaluation. Therefore, other criteria for economic evaluation have been suggested. The main alternatives to profit are economic efficiency, biological efficiency and return on investment. We will discuss the advantages and disadvantages of these methods, as compared to profit and will explain in detail the conditions for equality between different profit criteria and economic efficiency. It will be seen that these conditions are general enough that the problem of differing economic values for different profit criteria is less serious then originally thought. Finally, we will consider empirical methods for estimating economic values, based on actual prices and field data.

3.1. Economical and biological efficiency and return of investment as alternative criteria to profit for economic evaluation of trait unit changes

Profit (net income) and economic efficiency are defined as follows:

$$P = R - C \qquad [31]$$
$$E = R / C \qquad [32]$$

where P is profit, E is economic efficiency, R and C are returns and costs per unit production. Some studies have also used the inverse of economic efficiency to estimate economic values. The reasons for this will be explained below. One advantage of economic efficiency, as compared to profit, that should already be apparent is that economic efficiency is independent of the units used to compute R and C. We indicated that profit will be different if computed per unit product, per animal or per enterprise. This will not be the case for economic efficiency. Since the units of R and C will be the same, E is a unitless number. Thus, on the basis of economic efficiency it is also possible to compare different species and production systems. Furthermore, since R and C will generally be approximately equal, E will generally be close to unity.

One important disadvantage of both these criteria is that both R and C will tend to vary over time. Thus, "biological efficiency" (Dickerson, 1982) has been suggested as alternative to economic efficiency. Biological efficiency is defined as unit output per unit feed energy input. Assuming all quantities are measured on an enterprise basis, we can construct the following equations:

$$R = A_1(x_1) \qquad [33]$$

$$C = C_n + C_d F \qquad [34]$$

$$E_B = x_1 / F = [C_d R] / [A_1(C - C_n)] \qquad [35]$$

where A_1 is the price of a unit product, x_1 is quantity of product produced per enterprise, C_n is non-feed costs of the enterprise, C_d is the cost of a unit feed, F is the quantity of feed given, E_B is biological efficiency and the other terms are as defined above. Note that the middle term of equation [35] is in terms of biological inputs and outputs, while the right-hand term is in terms of economic units. Since in many production systems, the main economic component of both feed and product is protein, biological efficiency can alternatively be defined in terms of input and output of protein, rather than gross feed energy and product.

Although biological efficiency will be more constant in the long-term than either profit or economic efficiency, it is not a very useful criterion for economic evaluation. As pointed out by Dickerson (1982) it ignores the differing costs of feed for different species and the differing value of products (e.g. protein versus milk fat, or meat of old versus young animals). In addition it is possible to increase economic efficiency without changing biological efficiency. For example, breeding for disease resistance or calving ease may reduce non-feed costs and therefore, economic efficiency without affecting biological efficiency.

A fourth criterion that can be considered is return on investment, I_W, defined as follows:

$$I_W = P / C_W = (R - C) / C_W \qquad [36]$$

where C_W is investment and the other terms are as defined previously. Similar to efficiency, I_W will be a pure number. If all costs are included in C_W then I_W will be equal to E - 1. Moav (1973) suggested that costs that are a function of the quantity of production, but independent of weight and number of animals raised should not be included in C_W, specifically the feed required to produce the product. This is because decisions on the quantity of investment are taken before the product is produced. Thus, Moav (1973) defined I_W as costs per unit weight of animal. This criteria is probably only of interest to a potential new investor, or an investor who is contemplating expansion. Similar to other profit-based criteria, I_W will be correct only for a given situation. Since the results of nearly all breeding decisions will be long-term, it is difficult to justify this criteria for economic evaluation of trait changes.

3.2. Economic evaluation of trait differences by economic efficiency

In the previous chapter, the economic values of unit changes in trait values were computed by taking the partial differentials of profit equations with respect to each trait. This method can also be applied to economic efficiency. This will be illustrated using the example of egg production given in equation [22]. Profit per hen, P_2 was computed as follows:

$$P_2 = (A_1 - F_1)x_1x_2 - K_2x_1 - K_3x_3 - K_4 \qquad [37]$$

where A_1 is income per gram egg; F_1 is fixed costs per gram egg; x_1 is number of eggs, x_2 is egg weight, x_3 is hen weight; and K_2, K_3 and K_4 are fixed costs per gram egg, per egg and per hen, respectively. In order to differentiate between costs and returns, K_1 was replaced by A_1 - F_1. The inverse of economic efficiency is now computed as follows:

$$E_i = \frac{F_1x_1x_2 + K_2x_1 + K_3x_3 + K_4}{A_1x_1x_2} \qquad [38]$$

The economic values of x_1, x_2 and x_3 can now be computed by taking the partial differentials of E_i with respect to these three traits. One reason that E_i has been preferred is that calculation of partial differentials will generally be easier for this function. These partial differentials will be equal to the partial differentials presented in the last row of Table 5, divided by A_1, which is a constant. Multiplying the economic values by a constant will not affect the rate of genetic progress. Thus, we can conclude that at least in this example, economic values by the criteria of economic efficiency and by profit per unit product will be the same. This result is generally true and will now be explained in more detail.

3.3. Conditions for equality of economic values as computed for different profit criteria and economic efficiency

Different economic values are obtained when profit is computed by different criteria, such as per dam, per progeny or per unit product. Brascamp, Smith and Guy (1985) and Smith, James and Brascamp (1986) derived three conditions for equality of economic weights as computed by different profit criteria and by economic efficiency: 1) zero profit; 2) disregarding increased profit that can be achieved by rescaling of the enterprise; and 3) disregarding increased profit that can be obtained by correcting inefficiencies in the production system. Following their explanation, we will first use illustrative examples and then prove the general principles.

We will start with the example of pig production, with zero profit. “Zero profit” does not mean that the producer does not receive any compensation from production, but rather that a “reasonable profit”, necessary to make production worthwhile, is included in the “costs” of production. In the long-term, the price for any commodity will tend towards both equal marginal and average cost of production. Thus, if profit is computed as returns minus costs, profit will tend towards zero.

In equation [26] profit per pig, P_1 was computed as follows:

$$P_1 = K_1 - K_2x_2 - K_3/x_1 \qquad [39]$$

where x_1 is number of pigs weaned per sow, x_2 is slaughter age, K_1 is income per pig less costs independent of x_1 and x_2, K_2 is costs dependant of x_2 and K_3 is fixed costs per sow. Defining K as income per kg pig, less costs per kg pig and x_3 as slaughter weight we can rewrite this equation as follows:

$$P_1 = Kx_3 - K_2x_2 - K_3/x_1 \qquad [40]$$

as in the previous chapter we can compute profit per kg pig marketed, P_3, by dividing equation [40] by x_3 as follows:

$$P_3 = K - K_2x_2/x_3 - K_3/(x_1x_3) \qquad [41]$$

Similarly, profit per sow, P_2, can be computed by multiplying equation [40] by x_1:

$$P_2 = Kx_1x_3 - K_2x_1x_2 - K_3 \qquad [42]$$

The partial differentials of these three profit criteria with respect to x_1, x_2 and x_3 are given in the top three rows of Table 6. Under the assumption of $P_1 = P_2 = P_3 = 0$, these partial derivatives can be rewritten in the form appearing in the bottom three rows of Table 6.

Table 6. Partial differentials of profit with respect to pigs/sow (x_1), slaughter age(x_2) and slaughter weight (x_3).

Profit criteria	Partial derivatives		
	x_1	x_2	x_3
Per pig (P_1)	K_3 / x_1^2	$-K_2$	K
Per sow (P_2)	$Kx_3 - K_2x_2$	$-K_2x_1$	Kx_1
Per kg pig (P_3)	$K_3 / [x_1^2x_3]$	$-K_2 / x_3$	$[K_2x_2] / x_3^2 + K_3 / [x_1x_3^2]$
Per pig (P_1=0)	K_3 / x_1^2	$-K_2$	K
Per sow (P_2=0)	K_3 / x_1	$-K_2x_1$	Kx_1
Per kg pig (P_3=0)	$K_3 / [x_1^2x_3]$	$-K_2 / x_3$	K / x_3

We see that the partial derivatives by each criterion are now proportional. That is, the partial derivatives of P_2 are equal to the corresponding partial derivatives of P_1, multiplied by x_1, while the partial derivatives of P_3 are equal to the partial derivatives of P_1, divided by x_3. Since, as shown above, it is the *ratios* of the economic values rather than their *absolute values* that determine the direction of selection, the economic values are now the same by all three criteria.

3.4. Conclusions on the choice of criteria to compute economic values

Although all of the criteria suggested have advantages and disadvantages, those considered most appropriate were profit and the inverse of economic efficiency. We reviewed the anomaly of Moav (1973) that the relative economic values of different traits are different for different profit criteria. This means that different entities involved in breeding could have different objectives. Accepting the conditions for equality presented above, this problem can now be considered resolved.

In practice rescaling is often not a viable option. A farm may be set to handle a set number of cows. Thus, even if the enterprise is in a positive profit situation, it may not be possible to increase the scale of the operation, even if increasing production per cow would increase both returns and profit. However, these considerations are generally only short-term considerations for individual producers. Thus, overall producers, or for the national interest, it would seem that economic values should be computed either for economic efficiency, its inverse, or a profit criteria which is unaffected by scale and these criteria will result in proportionate economic values for all traits under selection.

3.5. “Empirical” methods for estimating economic values

The methods presented above to estimate the economic values of different traits assume that the simple equations presented are basically correct and that the economic constants in these equations can be accurately estimated. Often in practice neither of these assumptions are correct.

Dickerson (1982) suggested computing the partial regression co-efficients of the individual traits on economic efficiency from a simulation model. The advantages of these "empirical" methods for computing economic trait values are: 1) the economic values will be by definition of linear functions of the trait values; and 2) it is possible to include factors and relationships that may not be readily included in profit equations. The disadvantages are: 1) lack of generality. These methods are applicable only to the sample populations measured or simulated; 2) they do not account for changes in relative economic values due to selection. This is, in fact, the reason why the economic values of some traits are non-linear; and 3) can only be applied if an appropriate data sample is available, or if the parameter values of the simulation are known. Thus, in conclusion, it does not seem that these alternative methods can be recommended over the analytical methods described previously.

4. Long-term considerations

Animal breeding is by its nature a long-term process. For example, some results of the most important breeding decisions in dairy cattle are only realised after ten years. Thus, a number of considerations that may not be important for relatively short-term processes are of major importance for most animal breeding programmes. Furthermore, the different costs and returns in animal breeding procedures are realised at different times and with differing probabilities. Thus, factors that effect costs and returns in the long-term must be considered in the economic evaluations of genetic differences. Long-term consideration will affect both the attractiveness of investment in breeding programmes and the relative economic values of the individual traits included in the selection index. The main long-term considerations of animal breeding programmes are the discount rate, risk, profit horizon and reproduction rates.

4.1. Discounting of costs and returns

The first consideration with respect to discounting of costs and returns is which discount rate is appropriate. Most studies that have discounted costs and returns in animal breeding programmes have used rates of five to 15 percent. Smith (1978) lists three alternative criteria for setting discount rates in breeding programmes. First, d_s, the social time preference rate. This is the lowest rate and is appropriate for minimal risk investments in the national interest, such as building roads, ports, or public buildings. Second, the opportunity cost rate, which is the cost of borrowing in the financial market. The third alternative is a synthetic rate which allows for the returns foregone by diverting capital from the higher return rate to the lower d_s rate, but discounts the returns foregone and the actual returns by the d_s rate. The main causes for divergence between the two rates are due to the effects of inflation, risk and taxes on private investment.

"Nominal" interest rates are strongly affected by the inflation rate. Inflation will affect the nominal values of both costs and returns of a breeding programme. Thus, for breeding programmes it is necessary to correct the nominal interest rate, d_i, by the rate of inflation, d_t as follows:

$$1 + d_i = (1 + d_q)(1 + d_t) \qquad [43]$$

$$d_q = (d_i - d_t) / (1 + d_t) \qquad [44]$$

where d_q is the "real" interest rate corrected for inflation. For moderate rates of inflation d_q can be computed approximately as $d_i - d_t$. Although nominal interest rates have varied greatly over the last century, the real interest rate has remained quite stable in the long-term at close to three percent (Smith, 1978).

In addition to inflation, risk and taxation should also be included in the required nominal rate of return. Considering these factors, the required nominal rate of return, d_r, can be computed as follows:

$$d_r = \frac{(1 + d_q)(1 + d_t) / (1 - d_k) - 1}{(1 - d_x)} \qquad [45]$$

where d_k is the risk, d_x is the tax rate and the other terms are as defined above. Clearly the nominal rate can be considerably higher than d_q, even for relatively low rates of inflation, risk and taxation. For example, if $d_q = 0.04$, $d_t = 0.05$, $d_k = 0.02$ and $d_x = 0.1$; then $d_r = 0.127$ or 12.7 percent. This rate is similar to current nominal interest rates in most developed countries with moderate inflation rates, but considerably higher than d_q, which should approximate the d_s rate discussed above.

4.2. Estimating discounted returns and costs for a single trait with discrete generations

Returns from breeding programmes, unlike nearly all other investments, are *cumulative*. This important distinction will be elaborated with an example. A company invests in a new piece of machinery, which increases the efficiency of production and therefore, the net income of the enterprise. Eventually the machine will either be discarded or replaced. Therefore, this investment will generate additional income for a finite period. We will compare this example to the situation in genetic improvement. Assume that milk production per cow is increased genetically by 100 kg. Once this genetic gain has been achieved in the population, no additional investment is necessary to maintain this gain and contrary to the previous example, this gain will never "wear out" or need to be "replaced." Unless returns are discounted, the same gain in profit is obtained year after year and the total gain from any amount of genetic improvement will tend to infinity. If returns are discounted, the gain of a single cycle of genetic improvement extended to infinity is the minimum acceptable annual return, V, from an initial investment of N with a discount rate of d_r, which is computed as follows:

$$N d_i = V \qquad [46]$$

If V is now taken as the value of one year of genetic improvement, then the cumulative return (R), extended to infinity will be:

$$R = V / d_i \qquad [47]$$

Note that R, return from the breeding programme, has replaced N of equation [46]. If the annual value of a cycle of genetic improvement is US$10 and the discount rate is 0.1, then the discounted value of this gain, year-after-year, to infinity is US$100. Alternatively, equation [47] can be derived as follows: the return from a breeding programme to infinity, will be equal to the sum of a geometric progression of the form $V(r^1 + r^2 + ... + r^n + ... + r\infty)$, where $r = 1/(1+d_i)$ and n is the number of years from the beginning of the programme. The sum, S, of a standard geometric progression of the form Vr^n from n = 0 to n = T-1 is computed as follows:

$$S = \sum_{n=0}^{T-1} Vr^n = V(1-r^T)/(1-r) \qquad [48]$$

Thus, in our case, the net return is computed as S with T = ∞ less V, as follows:

$$R = \sum_{n=0}^{\infty} Vr^n - V = \frac{V}{1-r} - V = \frac{Vr}{1-r} = V/d_i \qquad [49]$$

Generally there will be a lag period of several years until the first realisation of any gain from genetic improvement. This will require a further discounting of returns as follows:

$$R = \sum_{t=0}^{\infty} Vr^n - \sum_{t=0}^{t-1} Vr^n = \frac{V}{1-r} - \frac{V(1-r^t)}{1-r} = \frac{Vr^t}{1-r} = \frac{V}{d_i(1+d_i)^{t-1}} \qquad [50]$$

where t is the number of years until the first return is realised.

Certainly no economic enterprise and not even a government will make decisions now based on returns expected one hundred years in the future. A more realistic alternative is to estimate returns and costs for a given time period, say twenty years, under the assumption that all returns accruing after the "profit horizon" have a current value of zero. Cumulative return will then be equal to the sum of a geometric progression of the form $V(r^t + r^{t+1} + ... + r^T)$, where T is the profit horizon in years. The net return is then computed as the difference of two progressions, as follows:

$$R = \sum_{t=0}^{T} Vr^n - \sum_{t=0}^{t-1} Vr^n = \frac{V(1 - r^{T+1})}{1 - r} - \frac{V(1 - r^t)}{1 - r} = \frac{Vr^t(1 - r^{T-t+1})}{1 - r} \quad [51]$$

Substituting r = 1/(1+d) gives (Smith, 1978):

$$R = \frac{V}{d_i(1+d_i)^{t-1}} [1 - 1/(1+d_i)^{T-t+1}] \quad [52]$$

As T approaches infinity, the term in brackets approaches unity and equation [52] becomes equal to equation [50]. The term in brackets can be used to estimate the proportion of the total returns of a cycle of genetic improvement for a given discount rate and lag time. For example, the "half life" of a cycle of genetic improvement can be calculated by setting this term equal to 0.5 and solving for T with known values for y and d_i. For example, if d_i = 0.03 and y = five years, then the half-life of a cycle of genetic improvement will be 27 years. Thus, if the profit horizon is set at 20 years, less than half of the total gain will be realised within the profit horizon with this particular interest rate. Conversely if d_i = 0.1, the half-life will be 13.3 years with the same lag period and the 90 percent life will be 30 years. For the simple case of t = 1 and T = infinity, the ratio of expected gain for two different interest rates and equal genetic gain can be computed as follows:

$$R_1 / R_2 = d_2 / d_1 \quad [53]$$

where R_1 and R_2 are the expected cumulative gains with interest rates of d_1 and d_2, respectively. In conclusion, for relatively low discount rates, determination of the profit horizon can have a major effect on the expected total gain; while for relatively high discount rate, the difference between a finite and infinite profit horizon will be minimal.

We can now extend this equation to consider an on-going breeding programme with a genetic gain of V each year. The *cumulative* discounted return can then be computed as the sum of a progression of the form $V[r^t + 2r^{t+1} + ... + (T-t+1)r^T]$. The sum of this progression is computed as follows (Hill, 1971):

$$R = V \left[\frac{r^t - r^{T+1}}{(1-r)^2} - \frac{(T-t+1)r^{T+1}}{1-r} \right] \quad [54]$$

for a discount rate of 0.08, a profit horizon of 20 years and first returns after five years, R = 32.58V. For an infinite profit horizon, equation [54] reduces to:

$$R = \frac{Vr^t}{(1-r)^2} = \frac{V}{d^2(1+d)^{t-2}} \qquad [55]$$

Continuing the previous example of a discount rate of 0.08 and y = 5, for an infinite profit horizon, R = 124.04V. Thus, even with a relatively high discount rate, a little bit of genetic improvement goes a long way.

Until now we have been considering additive genetic improvement, which is generally considered to be cumulative. Not all genetic improvement is additive and therefore cumulative. In many domestic species the commercial animal is a cross-bred produced by breeding different lines. Since it is necessary to reproduce the cross-bred for each generation, any gain in efficiency specific to the cross-bred will not be additive. Thus, for cross-breeding we can set T equal to the generation interval. Therefore, with low discount rates, it is much more profitable to utilise additive genetic variance than heterosis. For example, if t = 1 and d_i = 0.03 the net present value of one unit of genetic gain extended to infinity will be 1/0.03 = 33. To obtain the same discounted value by cross-breeding with T = 1, it is required that V/1.03 = 33, or a nominal gain of V = 34 units. This is, of course, an extreme example, but even with T = 10 and d = 0.15, the nominal gain from cross-breeding must be six-fold the nominal additive gain, so that the current discounted values extended to the profit horizon will be equal.

We will now briefly consider the net present value of the costs of a breeding programme under the assumption of constant costs per year. Unlike genetic gain, costs of a breeding programme are not cumulative. With an infinite profit horizon, equation [47] can be used to compute the costs with V replaced with C_c, the annual costs of the breeding programme. For a finite profit horizon, equation [51] can be used to compute the net present value of the costs, C. With first costs in the following year, C is computed as follows (Hill, 1971):

$$C = \frac{C_c r(1-r^T)}{1 - r} \qquad [56]$$

Using the values of T = 20, d = 0.08 and r = 0.926; the net present value of the costs of the breeding programme will be 9.82C_c. Thus, for t = 5, net profit will be positive if V > 0.31C_c. Note that profit can be positive even if yearly costs are greater than the revenue from yearly genetic gain. Again, this is due to the fact that genetic gains are *cumulative*, while costs are not. Extended to an infinite profit horizon, $C = 12.5C_c$. As computed above for this case $R = 124V$. Thus, profit will be positive if $V > 0.1C_c$.

4.3. Dissemination of genetic gain in populations for a single trait

In the previous section we considered the net present value of genetic selection on a single trait expressed once per generation with discrete generations. In this section we will expand the calculations of the previous section to a situation of overlapping generations and multiple trait expressions per individual. Annual genetic gain in the population can be computed as the sum of the genetic gains per generation by the four paths of genetic inheritance; sire-to-sire, sire-to-dam, dam-to-sire and dam-to-dam; divided by the sum of the four generation intervals. However, this equation will be correct only for a well-balanced breeding programme. If a new programme is started, or if an existing programme is modified, there will be a lag before any gain is obtained and then genetic gains will fluctuate around the equilibrium value for several generations. Equations [47] through [55] are correct only under the assumption that the rates of genetic gain and generation intervals are the same along the four paths of inheritance. Generally this is not the case. Fertility rates and therefore possibilities for selection, are generally greater for males, while many important traits, related to female reproduction, are expressed only in females. Due to both biological and breeding considerations, generation intervals are also different along the four paths. Finally, the time and frequency of trait expression can vary.

These last considerations will be explained with the example of dairy cattle. The main traits under selection are related to milk production. To evaluate the net present value of a sire's semen for milk production, we must first consider the probability that an insemination from this sire will result in a milk-producing daughter. If a milk-producing daughter occurs, this cow can have several lactations. It is necessary to account both for the probability that a given lactation will occur and also the differing time lag from the initial investment to realisation. Finally, the daughter will have a variable number of offspring, each of which will receive only half of the genetic compliment passed to the original daughter.

If we wish to compare the net present value of genetic improvement for meat production from the dairy herd, we are faced with an entirely different situation. Generally calves will be slaughtered at the age of one year. Thus, the gain from increased meat production will be realised sooner, but will of course be realised only once. Furthermore, no gain will be accrued in future generations from these individuals, since they will invariably be slaughtered prior to mating. Thus, increasing slaughter rate increases the probability of the realisation of this trait in the short-term, but decreases the rate of genetic dissemination in the long-term. A number of studies have addressed various aspects of these problems. We will first consider the economic evaluation of the genotype of a single individual for a single trait, with a single expression per animal, such as meat production (McClintock and Cunningham, 1974). They called their method the "discounted gene flow technique". Representations require the use of matrix algebra. (Readers unfamiliar with matrix algebra should skip to the beginning of the next section.)

Extending the calculations of the previous section, the net present value of the unit semen from a given sire, N, for a single trait can be computed as follows:

$$N = \mathbf{d}'\mathbf{u}(BV)a \qquad [57]$$

where **u** is a column vector and **d**' is a row vector both of dimension equal to the number of years from insemination to profit horizon; BV, a scalar, is the sire's breeding value for the trait in question; and a, also a scalar, is the economic value of a unit change in the trait. The elements of **u** represent the expectation of the fraction of the sire's genotype that will be expressed in his progeny in a given year. The elements of **u** are computed by multiplying the probability of the trait expression in a given year by the faction of the genome of the original sire passed to each descendant and assessing all possible descendants that could express the trait in that particular year. The elements of **d** are the appropriate discounting factors for the elements in **u**. The j^{th} element of **d**' is computed as follows:

$$d_j = 1/(1 + d_i)^k \qquad [58]$$

where k is the time period in years from original investment to mean trait expression and d_i is the discount rate. Although there is no general formula for computing the elements of **u**, McClintock and Cunningham (1974) provided formulas to compute this vector for the specific situation in their study. We assumed that the trait in question is expressed once a year. If this is not the case, then the dimension of **u** will be the number of different times that the trait can be expressed to the profit horizon over all possible descendants of the original sire and k must be computed accordingly.

For a trait that can be expressed several times by each individual, such as milk or wool production, equation [57] can be expanded as follows (McGilliard, 1978):

$$N = \mathbf{d'Um}(BV)a \qquad [59]$$

where **m** is a column vector of length equal to the possible number of expressions of the trait (lactations), **U** is a year-by-parity matrix and the other terms are as previously defined. If all expressions of the trait have equal value then **m** will be a column of ones. If, as in the case of milk production, lactation yield increases with parity, then one element of **m** will have the value of unity and the other elements will have values in proportion to the “standard” trait expression. The breeding value will be estimated relative to the “standard” trait expression. The elements of **U** are computed by multiplying the probability of the trait expression in a given year-lactation combination, times the faction of the genome of the original sire passed for each descendant and assessing all possible descendants that could express the trait in that particular year-parity combination. As in the previous example, there is no general formula for computing **U**, but McGilliard (1978) provided an algorithm for computing this matrix for the specific example of dairy cattle.

Equations [57] and [59] can readily be expanded to deal with the multi-trait situation. If several traits are expressed jointly, for example, milk, butterfat and milk-protein production, then it is only necessary to replace (BV)a with the aggregate genotype, H = **y’a**, where **y** is the vector of breeding values for the traits included in the index. H is also a scalar. If the different traits are expressed at different times and with differing probabilities, it will be necessary to compute **du**’ or **d’Um** for each trait. We are now confronted with the rather undesirable result that, unless all traits are expressed jointly, the relative economic values of the different traits will depend both on the discount rate and the profit horizon.

We have so far only considered the net present genetic value of a single individual. As we have already noted in the previous examples, generations for most domestic animals overlap. For example, both a cow and her daughter may be producing milk at the same time. Thus, although both records must be discounted equally, the expected genetic gains will be different. Hill (1974) derived general formulas to evaluate the net present value of single trait selection for a complete population with differing rates of male and female selection. These equations will become quite complex for most realistic population structures. It is likely that for most situations a reasonable approximation of the true economic values can be obtained by the equations of the previous section, which assume a constant rate of genetic gain per year. From the results of several studies it can be concluded that in general, the relative economic values of traits are robust to realistic changes in the profit horizon, the discount rate and the probability of income realisation.

5. Economic evaluation of breeding programmes

We will first consider the main cost elements of breeding programmes and then derive equations for the economic evaluation of breeding programmes. We discussed above whether the basis for economic evaluation of traits should be profit, economic efficiency or return on investment. This same question will of course apply to breeding programmes. The general theory has been developed only in terms of profit, although Hill (1971) also considered the criterion of return on investment. This question is more acute for the commercial breeder and will be discussed in some detail.

5.1. Major cost elements of breeding programmes

Traditionally costs of breeding programmes are minimal when compared to increased income or efficiency generated by these programmes. Many costs that traditionally have been considered part of breeding programmes would have accrued in any event, or generate information that has value beyond the breeding programme. For example, the main impetus for milk recording of individual cows was to use this information in progeny tests. However, this information once available is useful to the producer for other farm management decisions. The costs of keeping sires and collecting semen is generally considered a part of the cost of the breeding programme, even though it would be necessary to keep a minimum number of sires and inseminate females, even if no genetic selection was practised.

Until the advent of biotechnology the main cost elements of breeding programmes were measuring and recording traits, progeny testing, maintaining of breeding stock and statistical analysis. The first important technological innovation in recent times was the ability to freeze and thaw mammalian semen without loss of fertility. This made large-scale artificial insemination (AI) economically feasible and resulted in major increases in the rate of genetic gain for large farm animals (Van Vleck, 1981). Although AI has not had a major impact on the direct costs of breeding programmes, other new technologies will. At present multiple ovulation and embryo transplant are becoming economically viable options. In addition, embryo sexing and marker assisted selection are technologically possible. For the first time, the cost of breeding programmes has become a major factor in their economic evaluation.

In breeding programmes for large animals, recording traits are often the major cost of breeding programmes. Although it is now possible to automatically record milk production of each cow, milk samples must still be analysed for component concentration, which is still a relatively costly procedure. Although the main objective of most recording systems is genetic selection, it should be noted that the information recorded also has other uses, such as cow culling and predicting future production. Certain traits are not included in breeding objectives merely because recording is too expensive. The best example of this is feed consumption for large animals. A question of importance is whether breeding programmes should rely on data recorded by individual producers. This data tends to be less reliable then data collected by professionally trained personnel. Furthermore, the producer sometimes has an economic interest in the values recorded for his own animals. In this case, this data will tend to be biased.

For most large animals, female fertility is very limited, even though many traits of economic importance are only expressed in females. Thus, most genetic progress is achieved by progeny testing. A similar situation exists in poultry, in which most selection is based on family, rather than individual selection. Progeny testing can either be performed at regular commercial farms or at specific enterprises dedicated to this goal. In the first case, the cost of progeny testing will be the possible reduction in breeding value by mating to unproven sires, rather than the best sires available, plus an additional factor for risk. It is standard procedure in many countries for AI institutes to pay farmers to inseminate cows with semen from unproven bulls. In other countries, farmers are obliged by cooperative agreements to inseminate a fraction of their cows with semen from young sires. In poultry, progeny testing is generally performed at special stations. The commercial producers then buy breeding stock in the form of eggs from the commercial breeder. Often there is an additional stage in which the commercial breeder sells breeding stock to multipliers who then sell eggs to the general producers.

In species in which the traits of economic importance are expressed chiefly in females, males are maintained only for breeding or for progeny testing. In the absence of genetic selection, it is still necessary to maintain a minimal number of males for breeding, but this number is generally much less than the total number of males that are progeny tested. Only about one in ten progeny tested sires are returned to service as proven sires. Rather than maintain the males, it is possible to collect and freeze large quantities of semen over a relatively short period and slaughter the animals. Thus, the cost of animal maintenance is reduced, but the cost of semen collection and storage is increased

Previously, statistical analysis was a non-negligible cost of most breeding programmes. However, recent advances in computing equipment have rendered the direct costs of data analysis virtually insignificant compared to other costs. The cost of writing new programmes may still be important, but this cost is rarely borne by commercial breeding programmes in any event. Over the past several decades statistical methods have become consistently more complex without regard to the increased cost of analysis.

5.2. Alternative methods to economically evaluate breeding programmes

Similar to the economic evaluation of individual traits, several different methods have been considered to economically evaluate breeding programmes. The long-term profit from a breeding programme will be a function of the discount rate and profit horizon, in addition to the returns and costs of the breeding programme. Thus, one alternative is to assume that the discount rate and profit horizon are fixed and to compute aggregate profit until the profit horizon is reached. Alternatively, since gains in the distant future will have a negligible economic value with any reasonable discount rate, some studies have suggested estimating the cumulative costs and returns of one cycle of selection with a fixed discount rate and the profit horizon set at infinity. Since new breeding programmes generally require large initial investments, a third alternative is to fix the profit horizon and estimate the discount rate necessary to achieve a net profit of zero. Finally, it is possible to fix the discount rate and compute the number of years required to achieve zero net profit.

5.3. Accounting for differential discounting of costs and returns

We will recall that, on the one hand, genetic changes are cumulative and permanent; but, on the other hand, these changes must be discounted and gains that accrue after the profit horizon have zero value. We developed above expressions to compute the net present value of a genetic change for successively more complex situations. We will assume that all costs and returns are discounted to the beginning of the breeding programme. In the simple programme considered above, there is only one product. Thus, the cumulative discounted returns can be computed as in equation [54]. In addition to the return from the breeding programme, Hill (1971) noted that there is an additional "return", R_i, that can be realised by selling possessions belonging to the breeding enterprise at the termination of the breeding programme. (In practice this return is rarely realised, but should be factored into the equation.) Similarly, costs should be divided into initial costs, which need not be discounted and continuing costs, which should be discounted as given in equation [56]. Thus, the net present value of the breeding programme can be computed as follows:

$$P = V\left[\frac{r^t - r^{T+1}}{(1-r)^2} - \frac{(T-t+1)r^{T+1}}{1-r}\right] - \frac{C_c r(1-r^T)}{1-r} - C_i + R_i r^T \qquad [60]$$

where C_c and C_i are the continuous and initial costs, respectively; and the other terms are as defined above. Assuming that $R_i r^T - C_i$ is negligible with respect to the first two terms, this equation can be rewritten as:

$$P = VD_r - C_c D_c \qquad [61]$$

where D_r and D_c are the net present value discounting factors for annual returns and cost respectively. If the profit horizon, T, is extended to infinity, equation [60] simplifies as follows:

$$P = \frac{Vr^t}{(1-r)^2} - \frac{C_c r}{(1-r)} - C_i = \frac{R}{d^2(1+d)^{t-2}} - \frac{C_c}{d} - C_i \qquad [62]$$

with discount rates below 0.1, the profit horizon can have a marked effect on the net profit of the breeding programme.

5.4. Commercial breeders versus the national interest

Although these equations will apply both to a commercial breeder and to the whole industry, the specific values of the parameters will be different. The national market will be more-or-less fixed. However, a commercial breeder can increase his market share at the expense of other breeders. In addition, depreciation of genetic gains will be more rapid for the commercial breeder who must recoup his investment in a relatively short period, as opposed to the national aspect. Furthermore, in a competitive market, the economic value of genetic improvement is likely to be non-linear. That is, if the breeding stock of a particular breeder is below the genetic value of his competitors, it might have close to no economic value, while if the breeding stock is above the level of his competitors, it might have an economic value well in excess of the expected gain to the producer in either profit or economic efficiency.

5.5. Multi-trait breeding programmes

Nearly all breeding programmes consider more that one trait. Although in general genetic progress will be maximised by linear selection index, this does not provide a solution as to the economically optimum multi-trait breeding programme. In addition to the individual economic value of each trait, the different traits may vary as to the time and probability of expression, in which sex the traits are expressed and the cost of recording for the traits. For example, in dairy cattle, milk production is expressed only in females, while beef production is expressed in both sexes. In addition, the main income from beef will be from yearling male calves. Furthermore, milk production is expressed later, but several times during a cow's life, while return for beef production of yearling calves occurs earlier, but only once per individual.

The differential cost of recording various traits is also important. For example, pricing for milk is now generally based on an index of carrier, fat and protein. It is less expensive to measure milk production than fat and more expensive to measure protein than either fluid milk or fat. Thus, in an optimum breeding programme, it is possible that only a fraction of those individuals that are milk-recorded will also be analysed for fat and only part of those with fat records will also be assayed for protein. In addition, it is possible that in the future, many cows will be assayed for individual milk proteins, as these proteins have differential values in cheese production.

Conclusions

Although rates of genetic gain are at most only a few percent per year, animal breeding programmes are very profitable in the long-term. This is because gains obtained by breeding are cumulative and eternal. At present, nearly all major breeding programmes are centred in the developed countries. However, this does not have to be the case in the future. Advanced breeding programmes do not necessarily require large initial investments. Furthermore, the genetic material developed by breeding programmes for high maintenance genetic strains in temperate climates are generally not appropriate to developing countries with tropical or sub-tropical climates. The main difficulty that must be addressed is development of procedures for accurate data collection in conditions of low-input management.

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Case Studies

Case studies. Introduction

The objectives of FAO are to obtain information on specific technical, operational and policy issues and approaches which have an important impact on the successful planning, implementation and maintenance of initiatives to change / improve the genetic component of animal species in various production environments. These case studies will serve as a source of information for the above-mentioned Workshop.

Terms of reference

1. Briefly describe and analyse actual animal genetic improvement programme(s) / scheme(s) (straight-breeding and / or cross-breeding) in which you have been or are directly involved. Do this by identifying in particular those technical and operational aspects of the programme / scheme as well as national and local policies which were important, both in the positive and negative sense, to the implementation and the continued operation and effectiveness of the development.

1.1 The mammalian or avian **species** involved (complete a separate brief for each).
1.2 The **breed(s)** of this or these species which are involved.
1.3 The **approximate overall input level** (low, medium or high) of the production system concerned.
1.4 The **approximate number of animals** concerned.
1.5 Whether the improvement is targeting the **entire breed or only a sector** of it, and where the latter and a system of genetic dissemination is in place, how effective dissemination of the improved genetic material to the rest of the breed population was initiated and sustained.
1.6 The **approach** through which the **breeding goal** was established.
1.7 The **plan designed** to achieve this breeding goal and the plan actually **followed**.
1.8 If the plan to achieve the breeding goal differs from that actually followed, at **what stage** of the development of the programme did the diversion occur, giving the specific reasons for the change.
1.9 **Traits included in the breeding goal**.
1.10 The **selection criteria** followed, in terms of the characteristics actually observed (possibly measured and recorded) and used in making selection and mating decisions.
1.11 The actual method(s) used for the **dissemination** of improved males and / or improved females.

1.12 The population **breeding structure, e.g**. nucleus, stratified population, straight-breeding and cross-breeding. If cross-breeding, how any necessary straight-breds were maintained and improved and how cross-bred replacements were generated successfully on an on-going basis? If a straight-breeding nucleus, was this formed by an initial screening and / or continually open (how was the successful exchange of genetic material maintained between the nucleus and the next level), or did genetic material only move down the structure?

1.13 **Farmer and Government involvement**:
- financial support, initially and in the longer term;
- levels of acceptance of the scheme over time;
- policy development in relation to the implementation of the scheme, i.e. legislation passed, law modified, etc.

1.14 Type and nature of technical **support** during establishment and thereafter, including extension, involved in
- farmer support;
- research and development;
- training.

What actions were successful?

2. What are the main **reasons for introducing** the scheme?

3. What are the most significant activities and design peculiarities that have enabled the scheme to be:
- initiated (what made it really happen)?
- maintained over time?

4. What **changes** should be made now to the design and operation of the scheme to make it more successful, and why?

5. What are the **future** (say over the next five years for smaller species and ten years for larger species) directions for development in design, operation and policy to expand the success of the scheme overtime?

6. State any available estimates of **genetic change** in the population due to the scheme; meaning, overall improvement for cross-breeding schemes or rates of improvement and or change realised to date from straight-breeding schemes. Try to give this in terms of the traits in the Breeding Goal and / or the Breeding Goal as whole.

The open nucleus breeding programme of the Djallonke sheep in Cote d'Ivôire

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National sheep breeding programme

Sheep species

The species involved is the domestic sheep (*Ovis aries*). The species is classified among the thin-tailed hair sheep, within the sub-group of Tropical Dwarf sheep based on fleece and tail types (Epstein, 1971; Mason, 1991). The dwarf sheep are believed to belong to various breeds because of their different phenotypic characteristics related to their breeding areas. However, various authors recognised that there is a unique breed or type from which varieties or strains have progressively developed with differentiation and fixation of characters as a result of the influence of ecological environment and breeding practices (Doutressoulle, 1946; Epstein, 1971). The dwarf trypanotolerant sheep are believed sufficiently homogeneous to be considered as one single population. While the name Djallonké is used in most francophone West African countries, the name West African Dwarf or Guinea sheep is commonly used in anglophone countries. Other names include Fouta Djallon, Mossi or Landin (Epstein, 1971; ILCA/FAO/UNEP, 1979a;b; Bradford and Fitzhugh, 1983; Mason, 1991).

Djallonké Breed

The Djallonké breed is a small, horizontal eared and thin tail hair sheep. The breed is widely distributed throughout the humid and savanna zones of West and Central Africa (ILCA/FAO/UNEP, 1979a). Animals of that breed are compact of small mature height and size. Coat colour varies from spotted black and white to solid black or white. Some tan or brown coat colour and blackbelly are also encountered. Rams are horned but females are usually polled. The presence of mane or neck ruff on the males is a typical characteristic of the breed (Rombaut and Van Vlaenderen, 1976; Charray *et al.*, 1980). The breed is known for its adaptation to tropical humid and sub-humid environments. Although no scientific evidence has been unequivocally provided, the breed is widely believed to be trypanotolerant, mainly because of its ability to live and produce in the tse-tse infested zones.

Management and production systems

Farmers involved in the scheme are in low to medium input production systems. Flock management on-farm varied from exclusive utilisation of natural savanna pasture with little supplementation (private farms) to the use of natural and cultivated pasture with high level of supplementation (state-owned farms).

Sheep population involved

The programme (Programme National de Sélection Ovine – PNSO) was designed to take into account the maximum number of Djallonké sheep raised in the country. However, not all the farms were included in the programme. After several years of extension work, some farmers were chosen, based on their experiences and skills in improved sheep production techniques, to start the selection programme on pure-breed Djallonké sheep.

At the end of 1992, the base population of ewes was composed of 71 farms (including the two state farms), representing 12 000 breeding ewes enrolled in the programme. Of these ewes 76 percent were from private flocks and 24 percent from the state-owned farms. In March 1999, 143 farms were involved in the programme, which represents 17 000 breeding ewes (88 percent from private farms and 12 percent from state farm).

The flock of selected rams maintained at the PNSO Headquarters performance testing station is considered to be the nucleus. The station holds selected rams only. There is no ewe in the nucleus flock on-station. The ewe flocks are those of the farmers. The size of the nucleus was of 153 breeding sires in 1992. Since then it has fluctuated between 180 and 200 breeding sires. Every year 100 to 120 second category rams are sold to farms not in the selection base.

Targeted breed

The targeted breed is the entire Djallonké breed. All the farms involved are instructed to breed only Djallonké ewes and to eliminate from their flock animals showing Sahelian sheep type phenotype. The choice of the Djallonké breed is the number one requirement to participate in the programme. The dissemination of the selected rams is so effective that the number of second category rams produced every year is not enough to supply the demand.

Approach to establish the breeding goal

The breeding goal was established based on results obtained from a study on the performance of the Djallonké sheep both on-farm (Rombaut and Van Vlaenderen, 1976; Rombaut, 1980, Van Vlaenderen *et al.*, 1980) and on-station (Poivey *et al.*, 1982). The objectives of the programme were to improve growth and live weight of pure-breed Djallonké sheep and provide sheep farmers with improved breeding stock.

The PNSO programme was initiated in 1983 with farmers involved in the extension service since 1977. These farmers were recognised to be capable of keeping records of their flocks, correctly identifying their animals and following the prophylactic programme of the Ministry of Animal Production and supplementing their animals during critical periods. The enrolled farms consisted of private (smallholders and companies) flocks receiving technical assistance from extension services and two state farms.

The plan designed and followed

The structure of the PNSO is composed of one central performance evaluation station for rams (the nucleus) and farmer flocks of only breeding ewes (the base population). The number of flocks (breeding ewes) fluctuates from year to year, as new flocks enter the base and some leave. Selection is on the male side only. The initial rams in the nucleus in 1983 were from the two state farms and the research station where selection for high growth rate was already in practice. Farmers in the base population use the selected rams from the nucleus for mating. In return ram lambs in those farms are brought to the nucleus for evaluation and eventually selected to be sire. The outline of the structure, showing the gene flow is presented in figure 1.

Selected breeding rams maintained at the central station in Bouaké were brought to the farms for a mating period of about 45 days. After each mating, rams returned to the station for a minimum rest period of two months. Each ram was culled after three years of mating in rotation from one farm to another. Ewes were mated every eight months to a group of sires in a ratio of 30 to one with the number of sires in a group varying from one to 13. Replacement females were produced within the farmer's flock. However, farmers were allowed to purchase ewe lambs from other PNSO farmers.

Period of diversion

- For economic reasons, since 1987, farmers have taken on the responsibility themselves for the endo- and ectoparasite controls;
- By 1987 the practice of zero-grazing was stopped for animals of 180 days of age on-station. The change from zero-grazing to savanna pasture was made in order to allow ram lambs to get used to grazing on natural pasture, the most common management practice in smallholder flocks where they would later be used;
- Despite precautions taken to prevent disease outbreak, a serious case of ovine brucellosis in 1990 caused more than 50 percent of the rams breeding stock to be culled. Consequently, almost all ram lambs entering the central performance evaluation station in 1990, were kept as sires.

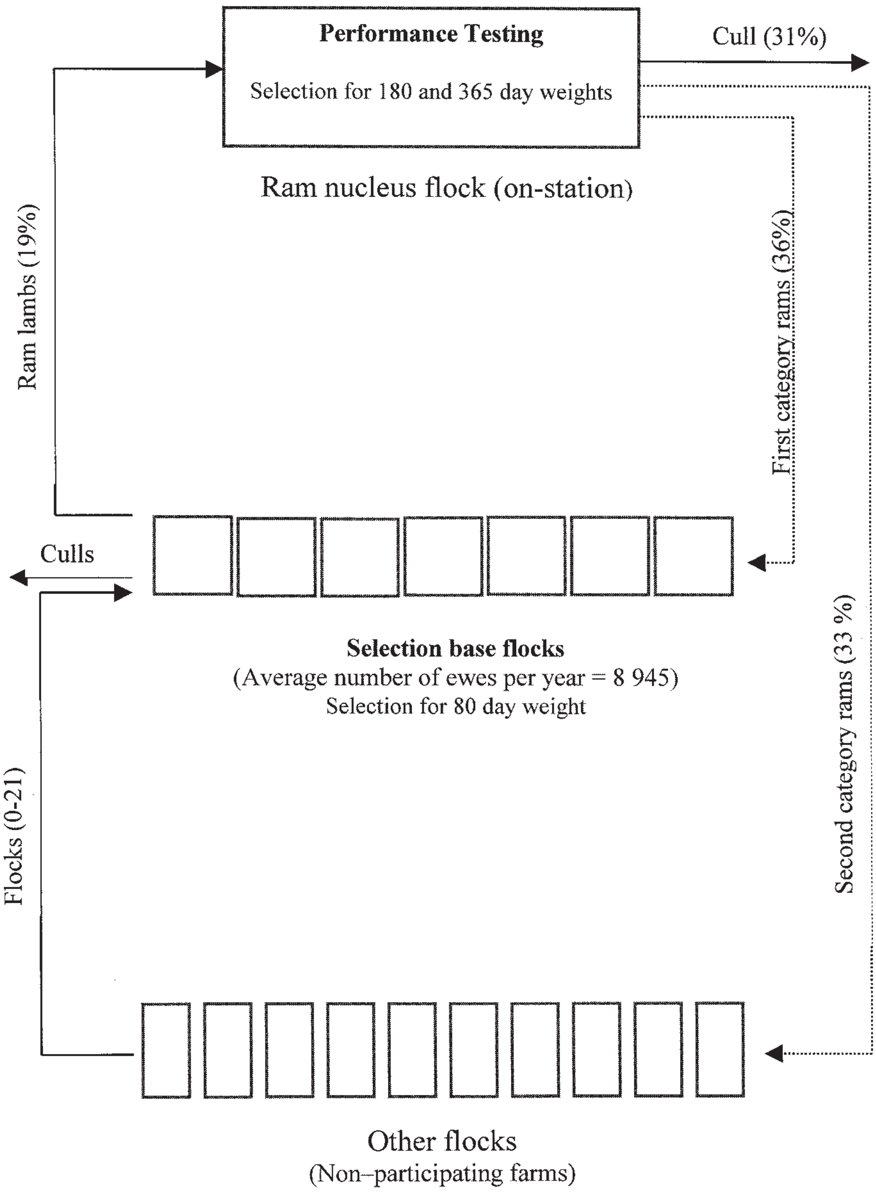

Figure 1. Outline structure of the national sheep selection programme.

Additionally, 79 rams were bought from farms outside the selection base population (only in 1990) in order to maintain mating schedules because of insufficient number of breeding sires.

Traits included in the breeding goal

On-farm 80 day weight

All ram lambs born on-farm in the base population flocks are candidates for selection. Two to three weights of each lamb born in the selection base were recorded and used to estimate 80 day weight. The first weight was taken when the first born lamb reached about 80 days of age. Subsequent weights were taken at about 23 day intervals. Male lambs were selected based on their 80 day weights linearly extrapolated using recorded weights.

On-station 180 and 365 day weight

Ram lambs selected from the base flocks were brought and maintained at Bouaké central performance testing station to go through further selection at two ages: 180 and 365 days of age. Animals were weighed three to four times over a period of ten to 12 weeks and their 180 day weights linearly extrapolated. Selected rams continued to be monitored with a second series of three to four weights until they reached 12 to 14 months of age. Their 365 day weights were then calculated and the final selection made.

Selection criteria

Rams were selected based on their individual live weights measured at 80, 180 and 365 days of age.

On-farm 80 day weight

Ram lambs having a weight equal to flock average plus one standard deviation were selected. In practice lambs having a weight greater or equal to 13 kg were selected. Non-selected ram lambs were castrated. Selected rams are bought by the programme from the farmers and transferred to the central performance testing station in Bouaké to be selected for the nucleus flock.

On-station 180 day weight

Rams with 180 day weights less than 20 kg were culled. From 1987 rams with weights greater or equal to 23 kg were classified as first category rams; those with weights between 20 and 23 kg, were classified second category rams.

On-station 365 day weight

After the second series of three to four weightings, selected rams that reached 12 to 14 months of age had their 365 day weights calculated and the final selection made. The truncation point for first category rams at 365 days of age, was 35 kg and for second category, between 30 and 35 kg. Only rams of more than 35 kg enter the nucleus flock to be used as breeding sire in the base population. Any ram with a weight below 30 kg is culled.

Dissemination method

Selected first category rams, the top ranking rams, were distributed to the selection base flocks. Matings were scheduled from the programme Headquarters in Bouaké to ensure that only selected rams were used for breeding. Second category rams were sold to non-PNSO farmers.

Breeding structure

The breeding strategy follows that of an open nucleus breeding scheme with selection based on individual performance. The selection scheme included three phases: on-farm pre-selection phase, on-station first selection phase and on-station final selection phase followed by the distribution of selected rams to farmers for mating. The selection yielded two categories of rams: first category rams used in base flock matings and second category rams sold to non-PNSO farmers.

Farmers and Government involvement

Up to 1998 the Governments of the Ivory Coast and France and the EEC through the European Development Fund, provided funding for the selection programme. Since 1999 the programme is funded by the Government of the Ivory Coast.

Farmers involved in the programme were required to have a property right on the land where their farm was located and easy access to a water source (river or agro-pastoral dams). The farm had to be accessible by car for the extension workers. Farmers were taught how to build night enclosures, shelters, collecting yards, sorting pens with traditional local material and footbaths. They were also instructed on how to castrate unwanted rams, to identify lambs at birth and to keep records.

A national commission on domestic ruminant genetic improvement was set up based on the experience of the PNSO programme.

Technical support

The technical assistance offered by the extension service consisted of organizing sheep producers in rural areas, promoting and rationalising private or communal sheep enterprises, encouraging villagers to establish new flocks using improved techniques and organizing the production and marketing of slaughter animals. In addition, the technical assistance collaborates with the veterinary health service in the vaccination, once a year, of farmers' flocks against major and the oversees prophylactic programme for endo- and ecto-parasites.

Farmers contributed to the programme by selling their selected ram lambs to be monitored until the final selection process. They offer their farms as field training laboratories for future candidates who are in the process of establishing their sheep farms. In the long run farmers will take over the management of the programme and will be responsible for looking for funding.

The contribution of the research institution has been the estimation of breeding values of the animals in the selection programme and the development of correction factors for some traits. About 98 percent of the lambs are born of unknown sires in groups of two to 13 sires. Prior probability that a progeny is out of a sire was used in the estimation of the breeding values. The research contribution is published by Yapi-Gnaoré *et al.* (1997 a,b).

Reasons for introducing the scheme

The drought of 1972-1973 in the Sahel, brought changes in Government policy towards livestock development. During the drought most countries were no longer able to keep up with rising demand for animal products of coastal West African countries for example the Ivory Coast. The Government, concerned with the future of livestock supplies of the country, declared animal agriculture as a high priority sector for development with emphasis on short or medium reproductive cycle species (MPA, 1976). A long-term campaign to promote livestock production throughout the country was launched by the Ministry of Animal Production through one of its extension agencies SODEPRA (Société pour le Développement de la Production Animale), with a mandate to initiate in 1977 a national sheep programme in the central region. One of the major objectives was to select and provide farmers with improved breeding stocks of Djallonké sheep throughout the country.

Significant activities

The desire of the farmers, most of who are smallholders, to move from traditional husbandry practices to new improved management techniques, has been the major factor that has keep the programme going. In addition, extension officers have been closely involved in all aspects of the programme since the beginning and financial support was available and non-interrupted.

Changes to be made to design and operation

- The use of single sire mating is necessary in order to obtain an accurate estimate of genetic changes. So far the programme was based on group mating. The proportion of lambs born of unknown sire was very high. Most lambs had unknown sire because of the sire group mating. The percentages of lambs born of unknown sires were 6.9, 55.7 and 60.6 in the analysis of 80, 180 and 365 day weights, respectively.

- Correction factors were derived. It would be worth trying to use them in the evaluation process. Lambs and rams were evaluated based on their own performance without any correction for non-genetic factors such as birth type, season or month of birth, ewe age or parity on-farm and on-station.

- There is a need to maintain high selection pressure throughout the year. It is more than likely that selection pressure has been declining over the years. Several rams were inappropriately selected. On average 28.1, 20.6 and 52.1 percent of ram lambs selected at 80, 180 and 365 days, respectively, had weights below the respective truncation points. The high demand for breeding sires sometimes forced the use of inferior ranking rams or even non-tested rams. When ovine brucellosis occurred among selected rams, most of them were culled (Oya, 1990). Four farms recognised as having the best performing rams, have been used since last year (1998) as test multiplier farms.

Future directions

The national commission on livestock genetic improvement and some funding agencies recommended that farmers themselves managed the breeding programmes. Farmers are being organized into cooperatives for each species and breed. For the Djallonké breed, a farmers' association called APRODJALCI (Association de Producteurs de Djallonké de Côte d'Ivoire) has already been created. This association is taking an active part in many forums related to livestock genetic improvement.

The Livestock Research Station in Bouaké of the Centre National de Recherche Agronomique (CNRA) has been designed to provide scientific back up and serve as a genetic evaluation centre to the national genetic improvement programme for all species.

Genetic changes

Genetic changes were estimated using data from 30 farms on the PNSO programme recorded from 1983 to 1992. Lamb breeding values were averaged over year of birth. Phenotypic values were obtained by deviation of year mean from overall mean. Phenotypic and genetic trends were obtained by regression of annual phenotypic and breeding values on year of birth using 1983 or 1984 as the base year.

Lamb weights at all ages were the lowest in 1989 and subsequent years. There was an average decline in phenotypic trend from 1984 to 1992 of the weights at 80, 180 and 365. Breeding values increased at rates of 28±18.7, 11±5.8 and 14±3.2 g/year for 80-, 180- and 365 day weight, respectively. These increases represented respectively, an annual progress of 0.28, 0.05 and 0.04 percent of the base year. Although the results of the analysis did not indicate a large rapid genetic progress for the Djallonké weight, the genetic trend was positive, in the desired direction. The genetic analyses indicated that genetic value was maintained or slightly increased during the period of selection. On the contrary, the environment has been significantly deteriorating over the years, causing a significant decline in phenotypic value.

This low selection response of the PNSO should not be counted as a failure. Although the data analysed was collected over a ten year period, it represents only three to four generations of selection. The selection programme was designed as a development project with farmers being the primary target. Results cannot expect to be like one that can be achieved theoretically or on an experimental station.

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Improving subtropical Egyptian fat-tailed sheep through cross-breeding with the prolific Finnsheep

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Background

Finnsheep (F) are well characterised by their high prolificacy, fertility and early sexual maturity. In the sixties and seventies, Finnsheep were introduced to many temperate countries and a few subtropical ones amounting to some 40 countries in different continents (Maijala, 1984). Different reviews clearly showed that the high fertility of Finnsheep for both males and females has expressed itself in various countries and has proven to be heritable in different genetic backgrounds. On the other hand, growth rate, carcass traits and survival rates, especially for pure F were not satisfactory. Maijala (1984), summarised the results of different cross-breeding trials involving Finnsheep as follows: an increase of 1 percent in F blood was associated with an increase in litter weight weaned/ewe mated by 1.4 percent and lambs born/ewe mated by 1.2 percent.

Egyptian sheep are subtropical fat-tailed sheep characterised by satisfactory fertility and ability to breed all year round, but have low prolificacy and growth rate. The Nile-Valley Ossimi (O) and Rahmani (R) breeds have a conception rate of more than 80 percent when bred once/year and over 70 percent when bred every eight months (Aboul-Naga and Aboul-Ela, 1985). Their prolificacy ranges from 1.15 to 1.25/ewe. The population of the two breeds is about 2.5 m head raised mainly by small farmers in mixed farming systems in flocks of three to ten head and fed on agro-by-products with some fodder supplement, whenever available, e.g. low to medium input production system. Active breeders in the villages are shepherds who own 30–100 head and keeping rams. Income from raising sheep by small farmers is mainly from their lamb production; lambs are usually marketed after weaning (3-4 months) and the market price is determined per head.

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Cross-breeding trial

The trial was initiated early in the seventies by the Animal Production Research Institute, Ministry of Agriculture (MOA).

Breeding objectives

The breeding objectives were to increase the prolificacy of Ossimi and Rahmani breeds usually raised in small farm conditions, yet keeping their ability to breed all year round, in other words, improve number of lambs weaned / ewe / year. There was no formal study to set the breeding objectives and their numerical economic values. The breeding objective of increasing litter size was decided based on the research workers' intuition.

Net income of small holders in full cost feeding conditions was estimated as 1.89 percent for a twining rate of 1.15 (average twining rate for local breeds), 7.74 percent for a rate of 1.25 and doubled to 16.2 percent for twining rate of 1.40 percent (Shehata, 1996).

Breeding plan

The Plan was to cross the local ewes to the imported Finn rams. The first cross ewes and rams were backcrossed to the local to produce a quarter Finn, three-quarters local (¼ F ¾ L) from each breed group. The ¼ F ¾ L cross was either *inter se* mated for some generations, involved in selection programmes for improving number of lambs weaned / ewe / year and establishing a new breed type with better lamb production, or utilised as a dam breed to be mated to terminal sire (Suffolk Cross, which is available at MOA) to produce fat lambs. The ¼ F ¾ L lambs were thought to be suitable for the local conditions based on the following criteria:

- their prolificacy would not be too high and twin born lambs can be managed easily by small farmers;
- they can stand the prevailing environmental conditions better than higher Finn crosses;
- the ewes will retain from their local parents, the ability to breed all year round;
- lambs produced have a recognisable fat tail, which has a consumer preference; and
- the genotype could easily be propagated using the ½ F rams produced in nucleus flocks on state farms or the breeders' flocks. One imported ram is estimated to produce three to four thousand ¼ F ewes in the breeders' flocks over five to seven years.

The last criterion is crucial in large-scale development programmes in order to improve lamb production from local sheep. The production plan does not involve artificial rearing of the lambs or hormonal treatment of the ewes. Later on, the component of using terminal sire on ¼ F ewes was excluded from the breeding plan, as the results were not encouraging and were impractical in small farm conditions.

The trial was carried out at Sakha Animal Production Research Stations starting in 1974 utilising four Finn rams, imported through an FAO project (UAR 49). With the encouraging on-station results of the Finn crosses, this was later followed by the importation of successive batches of Finn rams and ewes from Finland in collaboration with FINIDA (40 rams and 24 ewes). The Finn ewes were imported only for experimental work.

All Finn cross-bred ewes were mated every eight months, as were the local ewes. The mating seasons were September, May and January, each lasting for 35-45 days. All the Finn rams were mated naturally to the fat-tailed local ewes after a training period of copulating with the fat-tailed ewes.

Reproduction performance of Finn crosses

Aboul-Naga *et al.* (1989) reported data from eighteen successive seasons (5 589 records). The pure Finn ewes showed the lowest fertility (e.g. ewe lambed / ewe exposed), on the other hand, they were able to maintain their high prolificacy in subtropical conditions (2.43 lambs / ewe lambed). Lamb losses, however, were so high that Finn sheep had a lower advantage over the local breeds in number of lambs weaned / ewe exposed / year (Table 1).

The first cross ewes had significantly higher prolificacy than the local breeds by 0.37 and 0.30 lambs / ewe lambed for FR and FO, respectively. The ¼ F ewes were significantly more prolific than their respective locals. They gave birth to 0.11–0.19 more lambs and weaned 0.07–0.17 more lambs / ewe lambed than the local breeds. The advantage of ¼ F ewes over the locals was more detectable in annual lambs weaned / ewes exposed to range from 0.27 to 0.50 / lambs / ewes yearly.

Table 1. Reproductive performance of Finn crosses with Egyptian sheep breeds three times/two years.

Breed group	EL / EE*	LB / EE	LB / EL	LW / EL	LW / EE / year
F	0.50	1.26	2.43	1.71	1.32
R	0.72	0.92	1.31	1.17	1.23
FR	0.77	1.27	1.68	1.46	1.65
R . FR	0.80	1.11	1.42	1.27	1.50
FR . R	0.80	1.11	1.44	1.28	1.49
(¼ F . ¾ R) 2	0.76	1.06	1.40	1.24	1.40
O	0.68	0.81	1.22	1.08	1.08
FO	0.75	1.11	1.52	1.35	1.47
O . FO	0.72	1.00	1.41	1.25	1.34
FO . O	0.80	1.02	1.34	1.81	1.37
(¼F . ¾O) 2	0.65	1.26	1.42	1.19	1.38

* EL: ewe lambed; EE: ewe exposed to ram; LB: lambs born; LW: lambs weaned

The ¼ F groups were slightly less prolific than the first cross and detectably of better fertility. Their performance was better than expected, assuming a linear relationship with a proportion of Finn blood.

The *inter se* mating group of ¼ F ¾ R was of slightly lower fertility than their parents. Meanwhile they gave birth to 9 percent more lambs than the R, and in the end had an advantage of 17 percent for the annual number of lambs weaned compared to the local counterparts. Similarly, the (¼ F ¾ O) 2 ewes showed lower fertility than their parents, but weaned detectably more lambs than the local O ewes.

Although Finn crosses showed good ability to breed every eight months, their reproductive performance varied greatly from one season to another. September mating showed significantly better performance among different Finn crosses. Lambs weaned / ewe were 1.7, 1.29 and 1.22 from autumn, winter and summer matings, respectively.

Adaptability of Finnsheep and their crosses

As expected, Finn ewes showed detectably lower tolerance to prevailing hot conditions than the local sheep and showed higher physiological response than their half-sibs raised in Finland (Aboul-Ela *et al.*, 1987).

Physiological parameters for ½ F were much closer to the local sheep than to the Finn. Those of ¼ F were almost similar to the local, which indicate their good adaptability to the prevailing subtropical conditions.

Fattening and carcass performance

The results of a series of fattening trials showed that the cross-bred lambs attained a slaughter weight of 40 kg two months earlier than the local lambs. They also had better carcass performance, however, local carcasses were leaner, most of their fat being deposited in their fat tail.

Genetic Components: Utilising the estimates of genetic components to predict the performance of synthetic Finn crosses, Mansour and Aboul-Naga (1988), showed that their performance was somewhat less than that expected from additive contribution of F genes. Deviations from the expected means were higher in the F_1 than with back crosses. Such discrepancy in expectation for the high Finn crosses was attributed to early embryonic mortality in highly fecund ewes in subtropical conditions, and may also have been due to limited nutrient capacity inherited from their local parents. They indicated positive individual heterosis in the breeding activity of F cross-bred ewes.

On-farm trials

With the encouraging experimental results on ¼ F crosses, batches of ½ F rams (30) were sold to shepherds in two Nile-Delta provinces (Sharkia and Ismalia) during the period 1982 to 1992 to produce ¼ F ewes and rams and to disseminate them to randomly chosen small farmers.

Furthermore, 14 pure-bred Finn rams were distributed to large breeders having >50 lambs and interested in breeding activities, to investigate the possibilities of producing ½ F rams commercially.

A parallel programme was initiated in 1983 to provide 67 small farmers with three to five ¼ F ¾ L ewes plus one ram on a two year easy credit in the context of a rural development programme. Preference was given to small farmers having two to four local ewes to ease the breed group comparison.

Periodic visits were carried out to breeders to follow-up the performance of ¼ F cross in breeders conditions and for economic and financial evaluation of input/output relationship.

Performance of Finn crosses in farmer conditions

As expected ½ F rams performed much better than the pure Finn ram, especially when they were raised outdoors with shepherds (58 percent conception rate versus *26* percent*)*.

The ¼ F ewes raised with small farmers for two to seven crops and running with ¼ F rams all the time, have lambing intervals of 295 days versus 305 days for local ewes (Table 2). The number of lambs born/ewe/year averaged 1.65 for Finn crosses with a clear trend to augment with increase in age. Lambs weaned/ewe/year were 0.20 higher than the local ewes (Metawi, 1996). The advantage in litter size of ¼ F increased with age and with decrease in flock size. The weight of cross-breed lambs at four months of age was higher for small farmers than large herds. The litter size did not affect lamb's weight at marketing. Farmers preferred the ¼ F lambs' meat as it was better than the local lambs due to their low fat content.

The author added that performance of cross-breed ewes varied greatly between small holders and was directly associated with availability of feed stuff over the year.

Table 2: Reproduction performance of ¼ F ewes in small farm conditions.

Trait	Local	¼ Finn
No. of records	457	630
LB/EL	1.23	1.34
LW/EL	1.05	1.17
Lambing interval (day)	305	295
Age at first lambing (day)	537	558
LW/EE/Yr.	1.26	1.45

Biological and economic evaluation

Almahdy (1996) in a simulation study evaluating the biological and economic efficiency of Finn crosses versus the local ewes, in two different management systems, found that crossing with Finn has improved both biological and economic returns from local sheep. Biological efficiency (TDN / E) was significantly improved by 9.3 percent for one crop / year and 11.7 percent when production was three crops / two years. Economic efficiency (GM / E) was highly improved by 63 percent and 83 percent under the two systems of mating, respectively.

Table 3: Biological and economic evaluation of ¼ Finn Crosses under different management systems.

Breeding Group	One Crop/year		Three Crops/Two years	
	TDN/E	GM/E	TDN/E	GM/E
L	14.2	65.9	15.3	62.5
¼ F	12.5	107.6	13.0	114.3

Meanwhile, the financial analysis of the on-farm data by Metawi (1996) showed that the IRR increased from 14 percent for local flocks to 18.2 percent from cross-breed flocks. One of the factors affecting IRR was the weaned lamb sale price on the market, which was in favour of the local lambs due to the size of the fat-tail. Price difference was significant in the Sharkia Province, while insignificant for the Ismalia Province. Price differences were modified when lambs were fattened before marketing.

Lessons learnt

- Cross-breeding programmes involving crosses with specific breed combination are difficult to sustain at the farmer level. A range of combinations should be envisaged, e.g. in the present programme a 12-37 percent range would be allowed and probably investigated rather that the 25 percent F genetic;
- A structure must be established to guarantee the flow of the desired genotypes. In the present case, non-sustainability evolved as it depends mainly on state institutions to provide the exotic genotype;
- Enhancement of improved cross-breeding genetic material should be accompanied by access of breeders to inputs, e.g. regular availability of feed stuff;
- Phenotypic characters of local breeds involved in the consumer preference and consequently in market price, should be taken into consideration in the cross-breeding programmes with exotic breeds;
- A lower portion of the exotic temperate blood seems more suitable for crosses in subtropical conditions.

Breeding plans involving more than two breeds are not recommendable for small farmers in developing countries.

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NORFA: The Norwegian-Egyptian project for improving local breeds of laying hens in Egypt

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Introduction

The present case study deals with a large-scaled poultry research and training project performed at the Faculty of Agriculture, Menofyia University, Egypt, in close cooperation with the Department of Animal Science, Agricultural University of Norway.

The idea of starting a research and training project with the aim of improving the local breeds of laying hens in Egypt was suggested during the second author post graduate stay at the Department of Animal Science, Agricultural University of Norway (AUN), in 1977-1978. The project planning, such as scientific layout, the breeds that should be included, the facilities needed and the design of the buildings required, etc. were discussed and finally decided upon during the year 1978 before it was introduced and later approved by The Norwegian Agency for International Development (NORAD), who agreed to offer financial support for the first five years of the project period.

In the early spring of 1980 all the facilities, equipment, machines, etc., required for the experiments to be started were sent from Norway to Egypt. Before this the Faculty of Agriculture, Menofyia University, Egypt, (MUE) had decided to offer all the financing needed for buildings and other facilities, which were ready for use at the time the shipments arrived in Egypt.

Aim of the project

Egyptian indigenous chickens have the advantage of being well adapted to the local stressful conditions in the province; high temperature, serious disease problems, poor farming hygiene and unbalanced diets. Another "advantage" of the indigenous chickens claimed by the local consumers is the good taste and flavour of the products coming from the local breeds. On the other hand, the indigenous chickens have very low egg production performance compared to exotic breeds and hybrids.

Based on this basic knowledge it would be desirable to combine the advantages of local breeds, especially their good adaptation ability and the special taste and flavour of local eggs and chicken meat, with the high egg production performance of the highly developed strains. The more applied aim of the project, not outlined in the original design, was to improve the egg production of the well-adapted indigenous chickens at the farmer and small chicken holder level in the Menofyia Province.

Another important goal was to attract attention to and improve the general knowledge of different aspects of poultry improvement under low to medium input level conditions.

Outline of the project

The first step of the project was to establish a base population. This was done by crossing two local breeds (Fayoumi and White Baladi) with two high performance lines of the White Leghorn breed imported from Norway (L2 and L7). From the base population and through systematic selection, the principal aim was to develop new strains with acceptable adaptability and reasonable good production performance. The breeding and selection scheme of the project may be illustrated as follows:

Year	Indigenous breeds			Imported breeds (Norwegian
1980	Fayoumi (F)	W. Baladi (B)	x	White Leghorn L1 White Leghorn L7

1981 — 2 - way crosses

1982 — 4 - way crosses

1983 — 8 - way crosses

1984-85 — Base populations/Random mating

1986 — Selection Programme based on individual and family data

High egg no (EN) | High egg weight (EW) | Control (C) | Fayoumi Control(FC)

EN x EW | C | FC

1999 — (ongoing)

The most important traits directly considered in the selection programme were egg number, egg weight and body weight. A selection index technique was applied based on parameters obtained in the base population. Since 1994 various selection indexes such as “Two-stage Selection Index”, “Restricted and Reduced Selection index” and “Index including feed efficiency”, were applied, mainly because they produced data for scientific studies and training.

Approximately 3 000 birds were included in the project per year, and the original plan designed to achieve the goal was actually followed throughout the experiment and up to the present stage. In several meetings and conferences throughout the years the results obtained were discussed and some corrections made. A Panel Meeting about the NORFA Project and a Round Table Meeting were arranged in 1992 and 1997, respectively.

The two local breeds included in the project, *Fayoumi* and *W. Baladi*, are the two most frequently used local breeds for egg and poultry meat production in the province. The high performance lines, *L2 and L7*, were closed egg production lines imported from Norway, L2 selected for high egg number and L7 selected for high egg weight. The “new breed” developed from this synthetic population was named *Norfa*.

Conclusions

Native Egyptian hatcheries, constructed of sun-dried bricks, still play a significant role in supplying the farmers with day-old chicks. These hatcheries produce more than 65 percent of the day-old chicks in the villages.

Improvements in fertility and hatchability

Experiments carried out to compare the fertility and hatchability of eggs from the experimental strains and controls and further to compare results obtained in artificial incubators and in native Egyptian hatcheries, were expected to establish differences between genetic groups and to give an idea about how much is to be gained by using modern hatching machines to produce day-old chicks.

The results showed minor differences in fertility and hatchability between the genetic groups, but the difference between artificial and native hatcheries showed that there is a lot to gain by using artificial incubators, or as recommended by Abdou (1997), supply the owners of native hatcheries with cocks from improved lines to increase fertility and hatchability.

Testing NORFA-chickens on farms

One important aspect of the NORFA-project was to evaluate the genetic potentialities of the NORFA-chickens at practical farm level. Therefore, several tests were performed on small farms in the neighbourhood of the Research Centre at the Faculty of Agriculture, on other university farms and at locations outside the province of Menofyia. In general the tests showed promising results. The NORFA layers produced considerably more eggs than the local birds did, and the fertility and hatchability of the eggs were good. The conclusion was that even though the NORFA layers are still below the commercial hybrids as far as egg production is concerned, the NORFA layers proved to be very suitable to the villages where poor management in general prevails, due to their high adaptability to the local environment. On average the NORFA-layers exceeded the local birds in egg production by approximately 25 percent .

Research and training

The NORFA project was very well utilised for training and research purposes (see later) and all the equipment, machines and battery cages are still in good condition and their function is good. Moreover, computer units with modern computer programmes provided from Norway and later on from the Faculty of Agriculture, were successfully utilised in all the research activities carried out under the project. This transfer of technology and general knowledge may be regarded as one of the most important parts of the project.

Transfer of improved genetic quality to practise

Even though there was not a full-fledged scheme worked out in the original design for disseminating the hopefully improved stock into practise, there was a strong intention to include this issue into the overall plan. After a period of scientific research the project was meant to serve the small farms in the province with improved chickens for egg and poultry meat production. Regrettably, it has to date, not been fulfilled, mainly because of lack of resources. To overcome this problem there was an urgent need to establish an office for poultry extension in the Department of Animal and Poultry at the Faculty of Agriculture. An extension officer who is specialised in this field will undoubtedly be able to relay on helpful information and support to the small holders.

Financial and technical support

The final year of the five-year period of financial support from The Norwegian Agency of International Development (NORAD) was 1985. From this time the Faculty of Agriculture, MUA, has financed the project completely with its own funds. The authorities of the University and the Faculty of Agriculture have always very sincerely encouraged the project and kindly offered all the finance needed for the buildings and other facilities. Several of the staff members competent in different sectors of poultry science, have been very helpful and have done an excellent job since the initial stage of the project.

Scientific papers and training

The on-going project has played an important role as an arena for studies for a large number of undergraduates as well as for postgraduate students. The number of students at all levels doing their practical part of the different poultry production courses during the academic year 1998/99 was close to 500.

The following set up gives a survey of the number of PhD. and MSc. degrees obtained using data from the project as a basis for their dissertations. It also shows the number of scientific articles produced since 1980, most of them published in scientific journals, others are to be found in congress proceedings or in seminar reports:

PhD granted 5
PhD in progress 6
MSc. granted 12
MSc. in progress 3
Scientific articles published 52
Scientific articles in progress 3

Reasons for introducing the activity and what we learned

As mentioned in the introduction of the present case study, the idea arose during Prof. Abdous, the second author, two years post-graduate stay at the Department of Animal Science, ANU. Through very close scientific cooperation within the field of poultry genetics and production systems we very soon went into the problem of genotype-environment interaction and adaptability to various environmental conditions. From this point the idea very soon became reality.

This kind of cooperation between scientists and universities very often creates ideas. However, there is often a long way to go from idea to reality. In our case we were happy to get the support we needed to accomplish our ideas.

Nowadays the trend in developing countries is to import commercial hybrids and improved breeds of chicken. Some of the modern technology needed to satisfy high performance of these chickens is also imported including some feed ingredients, vaccines, etc. In most cases these imported breeds of chickens are lacking necessary adaptation to the local environment. Moreover, they are not resistant to the serious endemic diseases to which native chickens are genetically resistant. Therefore, if we were to start again we should take the following points into consideration:

- Adaptive quality
- Natural resistance to some serious diseases
- Selection under stressful effects

Three methods to improve native chickens are:

a. Importation of improved breeds to produce only F_1 for each generation.
b. After crossing exotic with native breeds a selection programme should be started to develop a new breed. The selection programme must include all important and relevant traits regarding the specific local conditions.
c. Systematic and long-term selection within native breeds.

A lesson from the present poultry breeding trends seems to be that there is an urgent need for establishing gene banks for indigenous chickens in developing countries. This is because indigenous chickens no doubt possess some advantages in their genetic potential that will be of great importance in the future. Lack of adaptive qualities of the different exotic breeds introduced to tropical and subtropical countries followed by reduced egg production performance, seems to be a matter of fact. According to Katule (1998) it seems to be more advisable to transfer the technology of chicken breed improvement than to transplant breeds to developing countries.

We have also learned from the present research and training project based on close cooperation between Egypt and Norway, that an experimental centre (centre of competence) like the one established at the Faculty of Agriculture, Menofyia University, is of great importance for the successful development of knowledge within the field of animal husbandry, both scientific and applied, in a less developed country.

National rabbit project population of Ghana: a genetic case study

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Summary

The National Rabbit Project (NRP) of Ghana, West Africa, is an internationally recognised programme. For several decades, the NRP has served as a model role to the lesser developed countries (LDC) as a means to alleviate national meat shortages by providing appropriate breeding stock, training, extension support, *etc*., to limited-resource farmers. The rabbit population at the NRP is highly heterogeneous, based on the original introduction of some sixteen exotic breeds which have been inter-crossed with local stock since 1972. In general, exotic breeds represented genes for improving production traits while the local population possessed genes for adaptation. Early cross-bred generations of rabbits reproduced and developed well at the NRP station in local conditions of climate, outdoor housing, forage-based diet, simple management, *etc*., as opposed to exotics which generally fared poorly. Cross-breeds (F_1 animals) were reported to be “thrifty and fast growing.” Distribution of cross-bred stock to farmers in villages was and continues to be successful. By 1975, the population size was 4 000 breeding rabbits. The NRP did not employ a station geneticist, so breeding goals and the selection programme were not clearly defined. However, production trait performance of the NRP stock has been at least comparable to that of other rabbit populations maintained in the LDC in adverse environmental conditions. In 1989, a formal USAID project was established between the NRP and Alabama Agricultural & Mechanical University (AAMU) entitled “Development of a Synthetic Tropical Rabbit Breed”. This closed, nucleus population was genetically characterised throughout this project activity. Individual 90-day body weight data were collected from 687 rabbits representing 61 sire and 194 dam families in two consecutive generations. Paternal half-sib estimates of heritability for first and second generations were 0.41 ± 0.19 and 0.43 ± 0.18. In the past ten years, the NRP has continued to provide genetically appropriate stock to farmers; however, utilisation as a practical and sustainable means of genetic conservation largely takes place in villages.

History of rabbit rearing in Ghana and the national rabbit project

The domestic rabbit was introduced into Ghana by missionaries well over a century and a half ago. Congregations under their parishes were encouraged to raise rabbits on a backyard basis since rabbit meat was the only known meat which had no known taboos as to its consumption either on religious or ethnic grounds (Opoku and Lukefahr, 1990). In addition, rabbits were easy to handle by women and children, feeding and management practices were simple and locally sustainable, and a plentiful (albeit inexpensive) meat source was secured. Rabbit rearing on small farms has spread throughout the country.

In recent decades, Ghana's demand for agricultural food products has been greatly dependent on importations which have contributed to its foreign exchange debt. In early 1972, the Government of Ghana (GOG) was approached by Mr Newlove Mamattah (the then Liquidator of the Centre for Civic Education), who had been a backyard rabbit breeder for thirty-seven years. The GOG had the goal of establishing a viable, diversified and growing agricultural sector as a basis for economic and social development and food self-sufficiency (Technoserve, 1975). Furthermore, the GOG was keenly aware that many low-income families could not afford to include animal food products in their diet because of national meat shortages. The small-scale, self-reliant model of rabbit production ("Rabbits for Food for the Millions"), as proposed by Mr Mamattah, convinced the GOG to invest 160 000 cedis (at the time equivalent to US$184 000) as a Government equity contribution to create the National Rabbit Project (NRP). Mr. Mamattah was appointed as the NRP's first director. The NRP was established at Kwabenya on 32 ha of land, some 15 km north of Accra, with the following original aims and objectives (Technoserve, 1975; Opoku and Lukefahr, 1990):

- to encourage and enable Ghanaians to take up backyard rabbit breeding as a means of providing adequate meat for their family table at costs lower than those prevailing on the market and to encourage the development of private commercial rabbitries;
- to provide improved foundation stock for sale to backyard breeders by a scientific programme of cross-breeding and up-grading of local rabbits;
- to carry out research in order to develop a rabbit husbandry system specifically appropriate to conditions in Ghana;
- to provide field extension services which would assist backyard breeders in acquiring the technical knowledge necessary for carrying out viable breeding programmes and applying improved husbandry practices; and
- to serve as the nucleus for the development of a Ghana Rabbit Breeders association which will serve as a guide for information and services between the NRP and individual breeders.

The NRP is wholly owned by the GOG with the original intention of making a modest return on its investment. By 1977 the first national census figure of 13 948 rabbits from registered breeders was reported (Anonymous, 1979). By the end of 1979 the NRP had released over seven thousand rabbits for both breeding and consumption, including meat supplied to departmental houses, restaurants and hotels (Opoku and Lukefahr, 1990). The GOG's strong interest and financial support of the NRP and the dynamic leadership of Mr Mamattah, largely accounted for the early success of this unique programme. Mr Mamattah was also most active in publicising the NRP by participating in international rabbit conferences and workshops, providing radio interviews and publishing reports in scientific journals achieved through collaborative ventures (Mamattah, 1978; Owen, 1981). In 1976 the first World Rabbit Congress was held in Dijon, France, where the World Rabbit Science Association appointed Mamattah as Secretary for Developing Countries. Mr Mamattah's legacy stemmed from his tireless promotion of small-scale rabbit production for the LDC as a means of hunger and poverty alleviation. By the late 1970s, Mr Mamattah had retired and a new director was appointed (Mr Eugene Opoku).

NRP population background

In 1972 eighty local rabbits were used as foundation stock for the NRP. Foundation animals were purchased from backyard breeders throughout the country. Between 1972 and 1984, several hundred rabbits of various breeds: Alaskan, Blue Vienna, Californian, Champagne D'Argent, Chinchilla, Checkered Giant, Creme D'Argent, Danish Giant, Danish White, Dutch, Flemish Giant, French Lop, New Zealand White and Thuringer, were generously donated or provided to the NRP, GOG, by the Governments of Denmark, Switzerland and the United States (Lukefahr *et al.*, 1992). It was Mamattah who requested the importation of exotic breeds. The aim was to procure "good quality, beefy-giant types for crossing and up-grading the local animals" (Technoserve, 1975), despite the fact that these standard breeds were developed in temperate environments and were predominantly from and selected in commercial and (or) fancy herds. However, by 1975 the initial population of 80 rabbits had increased to nearly 4 000 rabbits.

Unfortunately, the imported breeds were reported by Opoku and Lukefahr (1990) to acclimatise rather poorly (e.g. low fertility and depressed growth) to the stressful tropical environment in Ghana, in agreement with previous studies (Damodar and Jatkar, 1985; Matheron and Dolet, 1986; Sundaram and Bhattacharyya, 1991) involving comparable breeds and environments. For example, in 1980, the Danish shipment involving 1 349 does and bucks resulted in only 54 litters born by exotic does in the following two years. Nonetheless, rabbits continued to be propagated, largely through exotic male x local female matings, cumulating in several F_1 lines to produce cross-bred stock for both farmer distribution and for the NRP as replacement stock (Table 1). Gradually, F_1 lines were pooled, mainly through *en masse* random matings among individuals in the population. In local conditions of climate, fresh forage feeding with limited supplementation and simple management at the NRP (similar to small farmer conditions), straight-bred exotics were eventually lost due to poor adaptation and (or) low reproduction and survival success (N. Mamattah, personal communication). In contrast, while F_1 and the subsequent composite populations were observed to be generally thrifty, rapidly growing and fertile, no experimental comparisons were made between composite and local rabbits to determine the extent of genetic improvement. Nonetheless, when cross-bred stock were distributed to farmers in villages (purchases by private treaty), breeding and growth performance were quite satisfactory (Lukefahr, 1998).

Table 1. Exotic and cross-bred mature stock inventory in 1975 at the National Rabbit Project in Ghana[*].

Exotic breed	Surviving exotics		Born in Ghana Exotic		Born in Ghana Cross-bred	
	bucks	does	bucks	does	bucks	does
Alaska	7	0	0	1	9	9
Blue Vienna	20	4	6	12	22	24
Californian	3	1	0	0	0	0
Champagne d'Argent	6	2	0	2	1	1
Chinchilla	3	1	0	0	0	0
Checkered Giant	2	1	0	0	0	0
Creme d'Argent	9	1	6	7	0	1
Flemish Giant	3	1	1	0	10	18
French Lop	2	1	0	0	2	1
Thuringer	15	4	1	11	3	3
Total	70	16	14	33	47	57

[*]A total of 120 animals from Switzerland was shipped between 1973 and 1974.
Source: Technoserve (1975).

From 1984 to 1989 the period following initial exotic stock introductions, the breeding objectives and programme were not entirely clear for the heterogeneous, composite NRP population. However, based on interviews, there is evidence that replacements were selected if they had impressive 90-day, market weights (E. Opoku, personal communication). Also, closely-related matings (e.g. full-sib, half-sib and parent-offspring) were avoided and generations were over-lapping. In 1990 the population was characterised as having light mature body weight, small litter size and slow growth rate (Opoku and Lukefahr, 1990), although typical for local populations of rabbit found in both arid and tropical geographic regions of the world (El Amin., 1978; Finzi *et al.*, 1988; Lukefahr, 1988). However, by 1990 the NRP population had been downsized to as low as 30 and 150 breeding bucks and does, respectively, due to budget cuts from the GOG.

This population continues to exemplify remarkable phenotypic diversity in both qualitative (e.g. coat colour and pattern) and quantitative characters (e.g. adult weight, body conformation and litter size), as would be expected for a population with such a heterogeneous background. Production trait statistics, based on analyses of NRP data, are shown in table 2. Whereas litter survival rates are high from birth to 90 days of age, means for litter size are small, which may reflect the light mature body size of the stock (2 667 and 2 350 g for does and bucks) and (or) the adverse tropical environment. Within-trait variation was largest for litter size characters, intermediate for litter weights and survival rates and smallest for individual 90-day body weight.

Genetic characterisation project

In 1989 a research project directed by the author, entitled “Development of a Synthetic Tropical Rabbit Breed”, involved a collaborative venture between Alabama Agricultural & Mechanical University (AAMU) and the NRP, Ministry of Agriculture. In the same year, the USAID funded project was formalised via a Memorandum of Understanding. The research programme was aimed at genetically characterising the composite

Table 2. Production Trait Statistics for the National Rabbit Project Population in Ghana.

	Descriptive Statistics*			
Trait**	Mean	SEM	PSD	CV
Total litter size born	4.90	0.189	1.72	35.2
Percentage live births	98.2	0.79	7.2	7.3
Litter wt at 21 d, g	881	21.3	195	22.1
Litter size weaned (56 d)	3.81	0.147	1.34	35.2
Litter wt at 56 d, g	2596	73.6	618	23.8
Preweaning survival rate, %	83.0	1.86	16.8	20.2
Individual wt at 90 d, g	1355	23.8	202	14.9
Postweaning survival rate, %	87.8	2.06	18.8	21.4

*N = Data consisted of 92 litters born with 313 kits surviving to 90 d of age.

**Mean = least-squares mean, SEM = standard error of the mean, PSD = phenotypic standard deviation, and CV = co-efficient of variation. The model included sires (n=25), batch (n=4), and the residual term (df=64).

Source: Opoku and Lukefahr (1990).

population, which by this time was considered as a straight-bred population. In addition, AAMU sponsored a post-graduate, M.S. student, who specialised in rabbit breeding and genetics (Atakora 1992). In 1992 the candidate returned to the NRP, as the NRP director, to provide project leadership and genetic expertise.

According to the research study protocol, the NRP stock was randomly grouped into sire and dam families in a hierarchical experimental design (e.g. dams were nested within sires). All matings were made at random except for close relatives. On a within-litter basis (n=92 litters), offspring produced in the first generation were randomly selected as parents to produce progeny for the second generation. As an indicator trait of the heterogeneous population, data on individual 90-day body weight were collected over two consecutive generations (birth years were 1989 and 1990) from 687 rabbits representing 61 sire and 194 dam families. Paternal half-sib estimates of heritability for first and second generations were 0.41 ± 0.19 and 0.43 ± 0.18 (Lukefahr *et al.*, 1992). These estimates also confirm the heterogeneous nature of the NRP population because literature estimates of heritability are generally lower. In agreement, Moura *et al.* (1997) reported heritability of 0.48 for average daily gain (56 to 84 days) involving 1 446 rabbits from a four-breed composite population in Hawaii.

In addition, based on the assumption of an additive genetic model, table 3 presents fractions (upper limit) of common litter variance (V_{EC} = 0.16 and 0.18) and residual, within progenies environmental variance (V_{EW} = 0.43 and 0.39) for first and second generations, respectively, using methods described by Falconer and Mackay (1996). Alternatively, by relaxing the former model, upper limit estimates of dominance genetic variance (V_D = 0.57 and 0.52 in first and second generations) were obtained by setting V_{EW} to zero (Table 3). Of course, it is quite unlikely that V_{EW} was zero in this population. In the latter case, corresponding lower limit estimates of common litter variance (V_{EC} = 0.02 and 0.05 in first and second generations, respectively) were calculated. Perhaps the most useful knowledge gained from the variance component analysis was the high heritabilities and the narrow range of estimates for the common litter variance of 0.02 and 0.16 for generation one, and 0.05 and 0.18 for generation two, respectively. Common litter and (or) maternal effects appeared to be small in full-sib families.

In retrospect, a conservative estimate of the number of breeding males and females could be 30 and 150 animals. This would relate to a projected effective population size of 100 animals and a maximum rate of inbreeding of 0.5 percent per generation. To determine the extent that genetic response for 90-day body weight could or might have occurred, the following calculations are made. On average, a breeding doe would be expected to produce eight litters over a production lifespan of two years. Each litter would contain five offspring. Assuming equal sex ratio, this would relate to 1 / 20 or 5 percent doe selection rate. To account for attrition and culling,

Table 3. Within-generation estimates of causal components of variance for 90-day body weight (g) from the National Rabbit Project in Ghana, according to genetic model.

		Causal variance components*			
Model**	Generation	V_A	V_D	V_{EC}	V_{EW}
I	First	0.41	0.00	0.16	0.43
	Second	0.43	0.00	0.18	0.39
II	First	0.41	0.57	0.02	0.00
	Second	0.43	0.52	0.05	0.00

* Components expressed as fractions of total phenotypic variance.

** Model I assumes an additive genetic (V_A) model with upper limits for common (V_{EC}) and residual (V_{EW}) environmental effects, whereas Model II assumes an additive and dominance (V_D) genetic model with upper limits being estimated for V_D and lower limits for V_{EC} (V_{EW} set to zero).

Source: Lukefahr *et al.* (1992).

a 10 percent replacement rate is figured (i_f = 1.755). If breeding males remained in the herd for one year, on average, then 150 does producing 600 litters would relate to 1 500 male offspring. Selecting 30 male offspring would be a selection intensity of 2 percent. To be more conservative, the 2 percent figure is doubled (i_m = 2.154). The average selection intensity is 1.955. Heritability was estimated at 0.42 and the phenotypic standard deviation was 221.9 g. Generation intervals for males and females are figured at 1.5 and 1 year of age, respectively (age at first mating is six months). Using phenotypic, mass selection, the selection accuracy is the square root of heritability, which is 0.65. Predicted genetic response per year is 146 g [10.8 percent of the population mean of 1 355 g (Lukefahr and Opoku, 1990)]. Hence, it appears that the NRP had (has) the opportunity to realise rapid genetic improvement if this is deemed as the breeding goal.

Appropriateness of cross-bred stock for farmers

As elucidated by Lukefahr (1998), the maintenance of a heterogeneous population ("non-standard breed") which is locally adapted may have real merit in adverse environments, despite the conventional wisdom that local rabbit populations in LDC are genetically inferior. A high degree of heterozygosity or heterosis might be important for fitness-related characters (e.g. fertility and survival) as a means of eventual local adaptation (Falconer and Mackay, 1996). Obviously, the NRP population, in the breeding history and (or) conditions previously specified (e.g. foundation of some sixteen breeds [including a local breed], production of several F_1 lines and inter-crossings of these lines), should be highly heterozygous with a preponderance of desirable candidate genes for adaptation and production traits. Theoretically, the level of retained heterosis could be as high as 94 percent if all sixteen original breeds contributed equally to the composite population. Further, it is plausible that multiple alleles or polymorphism at relatively more loci than as found in other populations, many genes being found at close to intermediate frequencies, may largely account for the higher heritability (0.41 and 0.43) for 90-day body weight than is generally reported in the literature. In addition, genetic progress is likely to have occurred at two levels: first, that immediately realised from initial cross-breeding (infusion of genes for production), and second, from subsequent, within-population selection involving, no doubt, both artificial and natural selection (producing desirable gene combinations for adaptation and production). By the early to mid 1990s, it was considered that the NRP population was essentially a locally adapted, straight-bred population appropriate for small-scale farmers in low input conditions in Ghana.

From the perspective of the small farmer, the ultimate user and steward of rabbit genetic resources, NRP stock is observed to be prolific, growth and tractable, which explains their popularity and high demand. In addition, these rabbits appear to be anatomically and physiologically sound in many regards as these qualities presumably pertain to relative efficiency of reproduction, growth, longevity, etc. from a genetic adaptation point of view. For example, such qualities include lengthy ears, thin fur density, large body surface area, wide foot pads, good fertility even during hot months and high forage intake capacity. These non-traditional characters may have real merit as potential selection criteria and may have been the basis for indirect genetic gains achieved through selection for increased 90-day body weight. This breeding philosophy varies from the traditional selection approach involving measures on production traits (e.g. litter size, growth rate and carcass yield). More research in this area is certainly warranted.

Unfortunately, this novel straight-bred population has yet to be formally inventoried into FAO data banks. In general, locally adapted populations as opposed to exotic or upgraded straight-breds may be more amenable for inclusion in genetic resources data banks and for effective conservation. This approach is in contrast to frequently observed attempts in other countries to reintroduce and conserve exotic straight-breds or regular outcrossed lines at breeding stations which may well not be adapted or appropriate for small farmers. As a composite breed, only *inter se* matings are necessary for farmers to maintain the genetic integrity of this population, largely provided that numbers remain adequate.

Fortuitously, through stock utilisation in villages in subsistence conditions, small farmers have played a major role, albeit unplanned, in effectively conserving this novel rabbit population. For many farmers, stock has been purchased only once. Other farmers have purchased stock even on a regular basis. However, in either case there has been no known re-introduction of stock from farmers into the NRP population. The village cooperative breeding scheme simply has involved a two-tier structure. The NRP population is managed at both levels, therefore. Since farmers mate their rabbits as straight-bred animals, the breeding system is sustainable from a genetic management standpoint considering the large number of rabbits (e.g. tens of thousands) that have been distributed and maintained by farmers across villages. Fortunately, this figure certainly far exceeds the estimate of the effective breeding population size of 100 animals at the NRP. Hence, the breed has largely been genetically conserved and maintained by farmers under low input systems.

Conclusions

Since 1972 a very conservative estimate of over 37 000 Ghanaians having been directly assisted by the NRP through stock provision, training, visitation, etc., has been reported (Opoku and Lukefahr, 1990). This success, in part, is attributable to the direct support of the GOG, the dynamic leadership and expertise of the NRP founder, Mr N. Mamattah and later on to formal NRP staff development and graduate training in breeding and genetics. From a genetic standpoint, the success is also due to the suitability of appropriate rabbit breeding stock from the NRP which, for nearly 30 years now, has continued to be distributed to and in high demand by farmers.

In retrospect, some of the original breeds representing exotic introductions to the NRP (e.g., Alaskan, Crème D'Argent and French Lop) might have been excluded since they are fancy breeds, they would have offered few desirable genes for production. Also, the imported breeds could possibly have been procured from more similar, tropical environments to have enhanced the chances for survival and (or) genetic adaptation.

It would be desirable if the NRP was to continue measuring conventional production traits (e.g. body weight and litter size) but also anatomical and physiological characters (e.g., body surface area, ear length, forage intake capacity and fur density) which may be more closely connected to a genetic adaptation. Knowledge on the extent that these traits are genetically correlated would be very useful and of ultimate benefit to farmers.

In addition, it would also be useful to compare the present NRP straight-bred population to local rabbits (if still to be found) for traits of importance to small-scale farmers. From a genetic management standpoint, it would be desirable to allow outstanding animals from farmers to enter the NRP nucleus population. With an estimated effective population size of only 100 animals, the NRP needs not only to allow genes from outstanding animals to be infused, but also to at least double the breeding population size at the NRP. Of course, the former will require close collaboration between NRP staff and farmers, clearly defined breeding objectives, performance recording and genetic evaluation systems, etc. The latter will require an increase in staff, feed and supplies and operation budget.

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D'man sheep breeding programme in Morocco

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Introduction

D'man is an important sheep breed of Morocco. It acquires its importance from its exceptional reproductive performances and its high adaptation to the oasian environment. The D'man is known as one of the most prolific sheep breeds in the world (2.2) and one that does not exhibit seasonal anestrus. It is a small sheep with a fine bone structure and a narrow head. Females are characterised by a slightly curved profile. Rams present a convex profile and sometimes a skin fold on the forehead. Presence of horns is an undesirable trait in this breed. The legs of D'man breed are slender and often defective because the animals are raised in confinement, which makes them unsuitable for extensive management on rangeland. The fleece is coarse in texture and of various combinations of one, two or three colours: black, brown or white. Mature ewes and rams are 30-45 kg and 50-70 kg, respectively (Boujnane, 1996).

D'man traditional husbandry

There are approximately 240 000 head of D'man sheep in Morocco (Ait Hroch *et al*., 1997; Benlakhal and Ben Ouardi, 1997). They are found mainly south of the Atlas Mountains in the Draa, Dadès, Ziz and Ghériss valleys. D'man sheep are an essential component of the oasian farming system in Morocco. They convert oasian forages (alfalfa and grasses) and by-products (straw, culled dates and ground date pits) to meat for home consumption (42.5 percent) and cash (Khiar, 1987). They also provide manure for intensive oasian agriculture. Herd size in the traditional D'man farm (0.8 hectare) is around ten head (three to four ewes). This size varies with forage availability. Prolificacy and year round breeding constitute important adaptation traits allowing high flexibility and potentially rapid herd increase.

Traditional husbandry of the D'man sheep in Morocco is characterised by low input and minimal attention to flock management. The typical situation of a flock found in the oasian farms is characterised by:

- inadequate barns with no separation between animal categories;
- inadequate nutrition;
- year-round lambing (no grouping);
- frequent mating between related animals;
- young age (< 8 months) and low weight of ewes at first lambing.

These management practices lead to depressed fertility, high lamb mortality and low growth rates (Darfaoui, 1992).

Developmental history and future strategy

Efforts to improve the management of this breed were started in the late 1970s by INRA (*Institut National de la Recherche Agronomique*) and continued by the same agency along with the two regional agencies for agricultural development in Tafilalet and Ouarzazate (ORMVA: *Office Régional de Mise en Valeur Agricole*). The agronomic and Veterinary Institute Hassan II (IAV Hassan II, Rabat) and the National Agriculture School of Meknes also contributed through research.

Early experimental phase

The first D'man breeding programme was initiated by INRA in the early 1970s (Bouix and Kadiri, 1975). It concerned three herds composed of animals purchased from the region and gathered in three research stations. INRA aimed to conserve the D'man breed, which seemed threatened by droughts and mismanagement and to evaluate its performance under improved management. Selection programmes were initiated in the three stations with the objective of maintaining ewes' prolificacy rate at high levels and increasing lamb growth rate at least to the level of the remaining national breeds. Experimental animals were eartagged and their sires, dams and birth dates were recorded as well as lambs' birth weight and weights at standard ages (10, 30 and 90 days weaning age). These data were utilised for selection, but no adjustments for environmental factors were made.

Results of early experiments showed that with improved nutrition, housing and reproduction, D'man prolificacy was increased from 1.66 to 2.16. In addition, daily weight gain of lambs between ten and 30 days of age and between 30 and 90 days increased from 155 to 175 g and from 145 to 167 g, respectively. Animals produced during that early period by the INRA and the Sekoura station, established in 1972 by the ORMVA of Ouarzazate as a nucleus of a future breeding programme (ORMVAO, 1981), were distributed to selected farmers at a subsidised price. Evaluation of the impact of this action showed an improvement in the prolificacy of traditionally managed ewes (Table 1). The impact of the operation on animal weight gain, however, was not evaluated. Important extension and feed subsidy efforts were invested by ORMVA to improve management of the flocks with distributed animals. Since no genetic gain estimates were made, it is impossible to separate the portion of the increase in the phenotypic traits attributed to genetics and that to the environment. Nevertheless, the positive outcome of this first experimental phase captured the attention of the Ministry of Agriculture and its agencies, as well as interested farmers. The D'man sheep had shown promising production potential, but needed further research and development.

Table 1. Improvement of traditional flock prolificacy as a result of the introduction of improved animals.

Herd category	Prolificacy
Improved herd	2.16 - 2.31
Traditionally managed herds including improved animals	1.91 - 2.00
Traditionally managed herds	1.23 - 1.67

Source: ORMVAO (1981)

Initiation of a straight-breeding programme in the oasian system

Beginning in the mid 1980s, the National Sheep Development Plan (*Plan Moutonier*) designated pure-breed husbandry regions and allocated regions for cross-breeding programmes. D'man straight-breeding plans were adopted in both the Draa and Ziz valleys. Cross-breeding experiments were then started by INRA and the Agronomic and Veterinary Institute (IAV Hassan II) in different stations on the west coast and in the Tadla region.

A three-strata plan was adopted in each of the Draa and Ziz valleys in 1986. Each plan was composed of a nucleus, a group of elite-animal multipliers, and the remaining D'man raisers (Figure 1). One association of 70 farmers and six cooperatives composed of a total of 240 adherents, were founded in the Draa and Ziz valleys, respectively. These farmers were organized to establish groups of multipliers of the elite animals produced in the three stations belonging to INRA, the ORMVA of Tafilalet (for the Ziz valley) and the ORMVA of Ouarzazate (for the Draa valley). Cooperative and association adherents were chosen among farmers who were the most open to innovation, had consented to build adequate barns, and most willing to manage their herds according to extension technicians advice. Each cooperative and association group (eight groups) was assigned one technician to monitor their livestock, take records and provide necessary advice. In each of the valleys an engineer (master level) was in charge of the programme and coordinated the work. Improved animals produced by multipliers were to be disseminated to the rest of the non-organized farms. The approach adopted in both valleys for D'man sheep genetic improvement was similar, however, there was very little collaboration between the agencies involved and no exchange of animals between nuclei or among multipliers of the two valleys. Movements of animals took place only within each valley and mainly downward (Figure 1). Association and cooperative adherents within each valley were, however, encouraged to exchange selected animals.

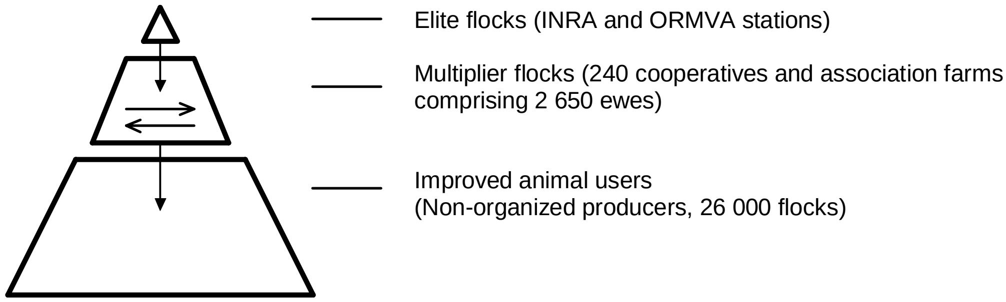

Figure 1. Structure of D'man sheep straight-breeding scheme.

This breeding plan was conducted between 1986 and 1994. Cooperative and Association breeders produced a large number of rams and ewes during that period (12 672). Selection was aimed to improve prolificacy and weight at 180 days and to eliminate horns. In practice, animals were eartagged and selected based on dam prolificacy, phenotype and conformation. There were several attempts to keep weight records for a more accurate selection, at least on the most advanced farms, but the task was difficult and was never done on a regular basis. At the station level, however, selection was carried out on the basis of dam's performance and individual standard weights. No adjustments were made for environmental factors.

A diagnosis of the situation performed by the ORMVA of Tafilalet in collaboration with the INRA and GTZ (Ait Hroch *et al*., 1997), showed improvement in the D'man performance in cooperative herds (Table 2). Herds of non-organized producers, however, continue to record lower prolificacy and lower growth rates (Table 2). The increase recorded in performance of nuclei and multiplier flocks is due both to genetic progress and improvement in management. To date, attempts have been made to estimate the genetic gains in these animals.

Table 2. Performances of D'man sheep at different levels of the breeding plan.

Parameter	Station flocks	Co-operative flocks	Non-organized flocks
Lambing interval (days)	240	210	250
Fertility rate (%)	95	92	86 - 97
Young Mortality rate (%)	9	12	16 - 25
Prolificacy (%)	227	212	153 - 186
Weaning weight (kg live weight)	20	14	10

This phase of establishment of the straight-breeding programme resulted in increased interest among farmers as well as public agencies and national professional associations such as the ANOC *(Association Nationale Ovine et Caprine*) in D'man sheep breeding. Until 1994 elite animals were produced in the three stations in both valleys. After that date, the ORMVA of Tafilalet closed its station for managerial reasons and the ORMVA of Ouarzazate transferred its station to be managed by the Draa valley D'man Breeders Association. At the present time only two stations (nuclei) continue to exist, the INRA station in the Ziz valley and the Sekoura station in the Draa valley. Each station raises approximately 80 to a 100 ewes. As a result of this first phase, multipliers in both valleys evolved in three different categories. The first category consists of farmers (10 percent) who specialise in D'man breeding and who raise between 30 and 70 ewes per flock. An intermediate category consists of farmers who raise ten to 30 ewes. The third category (50 percent) consists of farmers who continue to adhere to a cooperative or to an association to benefit from subsidised feed, but for diverse reasons (i.e. insufficient funds, unavailability of space to build a barn) never succeeded in initiating selection in their small flocks.

A drawback in the programme was that the non-organized farmers, who represented more than 90 percent of the D'man sheep raisers, continued to be ignored by the development agencies and benefited very little from animals produced by multipliers. The lack of concern for these non-organized farmers has been the most significant weakness in the D'man sheep breeding and development programme implementation to date. According to the Agricultural Investment Code, selected and subsidised rams and ewes are raised at least four years by their producers (multipliers) or sold to other farmers. However, most of the improved animals ended up at the slaughterhouse or as a sacrifice on the Aid Al Adha (Moslem holiday) instead of improving non-organized farmers' flocks. No monitoring was conducted to determine the proportion of these animals maintained at the multiplier level or that disseminated, as initially planned, in the non-organized farms.

Intervention of the ANOC

The *Association Nationale Ovine et Caprine* (ANOC), created in 1967, is a non-governmental organization in charge of organizing sheep and goat genetic improvement programmes and contributing to the development of the sheep and goat industry at national level in Morocco. In 1997 the ANOC was monitoring 27 groups composed of 1 500 sheep and goat producers. The total number of sheep raised by the ANOC breeders was approximately 550 000 head (307 400 ewes), belonging to six national breeds (Timahdit, Beni Guil, Sardi, Boujaad, Beni Hassan and D'man). The work of the ANOC with goats is in its inception. Only 80 goat breeders raising 2 000 does, associated in two groups, were monitored by the Association at the end of 1997 (ANOC, 1997).

Interest by the ANOC in D'man sheep started in 1994. Before that date, small herds of D'man represented little potential in the eyes of this Association. The results of the development work accomplished by the ORMVA agencies and the INRA lead to the appearance of farmers specialised in D'man sheep breeding and to the emergence of flocks of medium size (ten to 60 ewes). Both factors encouraged ANOC to start a selection programme in the largest and best managed herds (45 in the Ziz valley and 15 in the Draa valley). The ANOC objectives for this programme were to produce highly performing rams and ewes for increasing meat production in the oasis system and to augment prolificacy in the cross-breeding programmes. ANOC organized two groups. one in each valley. The two groups consisted of 135 producers. ANOC now carries out selection in 60 of the herds adhering to its programme based on the same criteria as previous ORMVA agencies. The same number of animals are selected and subsidised each year. It is important to note that ANOC's involvement in the breeding programme has initiated exchanges of animals among breeders in the two valleys. The exchanges are most prevalent at the multiplier category level. ANOC has today become a part of the D'man sheep straight-breeding structure that continues to run with a slightly increased efficiency than before. It has chosen to invest its efforts in selection, leaving ORMVA agencies and INRA to concentrate on improving flock management on the farms, diffusing the genetic progress within the base flocks and conducting research programmes.

ANOC also plans to establish a multi nucleus breeding system by producing elite animals in the most advanced flocks on the basis of indexes expressing the combination of dam lifetime performance and individual lamb performance. For this reason ANOC technicians have recently started keeping more accurate and regular weight records in five flocks in the Draa valley and five flocks in the Ziz valley. ANOC feels that this work is necessary and that nuclei flocks should be managed by private farmers as is the case for the other national sheep breeds.

Financial support and policy development

Several agencies have contributed to the financial support of the D'man sheep breeding programme, including the Ministry of Agriculture, via ANOC, ORMVA of Tafilalet, ORMVA of Ouarzazate, INRA and ANOC. Funding comes from a Government budget, NGOs (ANOC) or through loans facilitated by International funding institutions to local or national agencies. Additional investments are needed to ensure for continuous development of the D'man breeding sector. Better coordination among participating agencies and institutions to make the best use of available funds will provide improved opportunities for more achievements.

Encouragement for selection has been accomplished by subsidies offered by the Agricultural Investment Code (CIA: *Code des Investissements Agricoles*). Until 1988 financial assistance amounted to Dh150.00 per head (males and females alike), but was only offered to winning animals in a few organized competitions. Important subsidies were, however, offered for purchasing genetically improved animals. These subsidies accounted for 30 to 35 percent of the price of the sheep, males and females, purchased respectively, by individual farmers or cooperative members. These percentages were 20 and 35 percent for goats. In all cases, the CIA fixed maximum financial assistance to Dh 1 500 per small ruminant. After 1988 the legislature directed financial assistance to encourage production of genetically improved animals instead of their purchase. Now the CIA offers Dh 700 and Dh 500, respectively, for rams and ewes produced by breeders in cooperatives and Dh 450 and Dh 400 for those not belonging to a cooperative (Dh 1.00 = US$0.10). This substantial subsidy of the production of selected animals, in addition to a subsidy of 50 percent of the price of the most concentrate feeds and / or total payment to the breeders for transport, led to an increase in the number of farmers joining cooperatives and associations (from 310 to 520) and to an improvement in their flock management.

Selected breeding scheme and its maintenance

The primary reasons for introducing the currently adopted D'man sheep breeding scheme were to preserve and develop the breed and to valorise the improved animals initially produced in the public stations. For the designers of the scheme, the best approach to achieve these goals was to multiply the already improved animals in organized farms and disseminate them into mass flocks. The existence of the two regional agencies for agricultural development facilitated the initiation of the breeding scheme. ORMVAs are governmental entities endowed with financial autonomy and benefit from important funds and qualified staff. Since being implemented, the programme has been maintained by organized breeders who find it profitable and by Government agencies and NGOs convinced that D'man sheep can contribute more significantly in regional as well as national food security.

D'man flock size in the traditional oasian farm is small. This feature is a handicap to the sector's development, especially to selection. However, many producers have been willing to increase their flock size and to adopt D'man breeding as their primary activity. Financial assistance has helped make the operation economically beneficial, but few breeders chose to continue the genetic improvement of their flocks without presenting their animals to the selection committee. These producers realised that they could earn more money selling their animals at younger ages than keeping them a whole year to receive the benefit from the financial assistance. With proper management, the D'man straight-breeding scheme seems acceptable to all breeder categories, but more effort is needed to expand its benefits to the base flocks.

Future perspectives

At this stage, it is necessary to evaluate the scheme and its strategy of implementation, starting from the choice of the traits on which to apply selection. For instance, instead of selecting ewes on their own litter size and lambs on the average litter size at birth of their dams, selection on the basis of the number of lambs weaned per ewe could be more profitable. The number of lambs weaned per ewe is determined not only by litter size at birth, but also by fertility, number born and also viability, as this latter parameter is generally high and variable in this breed. Selection for liveweight at 90 days, instead of 180 days was shown by Boujnane and Kerfal (1990) to have a large effect on other growth traits as a result of their high positive genetic correlation. Estimates of genetic gains must be isolated from environmental ones, especially at the nucleus level in order to evaluate the genetic progress achieved by selection. Estimating genetic gains at the multiplier flock level may be more difficult to achieve, due to the great variability in their management practices and to the difficulties to maintain accurate and regular records. It could be initiated in a second phase.

The present two nuclei system (one in each valley), is probably more effective than a numerous nuclei system, preferred by ANOC. The two nuclei will be easier to control. The base flock in both valleys does not exceed about 80 000 ewes and therefore does not require multiple nuclei to produce the necessary number of rams. The two nuclei could be managed by private breeders, with the Government providing monitoring assistance at least for the next decade, until the system can be maintained independently.

Since the start of the programme and to maximise the breeders' benefits from selection subsidy, the national sheep selection committee, composed of ANOC, INRA and Government agents (ORMVAs in the case of D'man), has been maximising the number of selected animals. It is time to select fewer genetically high quality animals and make sure they benefit from the breeding programme. It is time to think about organizing the so called non-organized farmers into genetically-improved-animals-users associations. The main constraints that have limited any progress in this category of flocks is their small size. It is easier to start by organizing farmers owning at least four to five ewes to ensure that the activity is meaningful to the farmer and that he is ready to invest some time and money to improve his flock productivity. These associations will help use improved rams in a collective manner, which will require lambing grouping and will consolidate their efforts to benefit from better feed and product marketing prices. Their organization will also help them gain more technical assistance from specialised agencies.

Before 1988, the Government subsidised the purchase of genetically improved animals, now, it encourages their production. It is time to think about reintroducing some kind of encouragement for improved animal users, especially sheep and goats. Such a change will assure the proper dissemination of the genetic progress achieved in nuclei and multiplier flocks. To ensure the success of the plan, important consideration should be given to human resources. Training of the staff involved in this programme as well as the breeders and their assistants is necessary to achieve the fixed goals. Engineers and technicians require more knowledge in animal genetic improvement and electronic data processing, whereas breeders and their assistants could benefit from training on proper flock management and record keeping.

Cross-breeding plans

Based on work at several sheep research stations in the country, it was concluded that the D'man breed transmits its high prolificacy in an additive fashion in crosses with a less prolific breed (Table 3). Therefore, by varying the proportion of D'man inheritance, it is possible to set mean litter size at any desired level between that of non prolific breed (1.0) and that of the D'man (2.2). Furthermore, D'man also seems to transmit its early puberty, high fertility and long breeding season in a dominant fashion, resulting in cross-bred ewe performance in the traits superior to that of other local breeds, Sardi, Timahdit or Beni Guil sheep breeds (Bourfia, 1986; Boujnane *et al.*, 1991; El Fadili and Leroy, 1997).

Several two-breed (one-step) or three-breed (two-step) crossing programmes involving the D'man and one of the major local breeds (Timahdit, Sardi, Beni Guil), in addition to a meat ram (Ile de France, Mernos Precosse or Causses du Lot) as a terminal sire have been tested in research stations. In general, results have been promising (Table 3). Use of D'man sheep in cross-breeding to increase litter size in the private industry are practised in many cereal/sheep farming areas in Morocco. However, data are lacking on the number of these farms, their cross-breeding plans or performance achievements.

Table 3. Prolificacy of D'man cross breeds.

Author	Cross breed	Prolificacy
- Boujnane *et al*, 1982	F_1 (D'man * Sardi)	155
- Benlakhal, 1983	F_1 (D'man * Timahdit)	146
- Chafik, 1986	¾D'man * ¼ Sardi	179
	F_1 (D'man * Sardi)	155
- Chemsi, 1988	¾D'man * Beni Guil	166
	F_1 (D'man * Sardi)	171
- El Fadili and Leroy, 1997	TS* * F_1 (D'man * Sardi)	163
	TS * F_1 (D'man * Timahdit)	178

*Terminal sire = Meat breed rams (Ile de France or Merinos Precosse).

The most consistent work accomplished in this regard is the achievement of a significant step towards the formation of a synthetic breed (½ D'man, ½ Beni Guil) as a result of the collaborative work between the Agronomic and Veterinary Institute Hassan II and the Ministry of Agriculture (Bourfia *et al*., 1997). The new breed is claimed to be adapted to the harsh environment prevailing in high plateaus alfa *(Stipa tenacissima*) and white sagebrush (*Artemisia herba alba*) steppes, which is the same area presently occupied by the Beni Guil breed. This cross-breeding programme was initiated in 1992 in the Missour research station and the continued for the last seven years. Bourfia *et al*. (1997) confirms that prolificacy of the new breed averages 1.42 and growth performance is intermediate between those of D'man and Beni Guil. According to Bourfia (1999), more work is planned to stabilise prolificacy in the 1.2 - 1.3 range, improve weight gain and test the adaptation of the new breed in different areas, other than the Missour station.

It is clear that D'man sheep have the potential to increase meat production in Morocco and in the world. D'man can contribute both as a pure-breed in confined conditions (Oasis system for instance) or as a source for prolificacy improvement in cross-breeding schemes. However, a definition of clear and accurate objectives, adoption of an adequate strategy and accomplishment of harmonious collaborative work among the partners in this industry (research and development agencies and professional associations) are essential if these goals are to be achieved.

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Peul, Touabire and Djallonke sheep breeding programmes in Senegal

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Introduction

This paper reports on the plan, design and operational aspects of sheep breeding programmes established in Senegal since the mid 1970s. In the 1950s and early 1960s, a research station in each of the two agro-ecological zones (semi-arid and sub-humid areas), was created with the objective to increase the productivity of local sheep and cattle breeds through the genetic improvement of these livestock. Two sheep breeding programmes based on selection within breed have been implemented in Senegal since 1975. Cross-breeding programmes were also undertaken using exotic European or Moroccan breeds but these experiences were not maintained and unfortunately they are not documented. This report will therefore concentrate on the two selection programmes of Sahelian and Djallonke sheep. Information reported in this paper has been gathered from the annual reports of the Centre de Recherches Zootechniques de Dahra, Senegal and the Centre de Recherches Zootechniques de Kolda.

Description of the programmes

Breeds

The first breeding programme aimed at improving the Sahelian sheep breeds (Peul and Touabire), was established in northern Senegal in a state-owned research station. A similar programme took place in Southern Senegal with the objective to genetically improve the trypanotolerant Djallonke sheep breed. Both programmes were based on selection within breed.

Input level of the production system

The production systems under which both the Djallonke and the Peul breeds produce, could be defined as extensive low input systems. Animals graze natural pastures all year round. Roughage from cereal crop residues is also fed after grain harvest. Pasture quality is fairly good during the rainy season but quantity and quality are limited during the long dry season. Concentrate supplementation is not common for these two breeds on extensive management systems and therefore, nutrient requirements are not met in many months of the year. Water supply is also a major constraint for the vast majority of the Peul breed. Parasitic pressure is high for the Djallonke sheep and farmers seldom deworm their animals. It is estimated that ten to 50 percent of weight losses are attributed to the helminth infestation. Vaccination against major epidemics such as Peste des Petits Ruminants is not systematic and therefore high mortality rates are observed.

On the other hand, the Touabire breed is subject to intensive management by farmers. These animals are usually kept on-farm and are fed groundnut or cowpea hay and concentrate. Sheep fattening to supply good quality rams during religious ceremonies (Hedoul Adkha) is a common practice where the Touabire breed are preferably used for their high growth rate, big format and white coat colour. Therefore, the production system for Touabire sheep could be classified as a medium input system.

Number of animals

The population of Peul sheep in the area covered by the breeding programme maybe estimated at over 500 000 head. For Djallonke sheep, the population concerned is estimated at 200 000 head.

The nucleus flock reared on station was about 300 head for the Peul breed, 200 head for the Touabire breed, and 300 head for the Djallonke sheep. The extension of the breeding programme to village flocks in 1984 expanded the selection base to about 900 head of Peul sheep.

Targeted population and system of dissemination of the improved genetic material

Village flocks that were close to the breeding station were first targeted in this breeding programme. Attempts were made to establish an efficient dissemination system of the improved genetic material. Rams selected on the station from the nucleus flock were rented on an annual basis to farmers participating in the breeding programme.

Establishment of the breeding goal

A top-down approach was used to establish breeding goals. National livestock development policies emphasised the need to increase meat production in Senegal in the 1970s. Breeding goals were set by Government technicians through the interpretation of national objectives to increase meat supply. Breeding sheep for meat purposes was seen as a means to improve productivity to meet the increasing demand for meat in the country. Farmers were not involved in any stage of the process of the design of the breeding plan. Farmers objectives and characteristics of the livestock production system were not taken into account. It is true that farmers place great importance on rapid growing stock. However, features of the farming environment may have directed technicians to traits, for instance, that would improve adaptability of the breed in harsh environments with high ambient temperature and humidity, high worm burden and trypanosomiasis risk for the Djallonke sheep. The Peul breed has also to trek long distance to search for water and fodder and during years of drought these animals may be subjected to transhumance.

Changes in the design of the breeding goal

The sheep breeding programmes started in 1975 at Dahra for Peul, Touabire and Djallonke sheep breeds. From 1975 to 1980, only performance recording took place in the nucleus flock to gain more information on the breed characteristics. There was not actually any breeding design in operation. Culling procedures were just applied on old and non fertile animals. In fact, at the inception of the programme, the original idea was set for a cross-breeding scheme between Peul and Touabire sheep, both local stocks. These two breeds were mated and cross-breeds were reared on site. However, the design of the cross-breeding scheme was not explicit on the use of the crosses. In 1980 the decision was made to terminate cross-breeding activities and to undertake selection within each breed. As a result, a breeding plan was designed with the following features.

Nucleus flocks established in state-owned research stations produce improved stock that was supposed to be distributed to surrounding flocks. At weaning at four months of age, males are selected on the basis of their body growth rate and conformation. In addition to these two criteria, selection at 12 months of age should also take into account reproductive traits such as semen quality. Selected males were planned to be progeny tested. Best rams were destined to the station nucleus flock while others were sold to farmers. Replacement females were selected at four months on the basis of their body growth rate and conformation. Elite females to be parental stock of candidate rams were selected using their reproductive performances (fertility rate) after their first three lambings.

By 1984 major modifications occurred in the design of the breeding programme. Due to the limited number of females on site that constrain the possibility to progeny test candidate rams, the recording system was extended to village flock so that the selection base could be larger. Young males were planned to be bought from village flocks at four to five months of age. Both young males from the station flock and from village flocks would be tested for four months for growth rate. Selected rams would be disseminated into village flocks at 15 months of age. It was planned that rams could rotate from one flock to another.

Although both programmes planned to use artificial insemination, neither of them actually used it. Similarly, the assessment of semen quality was never performed.

The extension of the recording system to the surrounding flock was operated after ten years of programme implementation when scientists realised that the selection base on station was not sufficient for the application of progeny testing of candidate improved stock. The increase in the number of dams would ensure greater variability and would allow greater genetic progress.

Traits included in the breeding goal

The breeding programme for all sheep breeds was designed for meat purposes. Adaptation to the environment was not for instance taken into account for the plan regarding Djallonke sheep that are reared in areas with high parasitic pressure and the prevalence of trypanosomiasis.

Selection criteria

Peul and Touabire

Selection of replacement females was based on their own growth performance and on reproductive capacity of their parents. Females with highest growth rate (zero to 30 days) and good conformation and being daughters of dams with high fertility rates were selected for replacement.

Males are first selected at weaning at four months of age on the basis of their growth rate. Selected young males at weaning are then subjected to performance testing for four months. Growth rate during the performance test and conformation at 15 months of age are the final criteria used to select rams.

The original plan also included final selection of rams on the basis of the performance of their offspring through a progeny testing procedure that would involve both on station and village flocks. However, this aspect of the breeding programme was not implemented because of the limited number of offspring per ram due to the reduced number of ewes on station.

Djallonke sheep

Growth rate at weaning at six months of age and white coat colour were used to select males. Selected animals undergo a performance test for six months and animals with the highest growth rate and best conformation (largest height at withers) were selected at 12 months of age.

Dissemination of improved genetic material

For Peul and Touabire breeds, rams were actually distributed into village flocks on a rental basis. Farmers paid 5 000 FCFA (approximately US$10) per ram. For Djallonke sheep, the programme did not succeed to get to the stage of disseminating the improved stock. Due to management problems, high mortality rates were observed in the nucleus flock. Therefore, almost all females available were required as a replacement in the nucleus.

Population breeding structure

A nucleus flock was established based on purchases but this did not involve any screening. However, homogenisation of animals was done by removing those that did not exhibit major traits of the breed. White coat colour was set for the Djallonke sheep as a major trait of the breed. During the first years of the programme a closed nucleus was operated. In 1984, the need to involve village flocks was felt. According to plans, genetic material should flow to both directions, to and from the breeding structure. Village flock that benefited from selected rams was supposed to supply the breeding station with young males that will be tested on station. On the other hand improved genetic material produced on station would preferably enter monitored village flocks.

Farmer and Government involvement

Due to the top-down approach used in designing the breeding programme, farmers were not involved in the planning stage. Their participation was seen to accept the improved genetic material produced at the research station. With changes in the design, farmer participation was extended to ensuring that their stock was at the disposal of technicians for performance recording but they were not practically involved as main actors in the breeding programme.

Major financial inputs to the breeding programme were provided by the Government. Infrastructure establishment and maintenance, technical staff and the cost of the village recording systems were incurred by the state-owned research station.

Support system

Research in the area of reproduction in support to the breeding scheme (investigation on the required quantity of PMSG following treatment with vaginal sponge to synchronise lambings) as well as experiments aimed at improving the feeding systems, were undertaken at the same time.

The establishment of the recording systems required training of technicians in charge of the work in village flocks. This was secured by the research station that also supported, on a subsidised basis, basic health care routines such as vaccination and deworming of animals in monitored village flocks. The supply of concentrate was also part of an incentive package for farmers to participate in the programme in a sustainable manner.

In 1983 as part of a national programme designed to monitor performance of sheep and goats in Senegal, a large recording system was established in the Dahra area where the Peul breeding scheme was taking place. This involved 71 farmers and 958 animals. Although the recording system was not set for breeding purposes, this could serve as a basis for the establishment of a breeding plan involving village flocks. In fact, in the southern areas where Djallonke sheep are raised, the monitoring structure was used to screen animals that appeared to be resistant to helminth in connection with a research programme aimed at investigating the genetic resistance of Djallonke sheep to helminth infection.

The monitoring system, although not destined to support a breeding programme, was successful in terms of supplying basic information of breed characteristics, farmers' objectives and practices as well as identifying alternative solutions to identified technical constraints.

Reasons for introducing the scheme

The genetic improvement of local breeds was seen as a main strategy formulated within the context of prevailing agricultural policies in the 1970s geared towards the intensification of production systems. The specific objectives of the breeding programmes were to:

- improve sheep productivity;
- increase meat supply;
- reduce imports of sheep from neighbouring countries to celebrate religious ceremonies such as Tabaski (Hedoul Adkha).

Critical factors of the breeding scheme

Government willingness and commitment to support the scheme was critical for its initiation. Moreover, breeding experiments were already undertaken for cattle and the extension of the breeding programme to sheep was easier as infrastructure and manpower were already there.

Over time, the scheme was not maintained for both programmes in the north for Sahelian sheep and in the south for Djallonke sheep. The major reasons for this failure were the reduction in state funds to support these programmes. Structural adjustment programmes largely reduced the capacity of research stations to maintain breeding programmes. As a result of budget cuts, the personnel of breeding stations were laid off and funds were no longer available to assure village flock monitoring in terms of logistic means and subsidised vaccination and concentrate supply.

Limited and unstable trained manpower was a compounding factor that greatly constrained efficiency and maintenance of the breeding programmes.

It is also probable that the evaluation of these breeding programmes during the course of action could have assisted in redesigning the schemes but this was not done. In connection to this, the lack of accountability to failure or success of schemes was a major problem.

Future direction and required changes for successful design and operation of the breeding scheme

Many aspects of the breeding plan would need revision if a successful programme is to be established in the future. There is now a sizeable body of scientific and technical information gathered during the last decades that could form the basis for sound design of a successful breeding scheme. In addition the availability of more qualified national scientists would be a positive factor to realise this objective.

The definition of breeding goals takes into account not only adaptability traits but also farmer participation. The economic evaluation of the goals is the number one priority. Failure to select criteria on an economic ground has been a major drawback of past breeding programmes.

The involvement of village flocks was initiated but this was not sustained because of the shortage of financial and logistic resources but mainly because farmers were not sufficiently involved in the design and operation. Effective participation of farmers will require that they organize themselves to take charge in a collective manner, of tasks and costs associated with the programme and benefit from it. There was no producer association that could influence decision-making processes in areas where the breeding schemes were implemented.

Schemes should be as simple as possible in order to be implemented properly. Selection should be made at one stage and the number of criteria should be limited.

Breeding systems should be designed according to existing farming systems (intensive high input, medium and low inputs systems; market demands, prices of animals and meat). In this respect, selection within breed is a sound strategy for the Touabire breed in medium and high input systems in urban and peri-urban areas and in rural areas where husbandry conditions are improved. The Touabire breeds present traits that make production of profitably in medium and high input systems suitable. High prices paid for animals with good format and body conditions justify investment in breeding and other required inputs and this is already being done by a few farmers in urban and peri-urban areas. Performance recording in these flocks would allow the selection of young males to be tested and selected on station on the basis of their body growth performance.

Selection in low input systems should take into account adaptability traits according to specific locations and breeds. For the Peul breed in low input systems, selection within breed could take into account growth rate and reproductive performance that includes lamb survival. Another trait of importance for the Peul breed is the ability of animals to maintain body conditions in an environment with variable nutrient supply.

Many farmers keeping the Peul breed in Northern Senegal have large flock size, approximately 500 head. It would be possible to support these farmers so that they perform better breeding decisions than they are already making.

It is crucial that livestock development policies encourage the establishment of private professional breeding flocks either owned individually or by groups of farmers that will benefit from the scientific and technical assistance provided by research and extension institutions.

Selection within breed is also suitable for the Djallonke sheep with emphasis on adaptability traits such as resistance to disease and ability to use roughage.

Cross-breeding between Touabire or Bali-Bali, a breed from Niger, is also worth considering in medium input systems.

Estimation of genetic change

Genetic change was not estimated. However, genetic parameters of economic traits have been estimated.

An evaluation of the breeding strategies used in the development of the Dorper sheep and the improved Boer goat of South Africa

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Introduction

The development of the Dorper sheep and the Improved Boer Goat are undoubtedly two of the most successful long-term livestock programmes in South Africa. The Dorper is a composite mutton sheep breed developed through crossing an indigenous breed with a British mutton breed and the Improved Boer Goat was developed using a breeding strategy based largely on selection for fertility and meat production.

Both breeds were developed for low input production environments and both have subsequently been influenced by market preferences and trends as well as ‘fancy points’ that often have no bearing on adaptive or production traits.

Both breeds were also part of Government-assisted programmes and both benefited from the establishment of a breed society and a national recording and evaluation scheme.

This paper reviews the strategies put into place to develop the Dorper sheep and the Improved Boer Goat and discusses aspects that have been improved and could have been improved upon.

The Dorper sheep

The main objective of the Dorper programme was to develop a hardy meat-producing sheep for the extensive production areas of the country. The breed was developed by crossing Dorset Horn sheep with the fat-rumped black headed Persian sheep, a local Somali sheep variety.

A major catalyst in the development of the breed was market and consumer resistance to the carcass quality of traditional fat-tailed and fat-rumped breeds, such as the Afrikaner and the Persian, that made up most of the sheep farmed in the arid to semi-arid areas of the country during the 1930s.

The Department of Agriculture initiated a series of trials from 1933 to 1946 at research stations and participating farms in South Africa. This was done in cooperation with farmers who had indigenous breeds to develop a composite that could produce a quality carcass in harsh conditions. This followed less controlled cross-breeding using rams from exotic breeds such as the Suffolk, Border Leicester, South down, Welsh Mountain and the Dorset Horn. The largest disadvantage of the latter initiative was the fact that, while breeding half crosses again to British mutton breeds improved carcass quality, adaptability decreased. The need to keep breeding flocks of less adapted pure British mutton breeds was also a problem.

Trials to evaluate British mutton sire lines began in earnest at this stage. After analysing the results, it was decided in 1942 to develop a composite breed using the half-cross Dorset Horn-Blackhead Persian as a basis. Of particular importance was the fact that this cross was less seasonal as far as breeding was concerned.

The Grootfontein Research Institute of the Department of Agriculture played a major role in the further development of the breed. The overriding trait in the breeding programme was adaptability. This can be described as follows:
- ability to survive unfavourable conditions;
- ability to reproduce regularly in local conditions;
- ability of lambs to grow rapidly to a marketable size.

One of the major advantages of cooperative development is that it is easier to establish a half-cross composition this way. A sufficient number of animals exist to select and breed unrelated half-cross rams.

Although numbers of the composite increased, progress was not as expected until a breed society was formed in 1950. The name DORPER was also established. The years that followed saw participation in the national mutton performance testing scheme (introduced in 1964) and the development of the all white Dorper, a cross between the Dorset horn, Persian, Dorper and the Van Rooy sheep (an Afrikaner-Rambouillet composite).

As the popularity of the Dorper increased, its distribution widened from the more traditional arid to semi-arid areas to include higher rainfall areas and semi-intensive production systems. Selection in these conditions as well as buyer preferences had an influence on breeding objectives and breed standards. Table 1 shows changes in 100 day masses of performance tested

It can be seen that the Dorper has changed. It is shorter-legged and more compact. Fat is more evenly distributed and the hair coat is short and smooth. Performance data shows that growth has also improved.

Table 1. Changes in the 100 day masses of performance tested Dorper lambs (Data from the National Sheep performance-testing scheme).

Year	100 day weight (kg) Ram Lambs	100 day weight Ewe Lambs
1964	25.40	24.20
1970	30.60	28.22
1978	30.96	28.03
1982	34.83	32.40
1989	34.80	31.50

Is the modern Dorper still as adaptable as it was 50 years ago?

Can the breed still use the natural resources as effectively as it did in the 1950s? Is the shorter sturdier modern Dorper still as adaptable?

- Can it still move effectively in extensive conditions?
- Does it still have the necessary adaptive traits?
- Does it still graze effectively or has it become a destructive grazer?

Lochner (1996) claimed that breeding objectives had moved from a hardy extensive type to a type more suited to temperate climates and Nel (1980) was of the opinion that selection for size and discrimination against certain fat deposits could possibly influence the breeds' adaptive traits. Van Niekerk (1999) referred to changes as a result of breeding objectives that could influence sexual maturity and fertility and Campbell, (1998) advised breeders to pay attention to economically important traits of mutton sheep and to resist the temptation to intensively select for "fancy points". Olivier (1999) advised that there should be a balance between marketability and the genetic improvement of the breed. Over emphasis in either direction could do long-term damage to the whole breed.

The Breed Society is located in Middelburg in the Cape Province, about ten kilometres from Grootfontein Agricultural Development Institute. Close ties are maintained with key researchers and the Government still contributes a third to the running costs of the National performance-testing scheme that includes the small stock testing schemes. Grootfontein has also recently developed a new recording and evaluation system under the guidance of Dr Buks Olivier. The updated goal of the breed reflects these links.

It is, however, important to constantly monitor breed progress with the most suitable aids available.

Improve the efficiency of production of a marketable product. Meat and Skin

Performance testing should be used sensibly to facilitate a balance between reproduction and growth. The new small-stock recording and improvement scheme that has been developed at Grootfontein is capable of meeting all these needs.

It is encouraging to note that Grootfontein, the Institute that has contributed the most to the development of the breed, continues to do so, using a healthy balance between modern technology and phenotypic observation. This Institute would make an ideal small stock centre for Africa and has all the necessary facilities to render advisory and support services to all farmers and farm systems.

Participation in the new scheme has increased rapidly over the last few months owing to breeders and breed societies that had become disillusioned with performance testing. This is most encouraging and shows the Society's commitment towards on-going evaluation and improvement.

Modern breed evaluation techniques will now enable those involved to predict trends as far as the major traits were concerned. With this information, it will be possible to avoid a skewed approach to production traits where adaptability might be compromised by such directions

The improved Boer goat

The improved Boer Goat had its origins in the Eastern Cape Province where farmers began keeping lop-eared goats obtained from Hottentot and Bantu owners. During the early stages, the goats were multi- coloured and were used in the thornveld areas to utilise and control bush.

Although unsubstantiated, there are indications of early Eastern/Indian and European introductions. While these may have had an influence on some animals, the overall breeding objectives did not take these into consideration.

In the late 1920s and early 1930s a few breeders focussed breeding objectives on improved conformation for meat production, quality meat and the ability to browse. Colour selection followed and the typical white goat with a red head began to establish itself as the only meat goat in Africa. The late Theunis Jordaan, a farmer from near Somerset West in the Eastern Cape Province, played a major role in this selection and development programme by concentrating on heavier short-haired goats with light red heads.

A Boer Goat Breeders' Association was formed on 4 July 1959. The aims of this society were to:
- further improve the Boer Goat as a Breed in South Africa;
- appoint an administrative staff;

- implement an annual short course on Boer Goats and to train judges and inspectors;
- compile and distribute an information brochure and to organize demonstrations to disseminate information regarding the breed;
- establish an inspection service to class and inspect flocks;
- introduce a more efficient grading system for Boer Goat meat;
- stage sales and inspect all animals offered at sales under the auspices of the association.

First phase of the development of the breed

Government support included trials in the late 1960s on grazing and browsing patterns and its impact on the improvement of grass coverage. This was followed by research into the productivity of the breed. This information was made available in the form of departmental publications and through the popular agriculture media. Other Government assistance included technical advice and the establishment of herds at Dohne Research Station in the Eastern Cape and at Grootfontein in the Northern Cape. Additional institutional support came from the South African StudBook who provided certification services as the only registering authority in the country. Active membership of the South African Stud Book has, however, fluctuated over the years, particularly amongst breeders who saw no need for recording and identification. Currently, there are 12 breeders with a total of 3 866 animals registered with the South African Stud Book. Another eight breeders are currently being registered.

The lack of recording in some herds recently led to problems where embryos with no pedigree or performance information were exported to Canada. Prospective importers have been advised that only breed society endorsed genetic material can be guaranteed.

In 1964 when the mutton sheep performance testing scheme started Boer goat breeders joined the scheme. In 1970 a National Goat Performance testing scheme was started under the mutton scheme. This scheme provided a framework to record and evaluate the performance of goats through the following phases:

- Phase A: Records details of the dam, fertility, milk production and the growth rate of the kid / kids from birth to weaning;
- Phase B: Records the post weaning growth rate of the kid;
- Phase C: Records and determines the efficiency of feed conversion and the growth rate of male kids;
- Phase D: Measures the post weaning growth rate of male kids in standard conditions at a central ram-testing centre;
- Phase E : Determines the qualitative and quantitative carcass components of the progeny of a specific sire.

Second phase of the development of the breed

The number of participants has fluctuated over the years. In 1975 there were eight breeders with 500 ewes in the scheme and at present, there are 12 breeders.

Table 2 gives details of the mean adjusted 100 day mass (kg) of performance tested Boer Goat kids from 1970 to 1998.

Table 2. Mean adjusted 100 day mass (kg) of performance tested boer goats from 1970 to 1998 (Data from the National performance testing scheme).

Year	Ram (kg)	Ewes (kg)
1970	24.0	21.9
1975	23.6	21.7
1979	36.5	29.2
1982	32.3	27.8
1986	26.9	23.4
1988	25.3	22.3

Although selection has been largely concentrated on the ability to produce a saleable carcass off the savanna bushveld, there has been a tendency amongst some breeders to select for 'fancy points', some of which may be negatively correlated with more important adaptive traits. Campbell (1990) who has played a key advisory role in the development of the breed for many years warned breeders not to pay too much attention to traits of little to no economic importance when selecting breeding stock.

The breed was developed in the Eastern Cape where tick borne diseases were not a problem. Consequently, the Improved Boer goat has a low level of resistance to heartwater (*Cowdria*) compared to unimproved goats in areas where heartwater is endemic.

Management practices and selection policies in some herds have also seen a loss of maternal behaviour where ewes do not bond effectively with their kids.

These issues show that there is no universal breed. The Improved Boer goat was developed with focussed breeding objectives to fit into a specific environment. The development was very successful and the animals produce more meat per unit area than any other goat breed in a similar environment. The breed is also being used very successfully in semi-intensive smallholder systems in many countries. Environmental factors are of less importance where farmers can afford to make the necessary management adjustments. It should, however, always be remembered that small stock are often of critical importance as the only sustainable form of animal production in arid to semi-arid areas. As such, adaptability and the ability to produce a useable / saleable product are the key overriding considerations.

Future breeding plans must therefore always take aspects such as adaptability and production environment factors into consideration. Breed information should include production environment information to enable prospective breeders to make an informed choice.

Discussion. Using the experience to develop guidelines

The strategies followed and experience gained during the development of the Dorper and the Improved Boer goat will be useful when formulating guidelines for livestock breeding strategies for low input environments. In addition, modern animal recording and evaluation technology should be adapted for use with specific programmes. This will enable planners and farmers to ensure that objectives remain focussed.

The role of the Government and supportive institutions should also be taken into consideration, particularly when it comes to identification, recording, evaluation of production traits and processing of performance data

In developing guidelines, the following should be taken into consideration:

- What are the objectives of the programme? Meat, milk, fibre, a combination?
- What can the production environment support?
- What genetic material is available and what is the potential of this material?
- What shortcomings are there in the general phenotype and genotype?
- Can the available resource be used to produce?
- What breeds can be used to develop a composite that will meet the needs of the basic objective?
- Will the development require institutional support? If so, in what form? and what is available?
- What identification, recording and evaluation system will ensure that the primary objective remains focussed?

Taking the Dorper as an example, modern breeding, recording and evaluation technology can assist in ensuring that the initial objective, the development of an adapted meat-producing sheep will remain focussed. Evaluations would be able to predict trends that could be rectified earlier than present. Throughout this process, the following should always be kept in mind:

Breeding goals should always be defined in simple but explicit economic and biological terms. These include: more emphasis on reproduction rates, reducing the number of traits selected for by excluding those of doubtful economic importance and maintaining effective herd/flock sizes and composition (Hofmeyr, 1978).

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Case Study about the N'Dama breeding programme at the International Trypanotolerance Centre (ITC) in The Gambia

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Introduction

Very large areas of the sub-humid zone of West Africa are in need of indigenous breeds in order to exploit the available natural pastures, bushlands and crop residues. However, there is an urgent need to increase production because:

- there is a rapid increase in human population (in some countries population has doubled in less than 20 years);
- there is dramatic urbanisation (some large human agglomeration centres have doubled in less than a decade);
- some countries import large amounts of dairy products (mainly liquid and powdered milk) showing that even today the demand cannot be satisfied by local production.

As it is obvious, production can be increased by both increasing animal numbers and by increasing productivity of each animal. However, in some countries (e.g. The Gambia) the number of cattle has hardly increased during the last 15 years, strongly indicating that the carrying capacity of the land is largely utilised. Serious starvation at the end of the dry season is supporting this conclusion. Also the extension of crop production due to human population increase is reducing the availability of the natural grazing areas, but at the same time it allows increasing the intensity by using by-products of crop production as high quality feed (e.g. groundnut hay). Thus, these factors are very much in favour of increasing productivity per head. Genetic improvement is among other components to achieve this goal. For the prevailing low input system, indigenous breeds are absolutely necessary due to the periodically extreme scarcity of feed and the presence of serious diseases like Trypanosomiasis and Tick-borne diseases (Cowdriosis, Dermatophilosis and others). Fortunately with the

N'Dama breed there is one numerous breed available in West Africa which comprises several million heads. Any effective breeding and multiplication scheme could thus have a large impact.

The International Trypanotolerance Centre (ITC) in The Gambia was from its inception, devoted to enhancing the usefulness of genetically trypanotolerant animals.

In recent years ITC has implemented four genetic programmes for improving the efficiency of livestock production. These programmes are:

- pure-breeding N'Dama programme in cattle;
- pure-breeding Djallonké programme in sheep;
- pure-breeding West African Dwarf programme in goats; and
- a continuous F_1 cross-breeding programme for exotic dairy breed x N'Dama for peri-urban milk production.

Only the implementation and running of the N'Dama breeding programme will be described here.

N'Dama pure-breeding programme at ITC

From approximately ten million trypanotolerant cattle, more than half of them belong to the N'Dama breed (Hoste *et al*., 1988). These are distributed as:

Country	Numbers
The Gambia	290 000
Senegal (Casamance)	640 000
Guinea Bissau	300 000
Guinea	2 190 000
Sierra Leone	330 000
Liberia	10 000
Mali	410 000
Côte D'Ivoire	140 000
Ghana	30 000

In addition there are smaller populations in Zaire, Gabon, etc. Practically all of these N'Dama cattle are kept in low input systems.

After its inception ITC built up a large institutional herd of about 1 200 N'Dama cattle. In 1994 with support from BMZ / GTZ, a breeding scheme was initiated. It was decided to transform this institutional herd into an open nucleus herd. The intention was and is to have close collaboration with similar nucleus breeding schemes in Senegal and Guinea and jointly contribute to the genetic improvement of the N'Dama breed focussing on these three countries. The cattle of ITC were originally distributed in many herds all over the country and the transformation of that cattle stock to a nucleus breeding unit in two sites took quite a time especially until all the necessary recording of pedigrees and performance testing was organized. Thus the start of the breeding work can be taken as commencing in mid 1995 and we were starting essentially from scratch (few performance data and even fewer reliable pedigree data are available).

Breeding goals

In 1989 there was an FAO mission to look into the possibility of genetically improving the N'Dama breed. In that mission report it was clearly stated that several traits were of importance: disease resistance / tolerance (the main trait justifying the breed), milk production, meat production and ability for traction. After reviewing the literature and becoming more familiar with the local system, it was decided to organize the breeding scheme in such a way that milk and meat production would be improved without loosing adaptability (e.g. trypanotolerance). Looking at the critical time path it was decided that it is much more urgent to implement the proper performance testing and recording than to first spend a lot of time to decide whether the emphasis for milk compared to meat should be a little bit higher or lower. In addition quite a lot of parameters (economic and biological ones) were not known very precisely making any precise derivation of economic weights somewhat illusory. This pragmatic approach was in our opinion justified in order to gain time but it was also criticised.

Once the reorganization was accomplished and quite an efficient performance testing and data recording and processing scheme was in place and functioning, the question of breeding goals was revisited.

When trying to improve cattle population, one has to take into account the intention of the official policy of the countries. Most countries have some livestock development plans and these definitely have to be taken into account as the main objectives must agree to ensure the smooth operation.

A Consultative Workshop was organized in ITC in 1996 and was very helpful for qualitatively defining the breeding goals. The directors of the livestock / veterinary services and research organizations dealing with livestock of Senegal, The Gambia, Guinea Bissau, Guinea and Sierra Leone, issued the following statement with regard to:

Cattle in the low-input system

'The N'Dama will remain the cattle breed of choice for the low-input system from The Gambia southwards. Throughout the region the breed is regarded as triple-purpose (for milk, meat and traction) and emphasis for improvement will be for milk and meat without the loss of disease resistance and other adaptive traits'.

This statement nicely summarises the goals in a qualitative manner. However, from here it is still a long way to obtain an operationally defined breeding goal. In addition, there is another problem, the products of a breeding scheme are to be used by the herd owners and not by the politicians or researchers.

In cooperation with another project at ITC, a large Participatory Rural Appraisal Study (Bennison *et al.*, 1997) was carried out trying to find out the motives of cattle owners. The study was carried out (including also sheep and goats) in 45 villages. Matrix ranking was used and there were 130 completed matrices in the end. Again milk, meat, traction and manure figured prominently.

Finally, a biological-economic model was developed utilising all the known biological and economical relationships. This model (Dempfle and Jaitner, 1998) has some similarity with a model developed earlier for the New Zealand Dairy Industry (Dempfle, 1986). With this model the question was answered (by marginal profit) in what direction we have genetically to move the population in order to maximise profitability. The derivation, was carried out under the realistic assumption that the amount of Metabolisable Energy is limited and fixed (maximum carrying capacity reached). In this derivation disease resistance is indirectly taken into account in such a way that animals are raised from one to three years in an extremely high challenge area. Only animals which perform well under this environment having high daily gain will have a chance. It was not considered necessary to take traction into account. This model for deriving economic weights for use in the overall index is still being refined (Dempfle and Jaitner, 1999). The best present objective function is:

- H = 0.22.
- Breeding value in daily gain in g + 0.52.
- Breeding value in milk in kg.

The absolute values of the weighing factors are irrelevant, since as long as the ratio of the two weighing factors (0.22:0.52) stay the same, the same animals are selected.

Breeding plan

Dealing with a dual (triple) purpose breed (milk and meat) it was natural to think of a progeny-testing scheme having at any time test bulls, waiting bulls and old proven bulls. However, when we had to prepare for the laying off of the bulls after they had completed the first round of mating, we did two things: we looked for a cheap way of storing semen and we employed all our data to optimise our breeding scheme. That was done in two stages: first optimising within a testing scheme and then comparing the optima of the various schemes. We considered: progeny testing scheme, half-sib scheme and young sire scheme. Somewhat to our surprise the half sib scheme and the young sire scheme came out to be about equally effective and both being ahead of the progeny testing scheme (Jaitner and

Dempfle, 1998). Independently, Syrstad and Ruane (1998) came to very similar conclusions. Since a young sire scheme is by far the simplest to run, that scheme was of course chosen. Fortunately in the present plan there is no need to either store semen or to have any waiting bulls. The problems and costs of using deep frozen semen should not be underestimated.

The plan followed might be best appreciated by studying Figure 1. In the programme the traits of interest are: daily weight gain from zero to ten months (suckling period) and daily weight gain from 15 months to three years in an extreme high challenge area and as a minimum the 0-100 day milk yield (milk off-take) of the first lactation. These traits are determined by monthly weighing of all animals and weekly measuring of milk off-take. Milk off-take is the additional milk not consumed by the calf.

The active breeding stock at any time is about six breeding bulls and 400 adult females, in total there are about 1 000 to 1 100 animals. The animals are located at ITC's stations Keneba and Bansang. In Keneba there are the breeding females (with their suckling calves) and the breeding bulls. After weaning (at an age of ten to twelve months) the young animals are moved to Bansang. The breeding scheme is designed as a young sire programme: all animals are raised after weaning up to three years under a very high tsetse challenge. After finishing the performance test with respect to daily weight gain the selection takes place. The best males are chosen to replace the breeding males, whereas most of the females are allowed to breed in order to be performance tested with respect to milk yield. About 75 percent of those are chosen to replace females of the active breeding stock. For the estimation of breeding values the BLUP procedure is used utilising all known relationships.

The scheme is operated as an open nucleus. Thus the scheme is complemented by a large screening operation where during and after the main calving season milk recording at the village level is carried out (July to December). The goal of this screening is to identify outstanding village cows with respect to milk yield. After weaning, male offspring of such cows are bought and become part of the nucleus. Usually between 500 to 1 000 cows are screened each year in a thorough manner. The efficiency and especially the cost efficiency of the screening will have to be assessed in the near future. In the future the concept of open nucleus also implies the exchange of breeding material with other nucleus breeding schemes in the region.

Dissemination of genetic progress

We did not think that we would already have a product really worth disseminating (after four years breeding work in cattle starting from scratch, do not expect too much)! However, soon we will be able to have young bulls which are on average sufficiently better than any randomly picked bull. Thus preparation for multiplication has started and the first

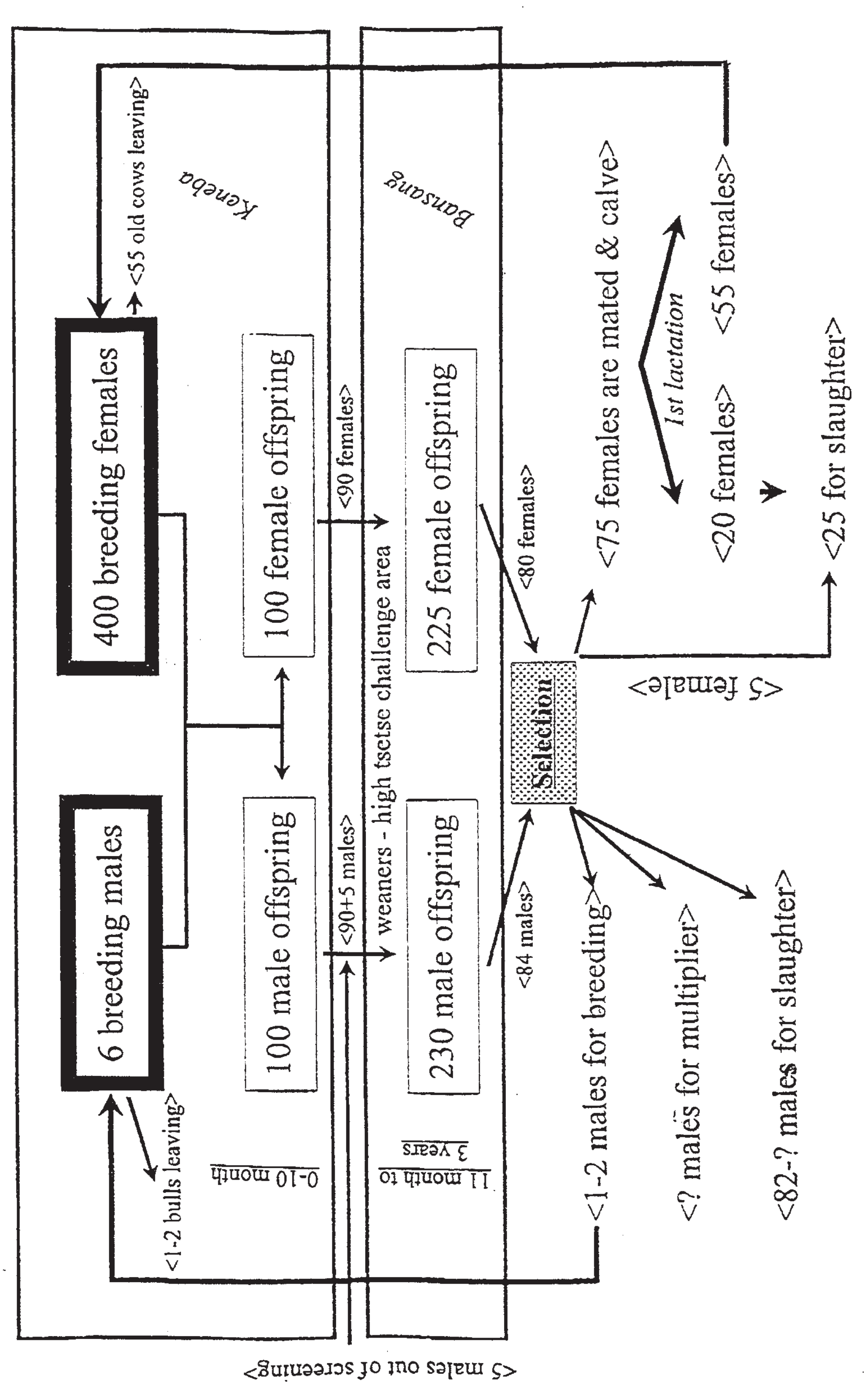

Figure 1. Cattle Nucleus Breeding Scheme (simplified).
Note: <...> annual movement; other numbers are stock numbers.

step was to learn more about the ownership structure (highly complex) and the management of the village herds. Also we will learn from our sheep and goat multiplication where, on a trial basis, presently we are building up multiplier herds (villages). In cattle it is envisioned to have a structure with

open nucleus -> multiplier -> producer

where any genetic progress is disseminated by males. It is to be remembered, however, that the final structure is not yet in place.

The breeding scheme is operated by ITC with funds from Germany (BMZ / GTZ) in cooperation with the Department of Livestock Service and building up links to organizations having similar breeding schemes in Guinea and Senegal. It was always tried to keep the scheme as simple and robust as possible (e.g. young sire programme) so that the running costs are low. A major factor in that respect is the training of dedicated local staff. It will only be sustainable if it is essentially run by local staff. The income generating ability of such a programme by selling breeding stock is judged as limited.

Additional remarks

As stated above, originally a progeny testing scheme was envisioned, but then due to the long generation interval of that scheme in general and especially the extremely long generation interval of the N'Dama, a young sire programme is more efficient and much more simple. Using the usual prediction equation (Rendel and Robertson, 1950) the genetic progress is calculated as more than one percent of the mean. It is hoped that by reducing the generation interval by means of management, that this figure can be increased. At present the testing period for daily gain is up to three years but the average age at first calving is five years. It should be tried to bring down this age at first calving. During the testing period (up to three years) the typical village management has to be applied but afterwards by supplementing, the heifers age at first calving should and could be brought down.

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Cross-breeding strategies for beef cattle production in Brazil

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Introduction

Beef cattle production in Brazil is an activity of historical importance. The bovine was introduced here in the first decades after discovery and since then, has not only been an important component of the socio-economic development, but also a fundamental element in the formation of the Brazilian agriculture Gross Income. The Brazilian bovine herd comprises of approximately 159 million head, while the *per capita* beef consumption is around 38 kg (ANUALPEC, 1997). The Brazilian beef production system is formed by three distinct phases: cow-calf, stocker and feeder phase. In spite of having some producers who develop any of these particular phases independently, the large majority of cattlemen work with the complete system, according to figure 1.

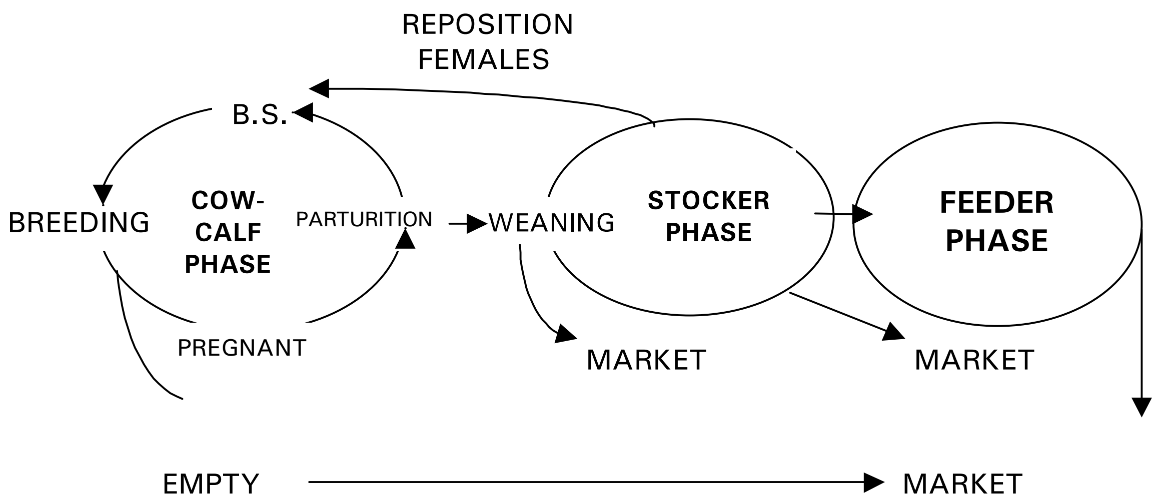

Figure 1. Structure of a complete Brazilian beef cattle production system. Source: Euclides Filho (1999a).

During the last years, similarly to what is happening in other important segments of the economy, this activity has been the object of a complete transformation. In fact, the different segments of the beef cattle production chain are becoming aware of the need to change due to the pressure imposed by different segments of the agricultural sector, especially those related to the production of swine and poultry and more recently, by external markets. The improvements should allow the establishment of a profitable, efficient and competitive business. In other words, the search for alternatives, which allow the establishment of a sustainable activity, becomes crucial. This scenario of changes is completed by modifications in the behaviour of consumers in Brazil that began to demand better quality products.

In such a context, the competitiveness of the final product constitutes an element of fundamental importance. In order to adjust them to this new reality it is necessary that the Brazilian beef cattle production systems make some changes. Among these changes are those which allow the production of animals to be more precocious in reproduction as well as in the finishing phase. Furthermore, it is important for such animals to produce beef of good quality, which should be understood as meat that is tender and free of residual toxicity as well as having low content of components known to be harmful to human health.

Among other things, Euclides Filho (1997) predicted that cross-breeding will, in the near future, play an important role in beef commercialised in Brazil.

On the other hand, it is clear that efforts are being made to integrate the different segments of the beef cattle productive chain. This, plus the demands put forth by the consumers, with respect to the quality of the final product, creates a requirement for animals which are able to produce tender meat in a biological and economic way. The average indexes observed in Brazil, however, are incompatible with such a need and are far from the known potential (Table 1).

Despite this scenario, several analyses performed during the last three to four years have indicated a clear possibility of increase in the participation of beef cattle in the Brazilian Gross Income. This is so, not only due to the increasing importance observed in the activity itself, but also by the great opportunities of insertion of Brazil in the international beef market.

This is possibly one of the reasons for enhancing beef production and for the establishment of an increasing number of animal breeding programmes in the country. Thus, what is presently observed is the existence of a great number of such programmes, with partner participation, all of them directed to genetic improvement of pure-breds and / or cross-bred animals.

Table 1. Mean performance indexes of the average Brazilian herd and in more developed technological systems.

Indices	Brazilian average	Improved System-1*	Improved System-2*
Birth rate	60%	>70%	>80%
Mortality until weaning	8%	6%	4%
Weaning rate	55%	>66%	>77%
Post-weaning mortality	4%	3%	2%
Age at 1st calving	4 years	3 years	2 years
Interval between parturition	20 months	<17 months	<15 months
Slaughter age	4 years	3 years	2 years
Slaughter rate	17%	20%	35%
Carcass weight	210kg	230kg	240kg
Dressing percentage	53%	54%	57%
Stocking rate on pastures	0.9 an./ha	1.2 an./ha	1.6 an./ha

Source: Modified from Zimmer & Euclides Filho (1997)
*Estimates taken from producers and from some experiments in process.

Cross-breeding as an alternative for genetic improvement

Among the several alternatives available to meet the demands mentioned above, cross-breeding could be emphasised. According to Euclides Filho (1996), this is an important tool for promoting improvement in the production and productivity of the beef cattle industry.

However, it should be mentioned that such expectation would only be met if the combination of breeds results in a composition that meets final business priority, which is, profitable. To meet this requirement, it is necessary that the animals resulting from cross-breeding produce high quality beef at competitive costs.

Under these circumstances, one way to fulfill demands related to meat quality and productivity of the systems, can be reached by crossing *Bos taurus* with *Bos indicus*. This tool has been utilised for many years with good results, but the frequency with which it has been applied varied through the years.

There are many experimental results and experiences in real production systems, which attests to the effectiveness of cross-breeding in contributing to the beef production chain as a whole, by improving biological performance (Euclides Filho *et al*., 1995; Euclides Filho *et al.* 1997a, b; Perotto *et al*., 1998). The contribution of cross-breeding can also be observed in the reduction in time of the production cycle by reducing the age at first calving and also, age at finishing and slaughter (Cezar & Euclides Filho, 1996 and Euclides Filho & Cezar, 1995). It is necessary, though, to proceed with more detailed evaluation, taking into account not only the capacity of the production systems to be profitable, but also account for their biological and economic efficiencies.

Cross-breeding involving an adapted European breed can also make a huge contribution, mainly, if that breed is combined with a specialised European breed. This should be done as a means of improving performance and carcass conformation.

Thus, the question is to find an ideal combination of breeds, which will meet expectations and contribute to sustainable and competitive production systems. Work done by Euclides Filho *et al*. (1999c) suggested that these needs can be attained by combining 75 percent of European genotype with 75 percent of adapted genotype (adapted European x half non-adapted European – half Zebu); or even, 75 percent and 50 percent, (non-adapted European x half adapted European – half Zebu), respectively.

Other experimental results have indicated that crosses between European and Zebu breeds, and even between adapted European breeds, can produce individuals which are good performers and have tender meat (Razook *et al*., 1986; Nardon *et al*., 1996; Euclides Filho *et al*. 1997a; Perotto *et al*., 1998).

First approach adopted by Embrapa Gado de Corte with respect to cross-breeding programmes

After the first great emphasis put on beef cattle cross-breeding programmes in the forties, this tool was largely forgotten in Brazil. Three decades later, however, in the beginning of the seventies, cross-breeding was rediscovered. At this time, several important cross-breeding programmes were initiated. During this period, the preference was geared to big size animals in clear support of breeding the objectives of weight and weight gains. Among the European breeds the chosen ones were the “Continental” breeds, and among the Zebu, the Nellore was the breed most utilised. At that time, late seventies, The National Beef Cattle Research Center from the Brazilian Agriculture Research Corporation (Embrapa Gado de Corte), started a cross-breeding programme based on a rotational scheme, which involved three continental breeds: Fleckvieh, Charolais and Chianina and the Nellore breeds. These crosses had weight gain and final weight as its main breeding objectives. After more than ten years of evaluation, it was concluded that the breeding objective should be changed and at least two aspects of the programme should be re-evaluated: the cross-breeding system to be utilised and the type of animal, which should integrate such a system. It is important to emphasise that the production system must be based on pastures, mainly for the cow-calf phase. This is so, due to the increasing requirement for efficiency improvement and to the need for maintaining pastures as one of the most important components of the beef cattle production systems in Brazil. This characteristic is crucial in the definition of the activity’s competitiveness.

However, it should be emphasised that, in general, these production systems are moving from a low input level to a medium and even, in smaller scales, to a high input one. This is true, especially for the other phases, namely, stocker and feeder phases (Figure 1).

With respect to the first point, cross-breeding programmes, it became clear that it should be set based on simplicity. As far as breeding objectives are concerned, the experience and the changes which have occurred in the demands pointed out the need for decreasing the emphasis on weight and weight gain. Discussions carried out on several workshops and meetings conducted with breed associations and representatives of other segments of the beef production chain led us to conclude that the breeding objectives should emphasise precocity while keeping in mind the importance of animal adaptability.

The new cross-breeding approach adopted

This new approach is focused on the search for genetic groups adapted to less use of chemical control of internal and external parasites, even though adaptation is not a breeding objective. Similarly, this approach will require profitability despite this trait not being included in the breeding objectives.

At this point in time, mid nineties, it became clear that the shift in the breeding objectives and precocity became the most important trait in their definition. Thus, the animals or genetic groups we are looking for should be early maturing, starting the reproductive life as young as possible; having moderate adult sizes and should also be able to produce tender meat in an efficient way.

Other important limitations related to the Brazilian production systems which affect their performance, include low managerial level of the farmers, inadequacy of labour reduced use of artificial insemination and limited capacity for investments. These constraints should be taken into account because they can limit the possible actions one can take and guide the introduction of any technology into the system.

Thus, any cross-breeding programme for such conditions should be based on two main aspects, which in turn will be the solution of the binomial profitability-simplicity. Euclides Filho (1999b), suggested that for tropical conditions, especially tropical Latin America, the beef cattle production systems should be based on the following cross-breeding types: i) terminal crosses; ii) use of a composite breed; and iii) use of cross-bred bulls, mainly the F_1s, as sires under natural service. More specifically the author classified the cross-breeding types as:

Terminal cross

1a) simple terminal cross; and
1b) classical terminal cross.

Composite genetic group

2a) Formed by F1s in *inter se* crosses;
2b) Formed by crosses between F1s out of two different sire breeds and from the same dam breed (third breed); and
2c) Formed by crosses between F1s out of two different sire breeds and from two different dam breeds (third and fourth breed).

These main lines of cross types in combination with the demands evidenced by the several meetings and workshops previously mentioned, have provided since 1993, the support that Embrapa Gado de Corte needed to redirect the work being conducted. Thus, the new approach was set up on the basis of three different lines of action:

i) comparison of efficiency of beef production systems that utilise F_1 females out of an European breed of medium size (Angus) and the Nellore breed, with the efficiency of systems based on F_1 female progenies of a large breed (Simmental) bulls and Nellore dams. In this case, a terminal sire is used and all the progeny is finished in a feedlot. This approach has the objective to identify the most profitable type of cattle for this production system;
ii) establishing the basic knowledge for the development of a composite breed involving Nellore, Caracu and Red Angus / Devon; and
iii) evaluation of crosses with the objective of developing, in a further step, a composite breed that combines only European breeds. In this case, two British breeds (Red Angus and Devon) will also be used with the objective of improving the reproductive and finishing precocity and carcass conformation. In order to execute these projects and to attend the proposed objectives it was necessary to establish cooperative work, in which farmers, breeder associations, research centres, private enterprises and universities have been involved. Such integration of efforts should contribute to greater efficiency in the transferral of the results to the entire beef cattle production chain and dramatically increases the scope of the project.

The last two approaches are based on the expectation that a composite breed, besides being able to utilise the benefits of heterosis would allow that small farmers utilise such benefits. Furthermore, the last approach would produce an animal that could be crossed with Zebu breeds allowing the system to capitalise important levels of heterosis.

Considering the first case mentioned above, the comparison tries to identify the animal type (medium or large adult size) that best adjusts to production systems where the cow-calf operation is kept exclusively on pastures. Since there is a need for less dependency on artificial insemination, the decision was to use a composite breed instead of an European one as a terminal breed. The composite breed chosen was a result of a cross between

Charolais and Nellore, named Canchim. The second cycle of this project should be based on the organization of an integrated system which combines Nellore breeders, F_1 female producers and terminal cross holders. The European breed to be utilised at this stage will be the most efficient one during the first phase.

Preliminary results of this project have indicated important differences between the systems based on animals of different adult sizes (Euclides Filho, 1995; Euclides Filho *et al.*, 1996 and Euclides Filho *et al.*, 1999a, b).

Considering the second and third alternatives, the initial work has been concentrated on the evaluation of crosses involving two different genetic bases for the dams: one based on a Zebu breed (Nellore) (ii), and the other where the dams are from an adapted European breed (Caracu) (iii). The results of this phase, also preliminary, indicate a great possibility of success. Euclides Filho *et al.* (1999_c), in a trial to evaluate the crosses involving one Zebu breed (Nellore) and three European ones, two non-adapted (Angus and Simmental) and one adapted (Caracu), observed that the cross-bred animals (half Caracu – quarter Simmental – quarter Nellore and half Caracu – quarter Angus – quarter Nellore) had higher weight gain and better food conversion than the Nellore. Furthermore, the authors observed that the cross including Angus conferred best food conversion and the greatest weight gain. Panel tests and the Warner-Bratzler Shear evaluation have indicated a high degree of acceptance of the meat produced by these animals with special reference to tenderness.

Regarding the crosses involving Caracu dams (iii), the results are still not available as the first inseminations were performed in the last breeding season. This project is being carried out in cycles. Each cycle should last for three to four years and will be composed of different groups of breeds. During the present cycle the following breeds are being evaluated: Caracu, Belmont Red, Senepol and Romosinuano.

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Dairy cattle breeding programme in Brazil development of the Brazilian milking hybrid (MLB)

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Introduction

The MLB programme (Portuguese standing for Brazilian Milking Hybrid) is described below. This was a research and development programme conducted by the National Dairy Cattle Research Centre of the Federal Research Organisation (EMBRAPA) with the assistance of the FAO / UNDP Project BRA / 79 / 010. Its main objective was to obtain experimental information to design selection criteria for new hybrid cattle breeds, combining dairy, reproduction, growth and adaptation traits, while developing cattle suitable for the dairy production systems of the Brazilian Tropics.

The programme was initiated in 1977 to estimate the genetic parameters for traits sought, a half-sib family structure was convenient, which was obtained by implanting a progeny-testing programme. This was the first dairy cattle progeny-testing programme in the country. It was also the first time that the idea of a multi-breed cattle composite was put to work in Brazil, as only two breeds were previously admitted as founders of new breeds in technical and practical circles.

Species involved

Cattle (*Bos taurus* x *B. indicus* hybrids).

Breeds involved

Most dairy cattle in the tropical regions of Brazil are *Bos taurus* x *B. indicus* hybrids. The gene fraction of each species varies widely, even within farms. Results of a recent survey involving 291 farms and 7 195 cows in the State of Minas Gerais are in figure 1. The predominant breeds were Gir (78 percent of the farms) and Holstein-Friesian (91 percent).

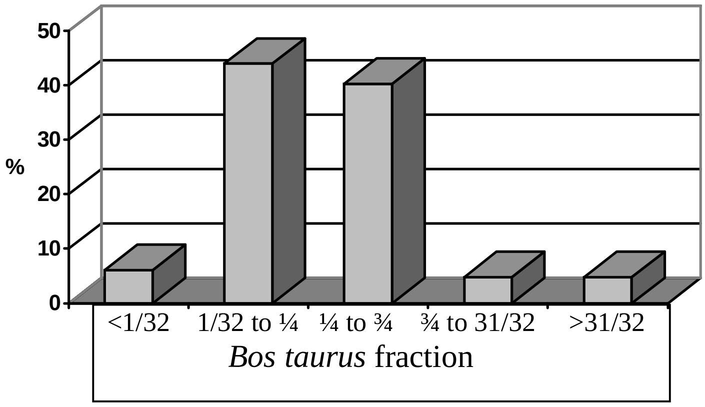

Figure 1. Percentage of cows in Bos taurus fraction classes (n=7 195). Source: Madalena et al. (1997).

When the MLB programme was formulated, several institutions and private breeders were separately engaged in projects for developing new synthetic *B. taurus* x *B. indicus* dairy breeds, based on different founder breeds of each species. Borrowing an idea from H. Skjervold in Norway, it was proposed that all those projects merged together in a single progeny testing programme, which would not be possible in the former separate single herd structure. Such merging required that each herd abandoned its previous breed composition and improvement target for a common selection criterion. Thus, any herd keeping dairy records of hybrid cows would be enrolled. Bull dams were selected as the elite top yielders in each herd, irrespective of breed composition (or type or coat colour). Breed composition was not a selection criterion because it was considered that good genes could be obtained from any breed (genes have no breed) and genetic variation was desirable. The composition of the overall population in the initially available 14 herds with dairy records is presented in table 1.

Besides using several founder breeds, the programme aimed at a flexible *B. taurus* x *B. indicus* fraction. Based on previous results, limits for the *B. taurus* fraction were set at 1/2 to 3/4 for bull dams and 1/2 to 7/8 for the young bulls themselves. This contradicted the taboo that new breeds must be of exactly 5/8 *B. taurus* fraction, still prevailing among many farmers although it was a long time since Lush (1927) had shown the irrelevance of blood percentage to predict individual performance.

The programme maintained its gene pool opened for new herds and individual bull calves to join in. It was also intended to introduce foreign germplasm of other tropical dairy breeds via insemination of bull dams but this could not be accomplished.

Table 1. Average gene percentage of elite dams and sampled bulls in the MLB programme.

	Dams %	Bulls %
Bos taurus	62	72
Holstein-Friesian[1]	52	64
Brown Swiss	2	5
Other[2]	8	3
Bos taurus	38	28
Guzera	20	21
Gir	12	4
Zebu-type	6	3

Source: Madalena (1989).
[1] Both Red and White and Black and White.
[2]Red Dane, Simental, Jersey, Caracu, unknown European breed.

Input level of the production system

A description of dairy production in Brazil was given (Madalena, 1998a). Dairy farms in the tropical part of the country are typically small, low input/low production systems based on hybrid cattle. In the above mentioned survey manual milking in the presence of the calf was practised on 95 percent of the farms and 78 percent of the cows were milked once a day. Nonetheless, a wide variation of practices exists, even within regions, associated not only to geographical differences but also to farm size and the socio-economic factors related to it. For example, once a day milking was practised on 95 percent of the farms selling <50 kg milk/day and on 33 percent of the farms selling >100 kg/day. Most (46 percent) farmers wished to keep the herd intermediate between *Bos taurus* and *B. indicus*, 13 and one percent wished to go pure-breeding of either species and 40 percent had no definite goal in this respect. In the Southeast Region, which produces 45 percent of the country's milk (7 million ton/year), average yield per cow is 885 kg/year.

It has been claimed that such production systems should be substituted altogether by intensive systems based on high yielding Holsteins. However, economic results do not sustain such claims. Capital intensive systems have not had higher net margins nor return on investment than the commonest extensive systems (Holanda Jr. and Madalena, 1998). It is not meant to say that prevailing systems are efficient, on the contrary, there is ample opportunity to improve them, provided new practises are adopted on the basis of cost/benefit, rather than on mere imitation of those in developed countries, where the economic conjuncture is completely different. Optimisation of use of local resources, such as solar energy, C_4 grasses and adapted cattle, may lead to very efficient systems, irrespective of milk yield per cow being much lower than in the intensive systems of temperate countries (Matos, 1996).

Numbers of animals

Initially 6 092 lactations of 2 300 cows in 14 herds were available to select elite dams of bulls to be sampled. This changed over time with some herds leaving the programme and new ones joining in. The programme was dimensioned to progeny test ten sires per year with 30 daughters each.

Target and dissemination of improvement

As a by-product of research the MLB programme produced semen of proven bulls. Being a pilot scheme, semen production would serve only a tiny fraction of the dairy commercial population, but it was assumed that after some years of improvement the elite herds would be transferring genes to other herds, both commercial and multiplier. There was a clear precedent in the now well-established beef breed Canchim, which was developed in the sixties by a Governmental institution and then handed over to private breeders.

Breeding goal

The goal was defined as “the development of a dairy cattle population adapted to the production systems prevailing in the Brazilian Tropics”. Research on formal definition of breeding objectives is very recent in Brazil. A major bottleneck is the paucity of data from farms keeping economic records. An earlier review (Madalena, 1986) failed to find economic evaluations of breeding objectives in tropical countries.

In the above goal definition, “prevailing systems” were considered those used on farms keeping records of hybrid dairy cattle, which by itself implies some improved management. The farms involved practised milking twice a day generally in the presence of the calf and with low concentrate inputs. In the 14 elite herds the average 305-d milk yield was 2 549 kg (mature equivalent) and in 23 herds for testing bulls the corresponding average was 1 793 kg (mostly first and some second lactations). It is conceivable that the best genotypes for such an environment might not be the best in the harshest conditions found in small farms milking once a day. However, it was not possible to test bulls in farms that did not use AI.

Breeding plan

The programme had a conventional progeny testing plan in which the ten bulls sampled every year were to be the progeny of the best sires and dams available at the time.

Initially, until specific matings could be arranged, candidate bull calves were chosen on dam performance only. In a second stage, sires of bulls were both MLB sons of the very best dams and USA and Canadian Holsteins with high milk predicted differences.

After proven bulls became available, it was intended to use the best two tenths of each yearly batch as sires of bulls (a stage never reached). In this way and by the continuous introduction of new herds and bulls inbreeding should have been kept reasonably low.

Actual versus planned programme

There were no major deviations from the planned progeny testing programme. However, improvements were gradually introduced in the genetic evaluation procedures. Initially, no suitable software was available to estimate genetic merit, so dam selection was based only on the cows' performance (most probable production ability), but later on specific software was developed (by Jan Dommerholt, 1981) to estimate breeding values on an index based on cow performance (first three lactations), sire and dam breeding values and the herdmate genetic level. Nonetheless, some outside bull calves were also sampled, for opportunity reasons, although their dams could only be evaluated on their crude dairy performance.

A major departure from planned action occurred in the research aspects of the programme, as adaptation traits could not be recorded as intended because of lack of funding.

Traits in breeding goal

As no formal, quantified definition of the breeding objective could be formulated, milk yield in the prevailing systems was provisionally the only trait included in the goal, until data became available for reappraisal of this point.

Traits measured

Milk yield in a standard 305-d lactation in the existing farming conditions was the sole selection criterion, again until the project had gathered enough data to review it.

A data set of 90 progeny groups was the target planned to estimate heritabilities and genetic correlations among dairy, reproduction, growth and adaptation traits. Traits measured (but not used for selection) were: milk, fat and protein yield, lactation length and age at first calving (in all females) and weights (only in some institutional herds having scales). A procedure to evaluate tick resistance of young bulls before semen collection was adapted from Australian protocols in consultancies with Drs R.W. Hewetson (1980) and K. Utech (1981). Bulls were artificially infested with 20 000 larvae of *Boophilus microplus* ticks and semi-engorged standard larvae (4.5 to 8.0 mm) were counted on the animals' right side on days 19 through 23 after infestation. Some female progeny were also scored for tick counts under natural and artificial infestations. It was not possible to collect data on rectal temperatures and worm eggs per gram as intended.

Methods of dissemination of improvement

Dissemination was through frozen semen of proven bulls, lent under contract to commercial AI companies, at their request. Since this was not a commercial programme, no special structure was established to market semen, although the semen production unit was officially qualified to do so and did effect a few sales directly.

Breeding structure

The structure may be described as a diffuse open nucleus formed by the elite dams screened. Genes would flow from the recorded herds to the rest of the population but new elite dams and sires could come from new herds or from abroad.

New herds with records, the sources of elite bull dams, were continuously being identified and incorporated into the programme as much as possible, due to limitations in financial resources. Incorporating a herd involved a visit, photocopying records, putting them into the computer, correcting errors, running the genetic evaluations, selecting bull dams and further visits to check the computer selection with the herdsman or farmer's opinion (they generally agreed) and to deliver the semen for the selected elite dams.

Farmer and Government involvement

The programme was based on two kinds of farms, those that had records and those receiving semen of sampled bulls. Some farms did both, some were institutional and some private.

Leadership was from the FAO / UNDP / EMBRAPA Project. The National Research Centre financed communications, data processing, semen production and distribution and milk recording in farms testing bulls. A bull rearing unit and semen processing laboratory were set up at EMBRAPA's unit in São Carlos, SP (presently Southeast Livestock Research Centre) by Dr H. Bruschi and operated by Drs J.P. Eler and R.T. Barbosa. Dr Raymond Jondet, from URCEO, Rennes, provided valuable technical consultancies to solve many semen production problems with young hybrid bulls (Jondet, 1981). Equipment for frozen semen production and milk fat and protein analyses were provided by the FAO / UNDP Project, as well as some funds provided by the Nordic project for development of AI.

Farms with records provided the bull calves, which were lent to EMBRAPA but continued to belong to the farmer. These bull calves were very valuable to breeders having their own breed development programme (sometimes going back for up to six generations) but would be sold as veal in common milk-producing farms. Transport to and from the semen collection centre, rearing costs and health exams were met by EMBRAPA. Farms testing bulls received two semen doses per cow free-of-charge, upon an agreement to keep the daughters up to the end of their first lactation allowing monthly dairy recording. Only well organized farms with good AI standards were accepted.

As a by-product of research the MLB programme produced semen of proven bulls, and as it turned out, the by-product became much more popular than the primary research objective. Initially Ministry of Agriculture officials would not license the bulls on the grounds that they were not pedigreed, but later on marketing of semen was allowed. It soon became apparent that a market existed for that kind of semen (something previously unthinkable) and some AI companies contracted programme bulls (or even used some hybrid bulls from other herds, pedigreed but not progeny tested). Some semen also found its way into neighbouring Paraguay.

Two items of legislation related to the scheme have now been modified, not necessarily because of it. It is no longer obligatory that AI bulls be pedigreed in Brazil, provided they obtain a special certificate justifying they are from sound genetic improvement programmes. Flexible limits for *Bos taurus* and *Bos indicus* fractions became accepted by the Ministry, when recognising the new Guzolando (Guzera x Holstein) breed.

Technical support

The Government invested heavily in the development of its research organization, EMBRAPA, which provided the highly trained staff, abroad or in Brazil, at PhD level. The in-service training provided by the FAO / UNDP Project was also of assistance in building up expertise at the National Dairy Cattle Centre in a number of aspects, including the logistic, technical, scientific, relations with breeders and general divulgation of progeny-testing and genetic evaluation concepts.

Research results are essential since many aspects have no precedent in the literature. Some follow.

Semen production

Late development of quality semen of young bulls was a problem for early testing. Based on 12 625 ejaculates of 156 bulls, the average volume was 4.7 cc, with 779 x 10^6 sperm cells / cc and 46.4 and 22.4 percent pre- and post-thawing motility, yielding 17.8 pre-thawing doses per ejaculate (Abreu, 1999).

Bos taurus fraction of bulls

In a recent study with MLB data, Freitas *et al.* (1998) found no differences among the progeny of 5 / 8, 6 / 8 or 7 / 8 *B. taurus* bulls, thus justifying the flexible limits adopted in the programme instead of strictly adhering to a fixed blood percentage.

Sires of bulls

As it turned out, whether the sire of sampled bull was pure-bred or cross-bred, it had no detectable effect on the granddaughters' yield (Freitas *et al.*, 1998).

Bos taurus fraction of mates

Because of the wide between and within herd variation in cross-bred types, from extreme *B. indicus* to extreme *B. taurus*, the type of mate would be a source of bias of progeny-tests. To make adjustment for it, the *B. taurus* fraction of mates (in eights) was assigned by visual inspection when not recorded and treated as an environmental fixed effect. In addition, bulls had mates assigned seeking uniformity of the *B. taurus* fraction distributions within farms. An effort was also made to have every bull represented at each farm, because farms differed in management and in breed composition. The relevance of these procedures was also supposed to be evaluated later on, when enough data would be available.

Lactation length

The cause for lactation termination was not usually recorded for the herds providing elite dams. It was initially thought that in the absence of information, discarding short lactation records (<120d) would eliminate abnormal terminations. Later work showed this procedure to be correct for individual cow selection, but not for sire progeny testing. Because in non-improved populations lactation length is heritable and its genetic correlation with yield approaches one, deleting short lactation records removes more genetic than environmental variation among the sire progeny groups. Adjusting for lactation length has a similar, but more pronounced effect. The result is a drastic reduction in the heritability and the genetic progress for milk yield (Madalena, 1988). This also applies to the comparison among cross-bred groups and is a main source of literature discrepancies on estimates of heterosis and recombination losses (Madalena, 1994).

Genetic and phenotypic parameters for milk and component yield

Parameters for dairy traits in the MLB programme are given in Table 2. Data included all lactations, irrespective of length and cause for terminating record. However, Freitas *et al.* (1995), analysing a similar data set, reported $h^2 = 0.14$ when lactations <120 day duration were deleted and $h^2 = 0.06$ when yield was furthermore adjusted for lactation length, thus confirming the bias caused by these procedures.

The estimate of heritability of 305-d milk yield was similar to the literature average of $h^2 = 0.25$ reported by Lôbo *et al.* (1999a) for tropical countries. Genetic parameters for dairy traits were also similar to those found in temperate regions, so the contention that genetic improvement would not be possible in hybrid breeds is not at all sustained by the experimental evidence.

Tick resistance

As it may be seen in table 2, heritability of tick burden was rather high and in line with the literature. The low genetic correlations between tick resistance and dairy traits indicate that there are no important genetic antagonisms between those traits.

Reasons for introducing the scheme

The scheme was introduced because improved tropical dairy breeds could meet the farmers’ preference for hybrid cattle without resorting to cross-breeding, difficult under the prevailing natural mating practice and several private and public projects were being conducted to develop such breeds.

Table 2. Heritabilities (in the diagonal), genetic (above the diagonal) and phenotypic correlations (below the diagonal) in inter se hybrid Bos taurus x B. indicus in Brazil.

	Milk yield	Fat yield	Protein yield	Lactation length	Log tick burden
Milk yield[1]	**0.23**	0.91	0.92	0.95	0.06
Fat yield[1]	0.87	**0.29**	0.96	0.94	0.07
Protein yield[1]	0.86	0.81	**0.21**	0.72	-0.14
Lactation length[1]	0.78	0.73	0.70	**0.10**	-0.13
Log tick burden[2]	0.13	0.12	0.17	0.16	**0.49**
	kg	kg	kg	days	
Mean	1 793	61	47	248	1.621
σ_P [3]	743	28	21	64	0.672
Repeatability	0.51	0.48	0.44	0.29	0.62
Observations	2.321	1.743	1.738	2.209	1.955

Source: Conceição Jr. (1997).
[1]Truncated at 305 days.
[2]Log (2 x count +1).
[3]Phenotypic standard deviation.

What made it happen (and cease)

The project evolved from a meeting organized by the National Dairy Centre to coordinate research, where it was seen that several institutions were separately directing efforts to breed development. The idea of joining efforts was readily accepted by most institutions and received strong support from the EMBRAPA Board of Directors, which made the programme really happen. The farmers' satisfaction with the progeny performance contributed greatly to maintaining interest.

However, when the programme started operating smoothly the authorities changed and the initial support was lost. Ironically, by this time it was apparent that several thousand hybrid dairy recorded cows could be recruited, the programme operational expenses could be met by semen sales and it had gained favourable opinion in the agricultural press and in technical circles. The programme had been formally terminated but a total of 121 sires were progeny tested. Summaries for milk and fat were published in 1995 for the first 68 sires and the information from the rest is available although not yet processed.

What changes should be made?

Private sector involvement

This is the more important element to guarantee continuity. The MLB programme showed in actual practise that progeny-testing of dairy bulls was a feasible and commercial proposition and in its track other progeny testing schemes were or are being developed, the eldest being that in the milking Gir, run together since 1985 by EMBRAPA and the breeder association (ABCGIL). This has been a successful partnership, as it allied the technical proficiency of the research staff with the operational ability of the private sector, thus overcoming the clumsiness inherent to public administration.

Investment level and legal framework

As mentioned above, there is a basis for a breed development scheme run on a much larger size than the pilot small-scale described, but this would require a larger investment. An appropriate legal framework is needed in a scheme directed at the commercial exploitation of genetic improvement. The lack of such organization was felt in several aspects. For example, lay off bulls had to be returned to their owners and there were cases in which they could not be recovered for semen production after becoming proven. The breeders' association structure has been instrumental in organizing testing but a more centralised organization would be better for selection decisions.

Defining breeding objectives

Although this should be the very first step in a selection programme, it continues ill defined, mainly because research institutions are not aware of its importance and do not devote efforts to this end. Some recent results indicated negative economic values for milk protein and fat, a question that calls for a national discussion of the different sectors of the dairy industry on the pricing of milk components, to avoid selecting in the wrong direction (Madalena, 1999). Other studies, unfortunately based on data of just one farm keeping detailed economic records, indicated that reducing cow weight was even more important than increasing milk yield, even in a dual purpose system, so liveweights at young ages had negative index weights. Milk flow, herd-life, mastitis and age at first calving were important components of the overall economic merit (Vercesi Filho *et al.*, 1999, Lôbo *et al.*, 1999).

There seems to be no reason to worry about milk let down since milking in the presence of the calf is the method preferred by farmers. Recent results have shown that twice a day suckling increased saleable milk by 10 percent over artificial rearing, while practically not affecting the calving to conception interval nor the growth of the calf (Campos *et al.*, 1993). Calf health costs more than triplicate with artificial rearing (Ugarte, 1992). Therefore, it remains to be proved whether artificial rearing is any better than restricted suckling in tropical systems. The same may be said to the related question of machine milking, which may or may not be convenient, depending on circumstances (Madalena, 1993).

Future

Experimental results now available indicate a large economic superiority of the F_1 and suggest a strong recombination loss for milk yield (Madalena *et al.*, 1990a,b). Farmers have now grasped this superiority and a commercial market has developed for F_1 females in Brazil (Madalena, 1998b) as is also the case in Venezuela and Colombia (J. Ordoñez and A. Restrepo, personal communications). Production of F_1 females has an economic basis both using AI or MOET (Madalena, 1993, Teodoro *et al.*, 1996).

Nonetheless, it must be recognised that not all farmers will be able or willing to buy F_1s or to use a cross-breeding system and some may prefer the simplicity of using a hybrid bull. In fact, in the survey on farm dairy practices mentioned above, a census by breed indicated that 40 percent of the bulls were hybrid (Madalena *et al.*, 1997). The strong development of the new hybrid breed Girolando (Gir-Holstein) founded in 1989, registering more than 6 000 animals per year, supports the commercial acceptance of this type of animal. In 1998 16 700 doses of semen of this breed were sold, amounting to 6 percent of the semen of tropical dairy breeds. The Breeders' Association has recently implanted a small-scale progeny-testing scheme and is seeking to strengthen it.

Although the Girolando is formally a Gir x Holstein hybrid, many founder cows are in fact of non-descript origin and have genes from other breeds as well. Thus, the multi-breed composite concept is being applied in practice, even if it is still not formally recognised. However, beef composites have had a strong commercial irruption in Brazil, so it is likely that the concept will also become accepted in the dairy industry as well.

The need for distinct breeding programmes in Brazilian Holsteins, milking zebu breeds (Gir and Guzera) and new synthetic breeds developed from hybrids has been recognised (Touchberry, 1979). Although selection in Holsteins for performance in the tropics has not received attention, programmes have / are been established in the other breeds, so the lessons and experience gained from the MLB programme were not entirely lost, although one generation of selection is being wasted.

It is felt that consolidation and expansion of the progeny-testing schemes in the Brazilian tropical dairy breeds will continue, as farmers progressively learn to distinguish supplies of genetic materials that genuinely improve economic performance in their production systems. The export market is also very important and will also favour modern breeding programmes, given the comparative Brazilian advantages in the logistics involved. How fast will developments occur basically depends on the investors perception that selection programmes are good business in the tropics, as they have been everywhere else.

Genetic change

The MLB programme did not reach the stage where genetic progress could be measured, as almost all bulls sampled were of the initial generation.

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Development of animal breeding strategies for the local breeds of ruminants in the French West Indies

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Animal breeding programmes were initiated a few years ago in the local breeds of three ruminant species used for meat production in the French West Indies: Martinik hair sheep, Creole cattle and Creole goat ("*Cabri Créole*") of Guadeloupe. The population size of these breeds is presented in table 1.

These breeds are the base of traditional farming systems, in small familiar farms with low input level, which represent the main animal production systems in the French West Indies. But they are also used in medium input level production systems on pasture, with the use of irrigation, mineral fertilisers, complementary feeding and intensive reproduction management. The management improvement is sometimes associated with the use of exotic breeds, in crosses or pure-bred, mainly in cattle. The development of breeding programmes for the local breeds is a new approach.

Table 1. Population size of Martinik hair sheep, Creole cattle of Guadeloupe and Creole goat of Guadeloupe.

	Breeding females	Total number	% total animal
Martinik hair sheep	11 000	28 000	95
Creole cattle of Guadeloupe	25 000	46 000	75
Creole goat of Guadeloupe	20 000	35 000	95

The Martinik hair sheep programme, initiated seven years ago, is the more active breeding programme. In the two other species, the programme is still at the beginning. The conception and development of these programmes is quite different in the three species, while the general background seems to be the same. Operational and technical aspects are presented below and the general policy will be discussed later.

Organization and operational aspects of the Martinik hair sheep programme

In Martinik hair sheep, a commercial structure has existed for years and controls about half of the total production. In 1993 some of the main breeders in this structure decided to create a breeding association, for the maintenance and the management of their sheep population. This population consists of animals originated from various hair sheep breeds largely spread out in the whole Caribbean and mixed in Martinican farms. For this reason, the individuals of the different phenotypes showed little differences in their body measurements and performances in local conditions. Then, all these phenotypes were grouped to constitute the Martinik hair sheep breed. However, 85 percent of the selected animals belong to the Black Belly type. Some phenotypic traits are rejected, such as wool or horns.

The breeding goal has been defined from a technical approach, according to the commercial objectives of the breeders: to improve the nursing ability of the dams and growth and body conformation of the lambs. The objective is also to sustain the qualities of the population, such as adaptation to the tropical climate, in particular to the use of pastures, the resistance to nematode parasites and good animal reproduction characters: prolificacy and deseasonnality. The reproduction system involves a high reproduction rate, with three lambings every two years and the regularity of lambing throughout the year, is also taken into account.

After two years of working, the Martinik hair sheep programme was completed in 1995, with its different operating levels in function. These levels are those defined in the French breeding system for the hardy sheep breeds used for meat production. It includes on farm performance recording and selection of young rams in a breeding station. The same criteria are used: number of lambing per year, litter size, viability of the lambs, live weight gain of the litter between ten and 30 days of age (ADG10-30), individual growth between 30 and 70 days (ADG30-70), estimated liveweight at 70 days (LW70), visual assessment of body conformation.

An individual evaluation based on the use of a BLUP-Animal Model procedure is applied on these different traits and performed in the national genetic evaluation process, the same as the other French sheep breeds. Separate indexes are calculated for ewes on litter size and nursing ability (including ADG10-30 and viability), and for the rams on the same traits and growth until 70 days (including both ADG30-70 and LW70). Genetic values of the lambs is also computed for the different traits. The on-farm selection concerns mainly the breeding ewes, for their own performances, particularly their nursing ability. Young male and female lambs are also selected according to the results of their mother, along with their own results for growth until 70 days.

Young rams selected from different flocks are then grouped in a station, where they are raised on pasture, with a limited amount of complementary feeding. Three bands of about 20 growing rams are controlled in the station each year, between eight and 12 months of age. The main purpose of the station is to control the dissemination of improved rams for breeding; another purpose is to ensure they reach adequate body development. This trait is evaluated at the end of the control period by a trained panel of experts, using a precise scoring method. Rams are finally selected upon a synthetic score including both their origin (parents indexes and individual performances on farm) and their final development in station. About half of the rams are disseminated to the breeders as improved sires, the rest being sold to slaughter.

Therefore, the sheep population in Martinique appears as a stratified population with a few elite breeders, owning about 800 ewes, involved in the breeding programme. Dissemination of selected animals is organized by the breeding association and consists in young rams from the station and ewes from the elite farms. About 200 ewes and 30 rams are sold each year, firstly to the selection breeders for the replacement of their own flock, but also to the base of the population, in the commercial herds or other farms. The selection base remains open, in order to include new farms and new breeding animals in the population under selection.

Technical design of Creole cattle and goat programmes

In the two other species, the breeding programmes have been introduced because experimental results showed the interest in the local breeds and their potential. The target was defined for the first time for the whole breeding population, due to a lack of professional organizations. The first step consists of the inventory of the population and a survey of the management system and the farmers' practices. The purpose of this survey is to describe the population structure and breeding management in order to identify the farmers more concerned with a breeding programme, according to their objectives, what type of animals they use, their strategy of mating and replacement of animals and the herd structure. This step leads to the implementation of a stratified programme, with a few selected breeders identified within the population and involved in the programme. The aims of the genetic improvement programmes are then defined from a technical point of view, according to the farming systems concerned and the production objectives, in terms of the choice of the breeding goal, the organization of the programme and the operations.

Creole cattle

This approach already led to the definition of a general framework, approved by the French Ministry of Agriculture in 1995. Then a breeding association was formed in 1998, with about 75 farmers owning more than 2 000 Creole cows. For these breeders, corresponding to intermediate production systems, adaptability of the Creole cattle is important in their extensive management conditions. But they are also concerned with beef production characters. So, the breeding goal is mainly to improve the meat production characteristics, and the main traits are growth and conformation. Maternal qualities are also considered, especially nursing capacity, as a secondary goal. The objective is also to maintain the adaptation of the animals: adaptation to tropical climate, resistance to internal parasites, ticks and tick born diseases and longevity.

The technical tools are those used in the French beef and hardy breeds, for the usual production traits; but some adjustments due to the evaluation in local conditions and to particular traits are necessary. On farm performance recording concerns the growth of calves during the first four and seven months, in order to improve nursing ability of the cows and to take into account both maternal and individual abilities for growth. Body development of the calves is visually assessed at weaning. To maintain the adaptation of the local Creole cattle to tropical conditions, the controls took place in usual management conditions in traditional or commercial farms. The initiation of the practical operations took place in 1999 and are carried out by technical extension services.

A breeding station has been planned for the selected young males from the field, but is not yet operating. In this station, bands of about 15 young bulls, selected periodically at weaning, will be maintained on pasture for a year, under improved grazing management. Intensive grazing management will ensure regular growth, but also the direct incidence of tropical climate, parasitism and medium quality forage. Finally, growth on pasture and conformation of the bulls will be estimated at the end of the period. For the first time, adaptation traits will be indirectly assessed by the production obtained in regular conditions; but they could be included in the scheme when some easy control procedures will be developed.

Creole goat

The precise definition of the breeding programme is still being studied, but practical aspects could be similar to those of Martinik hair sheep. Important traits in Creole goats concern the mothering quality of the females, which should be maintained. A high prolificacy is usually obtained and probably should not be raised further; but its standardisation could be a reasonable objective. A more consistent genetic progress can be expected for nursing abilities and growth until weaning for which maternal effects are quite extensive. Growth and body conformation are also quite important for the producers. Finally, particular attention is focused on genetic resistance to gastro-intestinal parasites, which is a major disease for goat production in our conditions.

General policy for the design of animal breeding programmes in the French West Indies

In the different species, the design of the breeding programmes is conditioned by the French and European policies for the animal breeding programme, warranted by the French Ministry of Agriculture. The plans have to be approved by a national commission, which evaluates the different technical and organizational points of the programmes. The general procedures and methods are defined by technical and scientific national institutes, while the practical implementation of the programme for each breed is the responsibility of local technical and administration levels, including breeder representatives. This general framework can be seen as a facility, as the different steps are already well defined and operational tools exist in the French system. According to that scheme, the programmes for Martinik hair sheep and Creole cattle have been both discussed and approved by professional and administrative structures, locally and at a national level. However, in the French overseas departments, the agricultural sector is under-developed and a lot of administrative, organizational or technical aspects have to be newly implemented, without any background.

These policies first suppose that breeder associations are active in control, management and promotion of the breed. They are fundamental in the organization and implementation of the selection procedure at farmer level. Such an association has existed for years in Martinik hair sheep, where the programme was initiated and has been particularly active since the early days. The success of the programme can be attributed to the existence of a strong professional structure, for which its development was also discussed. It also depends to a larger extent on active technical extension services, organized in the early 1970s. European and national financial supports permitted the initiation of the programme. In particular, the investment at the beginning was made by European structural funds. Salaries of two technicians in charge of the farmer technical survey, the on-farm performance recording and the operations in the breeding station, are financed by regional professional structures, partly with their own funds and partly from public subsidies.

In Guadeloupe, the main difficulties in setting up the programmes are the absence of professional structures and the lack of public financial support to initiate the operations. Technical extension services were reorganized in the early 1990s and European and national subsidies for equipment and salaries of technicians were only received in the last few years. In Creole cattle, while the breeders association was constituted in 1998, the technical part is not yet active in the field. This lack of technical support could impair the development of the whole programme, as farmers could loose their trust in it. It constitutes the priority for the next few years, as a consensus exists concerning its interest. For the same reason, the accent in the Creole goat programme has been put firstly on the implementation of a technical survey and performance recording in farm.

The implementation of selection programmes may also appear as a way to organize the animal production sector. Breeder associations are considered as technical extension services and their advice concerning the herd management is also required by some farmers. In Martinik hair sheep for example, one of the first outcomes was the definition of breeding management strategies, including mating lots and separation of the physiological stage. Technical advice is also required in animal feeding or animal health, in the different species.

The management of animal genetic resources, however, remains controversial. Genetic improvement has often meant the use of specialised breeds. Industrial cross-breeding (first or second generation) is often practised, but also rotational crosses or the substitution of the local animals with specialised breeds. This breeding management is partly due to the awareness of a “fair animal” by the farmers. It is also a consequence of a policy from technical, commercial or administrative organizations, which provides subsidies or technical support to these practices. Technology transfer facilities, such as the promotion of AI or the import of selected animals from northern countries, appears as a short term and low cost solution for animal production improvement. In most cases, technical solutions are adopted without real knowledge of the conditions of their use and their consequences. For example, basic notions on genetics are unknown by most farmers; therefore advantages of AI and cross-breeding in beef cattle are often attributed only to the semen of the selected bull used. Then the necessity to maintain and improve the local breed and its possible contribution as a maternal breed, are neglected. The development of breeding strategies based on local breeds for the usual farming systems appears therefore as a goal. Information and education on breeding management also appears as a key point for the development of animal breeding programmes.

Particular support is given by national research and technical institutions. In particular, experimental results led to a reappraisal of the interest of local breeds. In addition to scientific results, research institutions also play a role in the dissemination of information through education and training. Their references also permit the definition of the technical conditions for the selection programmes: evaluation of the genetic parameters for the different characters, set up of genetic evaluation models adapted to local breeding conditions and studies of the genetic variability of the resistance to parasites. Experimental herds can also be seen, at the present time, as nucleus herds. While the breeding programmes in Creole cattle and goats are not fully operating, experimental flocks can play a role in the dissemination of selected material. But limitations are due to the low number of animals in these flocks. The implementation of on field programmes, based on a sufficient number of dams, is a necessity. In Martinik hair sheep, the selection base is still limited and should also be enlarged in the next years and particular attention is given to the management of the breeding animals, in order to avoid consanguinity.

Several research results showed that the local breeds could be valuable resources for the development of animal production. The techniques and methods to improve their performances are known and have been adapted to various conditions. The maintenance of the breeds and their improvement depends on the adoption of breeding strategies adapted to local animal production.

Breeding strategies for low input animal production systems: a case study from Central America and Mexico

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Introduction

Several breeding strategies and management systems have been designed in various environmental conditions and for various reasons. The reasons for such strategies have in general been associated with the problems related to the environment and challenges that they present. For example in tropical environments, specialised and high producing genotypes for meat and milk were in the past, and in some instances even today, introduced with the expectation that they would continue to produce at the same level as in their original environments. However, the adaptation problems associated with them made it impossible to achieve such desired levels of production. In the meantime, the introduction of high producing and specialised breeds to the tropical environments caused erosion, if not irreversible changes, to the genetic identity of certain local genotypes. The local genotypes, if used strategically, could have contributed to the alleviation and need for more livestock productivity in most developing country conditions in general and tropical Latin America in particular. This has created a condition where some of those genotypes, such as the criollo cattle of Central America and the Caribbean and other breeds of other species such as the local pigs known as cerdo pelon in Mexico, are at present vulnerable or at risk.

Efforts have been made to develop breeding strategies using locally adapted genotypes especially those of the bovine in certain areas such as Central America with the Criollos, which are basically *Bos taurus*. In this, the main objective was to look for alternative genotypes, like the Criollos, that can fit in low input production systems consisting of pasture grazing systems. Even though that was the case, modifications to the original breeding strategy that consisted of straight-breeding and/or up-grading were later modified to simultaneously incorporate cross-breeding systems while at the same time being capable of maintaining themselves as straight-breeds. This was the case for so many years with the Central American Dairy Crollos and the Romosinuanos. This will be dealt with in more detail later.

Some of the underlying assumptions of genetic improvement strategies include: a) the existence of sufficient genetic variance (additive and/or non-additive) for some bio-economically and environmentally important traits; b) the possibility that genetic progress is feasible even in harsh environmental conditions; c) that some or all of the genetic progress possible to be achieved can indeed be used by the producers hence better overall productivity; and finally d) that livestock policies can be influenced at national and regional levels. Observed successes or failures from such strategies have been shown to be due to any one or combination of these factors. As there have been experiences that clearly elucidate these assumptions, it seems imperative that for eventual designs and planning of breeding strategies for cost effective production systems, all negative and positive results from such programmes be considered.

In this manuscript efforts will be made to document and examine experiences as case studies in a breeding programme where the author was directly involved for ten years in Central America and later on at national level in Mexico.

Description of the Central American programme

Since the early 1940s a breeding management programme was initiated at the Centro Agronomico Tropical de Investigacion y Ensenanza in Costa Rica with the objective of promoting the use of locally adapted genotypes that can produce in pastural conditions in the tropics and therefore achieve production objectives in beef and milk under low input production systems. Two tropically adapted genotypes of cattle, the Central American dairy Criollos and the Romosinuanos, were used as straight-breeds at the beginning and later also to produce crosses but for the same objectives. The former, as its name implies, is a dairy type while the latter is a beef type. Both were managed in pastural conditions and in experiment station conditions and can generally be referred to as though they were managed in a low input production system. The crosses in the case of dairy included first generation F_1 with the Jersey (Criollo x Jersey including the reciprocal crosses) as well as back crosses to the respective breeds; while in the case of the beef production systems crosses involved the mating (natural) of Romosinuano bulls to *Bos indicus* cows mainly Brahman (no reciprocal crosses were permanently produced over time even though efforts were made to introduce other European beef breeds as terminal sire breeds such as the Charolais) and the cross-bred females from this were bred back to the Romsinuano bulls.

In both the dairy and beef production systems in pastural conditions, it is important to emphasise that the objective was to develop low input production systems using improved local genotypes via selection and cross-breeding in relatively harsh environmental conditions. While doing so the number of breeder females in both the beef and dairy herds oscillated between 125 to 180 and 85 to 120, respectively. Breeder males were generally produced in the herds except the pure bred Jerseys that were introduced from external markets via artificial insemination, for example, semen was bought from commercial companies who in turn imported it from foreign countries. Therefore, genetic improvement through selection was primarily directed towards these two nuclei in Costa Rica even though the advantage of cross-breeding was also considerable. Right from the beginning of the programme individual records on milk traits such as milk, fat and protein yields, fertility and growth traits measured at birth and weaning, were kept. Thus, the importance of the programme in terms of its capacity to have developed a strong and continued database for tropically adapted animals in tropical environments is absolutely evident. In general, milk yield per lactation, which was generally of 270 days, in the dairy Criollo and Jersey, was the selection criterion while in the Romosinuano the selection criterion was consistently the weaning performance of the animals. In the Romosinuano cattle and their crosses with the Brahman, other growth traits such as post weaning growth traits were also noted but were not consistently recorded in that they were taken only during a certain number of years and then interrupted for different reasons.

During the years that these herds were managed, closed nuclei efforts were made to avoid breeding schemes that could otherwise result in high levels of inbreeding. Several research papers were published showing the existence of genetic progress and variance for at least the traits that were being used as selection criteria and for which cross-breeding was undertaken as described above. Such studies confirmed some of the underlying assumptions on which a breeding strategy should be based for herds in tropical environments. However, these results were mainly based in experimental station conditions and were not checked or validated in producer conditions with whom the programme may have had established relationship and cooperation.

This is because, and it should be emphasised here, that most of the selection and cross-breeding work carried out with the dairy Criollos and Romosinuanos was mainly in experiment station conditions and there was little participatory collaboration of producers in any one of the countries in the region. The most that took place was that Romsinuano and Dairy Criollo sires, from the nuclei in Costa Rica, that had positive genetic potential for weaning and milk yield, respectively, were either distributed (mostly sold) as sires or in the form of semen. In the case of the Romosinuanos most sires ended up in Costa Rica, the USA and Panama while dairy sires were also used in Costa Rica but their semen was distributed in several countries such as the Dominican Republic, Paraguay, Mexico and Honduras among others. Improved females were not generally distributed to any country. Even though there was modest distribution of the genetic material, no follow-up and monitoring of the performance of such genotypes in relation to that of the main nucleus was undertaken. From the beginning, this was the main flaw of the programme as the need to promote, at producer level, the use and follow-up of such improved local genetic material that can sustain low input production systems in real world conditions was never incorporated into its operation. In future designs of breeding management where low input production systems are the main target and where they can be served by the incorporation of genetic improvement, then the participation of the producers becomes not only desirable but a necessity.

It is also important to note the input level under which these genetic resources have produced ranges between low to medium input. This is because there were records (production, growth and reproduction records) maintained throughout the time that these animals were in the station, group breeding with defined breeding and weaning season in the case of the Romosinuanos as well as artificial insemination in the case of the dairy Criollos, was satisfactory. Also good health management practices were also in place including rotational grazing on improved pastures.

As previously indicated, the formal and collaborative programme with producers never really existed. However, significant training activities were undertaken directed to the producers of the Central American region and also formal graduate students from all over Latin America who did their thesis work using the data generated from the station. Training was probably the most important impact this programme had in the decades that it was operational. Along these lines, it should be recognised that there were very few producers who started up-grading their herds towards the Romisnuano without any formal relations with the central programme. The same can be said for those dairy producers who used sires from the Central American dairy Criollo. It should be noted that these producers did not start because the programme had an outreach activity to promote these breed types. Instead most of the producers started on their own and based their activities on informal communications with other producers or with the people who managed these herds at the experiment station in Costa Rica. An exception was the existence in Nicaragua of the Dairy Criollo managed in a dual purpose production system that contributed towards the formation of the Costa Rican dairy Criollo herd. The important issue to emphasise here is that there was no outreach activity inherently tied to the programme.

Breeding design planned versus followed

The improvement strategy planned included the production of breeder males from the same herd. A closed nucleus breeding management was considered to the extent that mating between closely related individuals was avoided. This policy was continually implemented from the inception of the programme. Families (five and four families were established in the Romosinuano herd and the dairy Criollo herd, respectively) that consisted of 25-35 breeder females were constituted and males were identified from one group to serve in another group in such a way that high level of inbreeding was avoided. From 1954 to 1991 the cumulative inbreeding in the Romosinuano herd reached 17 percent. Inbreeding was found not to be negatively influencing any of the traits of importance including fertility for which these animals, as are the dairy Criollos, are very well known in the tropics. Additional males were identified, again based on their genetic potential for growth and maternal influence in addition to ensuring the absence of any anatomical defects in the case of the Romosinuanos and milk yield per lactation in the case of the dairy Criollos. These sires were used in cross-breeding with the Brahman in the case of the Romosinuanos even though all males who served for two years in the nucleus herd were also used in the cross-breeding programme of the system. The same was done in the dairy Criollo herd. Therefore, these herds were indeed capable of producing sires for cross-breeding while at the same time they maintained themselves as pure breeds. This is one important feature of breeds of any species that can warrant its identity while still contributing towards the efficiency of the production system and should be looked at very critically while deciding on the management of such genotypes including the genetic improvement strategy. In general, it can be said that the design planned closely followed what really took place in reality. During the last four years the population size of the dairy Criollo has decreased to less than 80 while that of the Romosinuano decreased to approximately one hundred. However, there are sub populations of the dairy Criollos in Nicaragua that can reach up to 300 and a few in Mexico while that of the Romosinuanos can amount to 250 mainly in Cost Rica even though there are also other herds in Florida USA, Paraguay and Panama.

The improvement strategy followed with these animals had no relationship with that practised by the producers who mainly relied on up-grading their Bos indicus based herds and no records were kept on them. However, there were at least some similarities in the production systems as the producers also ran their cattle in pastoral, mostly unimproved, conditions.

Basis for the genetic improvement of these herds

Ever since the inception of the programme genetic improvement was established based on growth traits for the Romosinuano and milk yield in the case of the dairy. In both cases it was recognised that they had merits for fertility that later became one of the most important and unique traits for which such genotypes were in demand from some organizations. As stated above, most studies undertaken in the experiment station conditions showed that there was indeed sufficient additive genetic variation for some traits such as weaning weights in the Romosinuano cattle; milk, fat and protein yields in the dairy Criollo cattle. Also characteristics and parameters related to lactation curves and total productivity were duly investigated and results showed that significant additive and non-additive genetic variation existed for such traits too.

In the case of cross-breeding effects, it was clear that there was some advantage in crossing the dairy Criollo with the Jersey-Jersey as on average the F_1s produced more than the breed average of the two breeds (28 percent more). Also when the Romsiunao were crossed with Bos indicus some advantage was achieved in growth up to weaning. Fertility of the cross-bred females in both cases became closer to the dairy Criollo and the Romosinuano hence emphasising the utility of these genotypes in tropical environments. In the case of the dairy Criollos-Criollos and Jersey-Jersey crosses, approximately 77 percent fertility was achieved in the first two inseminations while in the Romosinuano Brahaman crosses, approximately 85 percent fertility was constantly obtained per 100 cow exposed to a bull in natural mating per year. Corresponding levels of fertility of the respective pure bred Romosinuano and dairy Criollo was similar to that observed for the crosses in similar management conditions in the station.

Farmer/producer and government involvement

The programme previously discussed did not have decisive and participatory Government and producer involvement. Several factors contributed towards this situation. Firstly, the herd belonged to a regional centre and not to a specific Government or producer organization. Secondly, appreciation for other breeds in the countries played against such genotypes in that no policy at country level was ever made or developed as a result of the different studies, evaluation and improvement strategies that were being made on experiment stations. Thirdly, from the very beginning the programme did not include the participation of the producers in its operation, however small a group these were. Finally, the international agenda in this matter was not strong enough to warrant it significant and continued support. Therefore, the financial support to maintain both nucleus in the management systems described was generated mainly from the same herds, from sales of their own produce and culled animals as well as sale of germplasm. Lack of funds and other previously mentioned reasons later became the causes for reducing the size of the conservation part of the programme and hence endangering the genetic identity of the two nuclei. Efforts should be made in order that such nuclei of herds do not disappear.

The programme in perspective

The programme described represents one of the few programmes that has lasted long enough with little changes in the breeding goals and objectives over the years. At the same time it has maintained some of the animal genetic resources that have unique traits in tropical foot and mouth disease free environments. Also, genetic variation in the respective herds was continually conserved. At a time when the need for sustainable production systems are being emphasised, such genetic resources should and can indeed be considered as potential gene sources. At present, this can greatly be enhanced thanks to the biotechnological advances taking place.

Most importantly, genetic and non-genetic evaluations have been made for the productive and reproductive traits of the Romosinuanos and the dairy Criollos in that their potential contribution to low input livestock production systems can be determined a priority. Also they have contributed towards the generation of founder herds in other countries such as the USA.

The most important lesson learned from this programme however, is the fact that any breeding strategy and management such as this should go hand in hand with management practices at producer level with their active participation as long as there are external and local funds available to enable this. This will allow a simultaneous validation and therefore facilitates the transfer of significant genetic improvement that can be achieved in the nucleus herds.

The case of Mexico

Recently Mexico involved itself in the development of a national programme of animal genetic resources in view of the economic, social and ecological importance that livestock has in the country's economy. In the process of the development, some of the previously mentioned lessons, both successful or otherwise, were duly taken into account. The first thing that was clear was that the producer or breeder major stakeholders of all the programme, had to be directly involved in the deliberations and discussions involving all animal genetic resources in the country. As such organizations of beef cattle breeders, dairy cattle breeders, sheep producer associations, poultry producer associations and equine as well as swine producer associations, had full and active participation in all the four forums that took place during the two years. This was a very important step to take even when the process was being sponsored by the Government with the cooperation of the technical educational and research institutions in the country.

After very detailed discussions and deliberations a national programme on animal genetic resources was developed and is now being implemented. The important thing here is the fact that from the very beginning the producers have consistently taken an active part and thus every phase of the implementation considers such participation. In fact, the implementation phase is presided over by a producer representing the producer organizations in the country and with technical support from the national educational and research institutions via the National Commission on Animal Genetic Resources that was recently founded for the first time in the country.

The national programme of animal genetic resources consists of four main programme activities. These are:

a) establishment and maintenance of a database by species that will not only allow the definition of breeding strategies to be applied by the producers of each species in different production systems as long as they are cost effective but also to determine the status of most of the animal genetic resources the country possesses;

b) conservation of valuable genetic resources applying, when appropriate, molecular techniques;
c) strategic use of the genetic resources including evaluation and production controls; and
d) promote training programmes directed to producers and technical staff within the scope of the programme.

To summarise, breeding strategies for low input production systems have been designed and implemented as described above and different types of results have been obtained. It should be highlighted that the main result that should be emphasised from the Central American herds was their ability to produce cross-breds while still providing for their own genetic identity. On the other hand, strategies such as those described for the Criollos and the Romosinuanos should have had outreach activities tied up to them since the inception of the programme. Such results, negative or positive, have contributed in part towards establishing breed and breed type evaluation programmes in some countries while in others, have directly or indirectly contributed towards the definition of a national programme. An example of the latter is the one described for Mexico. Finally, one should bear in mind that any programme or breeding strategy associated with low input production system requires the necessary budgetary allocation by any entity if such a programme is to be part of a policy that an organization or Government pursues.

Structures for improving smallholder chicken production in Bangladesh breeding strategy

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Introduction

The framework for rural poultry development in Bangladesh has been developed through an historically long learning-by-doing process. The two main actors in this process are: 1) a national NGO, the Bangladesh Rural Advancement Committee (BRAC); and 2) the Government through the Department of Livestock Services (DLS).

In the late 1970s BRAC identified poultry rearing as a source of income for landless, particularly destitute women. In the early 1980s BRAC and DLS initiated a participatory action research programme aimed at increasing the productivity of small flocks of hens in village conditions and to develop a replicable smallholder model.

In 1987 the experiences of poultry development and the Government food for aid for destitute women were integrated into an independent programme 'Income Generation for a Vulnerable Group Development Programme'. The results were very promising and other development programmes built on the same concept followed, but were further refined based on previous experiences.

Currently ten national NGOs are involved in the smallholder concept and Governmental institutions; extension, education and research are in the process of being integrated in the smallholder concept. However, BRAC is by far the leading NGO in the development of a smallholder poultry sector. The possibilities for women's participation in poultry development are according to Dr Saleque and Shams Mustafa (1996) (BRAC), as follows:

1. About 70 percent of rural landless women are directly or indirectly involved in poultry rearing activities. Traditionally these women have some experience in poultry rearing, which therefore represents skills known to them.

2. BRAC has proved that homestead poultry rearing is economically viable. If the landless women are properly trained, supported with

Table 1. Summary of poultry activities and projects.

Project	SLDP I	PLDP	PNP	SLDP II	IGVGDP	RDP / BRAC
Project Period and Donors	1992-98 IFAD / Danida	1998-02 ADB / Danida	1997-01 World Bank	1999-03 Danida	1987- WFP	1986- Continue as a BRAC activity
Thanas covered	80	89	40	26	Country-wide	Country-wide
Benefi-ciaries: number and type	Landless poor women 400 000 HHs	Landless and poor women 363 000 HHs	Poorest HHs with a child below 2 years or pregnant women 69 000 HHs	Primary poor women 109 000 HHs	Very poor women 400 000 HHs	Rural poor 1.2 million HHs

Kazi Abdul Fattah (1999). Director General of DLS
HHs: House Holds
Thana: Administrative unit. Bangladesh is divided into some 460 Thanas.

credit and other necessary inputs and made to operate under the supervision of extension workers of both Government and BRAC, the Government machinery is activated to provide for the delivery of services, the poultry sector could be one of the most productive sectors.

3. Poultry rearing is suitable for widespread implementation as it is of low cost, requires little skill, is highly productive and can be incorporated into household work.

4. There are few or no job opportunities for the landless, disadvantaged women. Poultry is the only activity in which a large number of landless women can participate.

5. In the small-scale poultry units which support the landless, production per bird may be low, but distribution of benefits will be more equal and have great human development impact.

6. Poultry rearing is culturally acceptable, technically and economically viable. Moreover, the ownership of poultry is entirely in the hands of women. This is an asset over which the poor women actually have control. This activity can therefore play an important role in poverty alleviation which is the main goal of BRAC.

BRAC has taken the advantages of using poultry as an instrument in its poverty alleviation programme. BRAC had, in 1997, 2.2 million members of which more than 1.2 million were involved in poultry activities. Table 2 shows the development of BRAC's poultry activities.

Table 2. Component wise poultry programme participants – cumulative numbers 1990-97.

Component	1990	1991	1992	1993	1994	1995	1996	1997
1. Poultry worker[1]	3 841	5 000	7 504	22 788	25 033	31 135	33 572	41 228
2. Chick rearer	650	1 106	1 952	5 836	8 244	8 453	10 986	14 723
3. Smallholder[2]	56 664	105 051	191 457	455 441	638 104	802 906	840 488	1 190 490
4. Pullet rearer							1 308	2 260
5. Model rearer(PS)							7 761	11 195
6. Egg collectors				2 255	2 284	2 384	2 629	2 798
7. Hatchery owners				327	454	955	1 115	1 349
8. Feed seller	24	52	104	807	1 515	2 800	2 347	2 450
9. Cage rearers							50	5 000
10. Broiler rearers							25	1 000
Total	61 179	111 209	201 017	487 454	675 634	847 633	900 281	1 272 493

Saleque (1999)

[1]Para vet.

[2]Key Rearer with 10 hens

BRAC has established a commercial wing for supplying inputs to its members.

The smallholder model

The smallholder described below is intended to provide the background for understanding the formulated breeding strategy. For a more functional description of the model, reference is made to Jensen (1996) and Saleque (1996 and 1999).

Objectives and target groups

The smallholder sector is built up by the implementation of a number of development projects. The development objectives of the Government are improving living standards and welfare of the poorer strata of the rural population. The development objectives of the projects are a sustainable increase in the smallholder poultry sector and therefore, gives support to women especially those from the poorest and landless households. The immediate objectives are improved husbandry practice and increased institutional capacity of Government institutions and the participating NGOs leading to increased productivity.

The target groups are women belonging to the poorest segment of the rural population. The potential beneficiaries are all selected on poverty criteria.

Development Strategy

The common features of a smallholder development project are: 1) a component directly targeting the beneficiaries, the NGO component; and 2) a component targeting institutional development, the DLS component.

The smallholder model is based on creating an enabling environment, *inter alia*, an environment in which all inputs and services needed are available in the village to minimise the risks for investment in a smallholder activity. Furthermore, no subsidies are involved at the user level, all the activities operate in free market conditions.

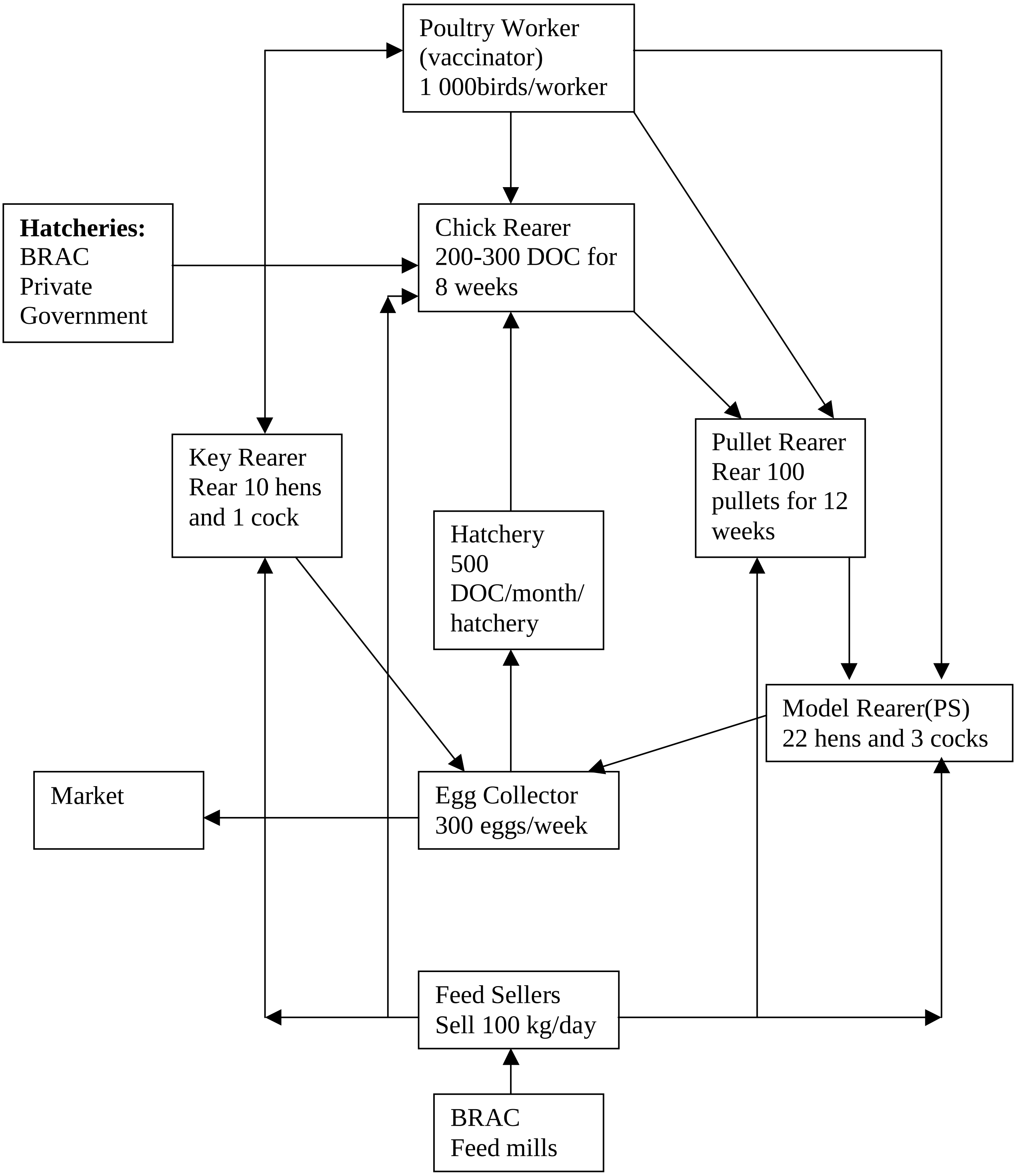
Poultry activity is compulsory for the first loan, but after repayment of the first loan the beneficiary is entitled to a new loan and is this time free to select an activity of her own choice.

The NGO component comprises: 1) establishing of area offices, one for each 3 000 to 6 000 members; 2) selecting potential beneficiaries; 3) organizing village groups; 4) commencing a savings programme; 5) training of beneficiaries; 6) creating and enabling an environment by establishing income generation activities such as input suppliers, veterinary service activities and marketing; 7) providing loans and assisting each of the beneficiaries in establishing an income generation activity; and 8) technically supporting the operation of different activities.

The establishing cost and first three years operational costs of an area office are usually covered by the project (Donor). After that, the profit margin from loans, sales of inputs and service fees from the 3 000 to 6 000 members is enough to cover the NGO's cost of maintaining and operating the office.

The DLS's role, as the implementing agency, is to coordinate, monitor, control and to provide technical support. An important activity in this respect is to accumulate experiences from previous and on-going projects and ensure that these experiences are reflected in formulation of new projects.

In on-going and planned projects there are DLS components such as: 1) activities and facilities for implementation of a breeding programme; 2) activities and facilities for establishing a Management Information System; 3) activities and facilities for establishing an international training institution; and 4) budgets for applied research activities and a comprehensive human resource development programme.



BRAC Poultry Programme. Modified after Saleque 1999.

BRAC broilers and layers in cages are not included in the above flowchart. The activities shown in the flowchart have to be compared with the numbers in Table 2. For instance there are more than 14 000 chick rearers, each rearing some 250 chickens four times a year, making an annual production of 14 million eight week old pullets.

Breeding strategies

Context

The end user, the smallholder, keeps a small flock of chickens, which is normally composed of four to six high yielding variety (HYV) hens, one HYV cock and three to four Desi hens. The Desi hens are used in the traditional way: incubating, rearing and laying (reference is made to Jensen, 1996). The HYV hens are used for production of table eggs and to some extent to production of hatching eggs. The hens are scavenging for the main part of their feed, but in particular, the HYV hens are also provided with supplemental feed.

The distribution flow is rather complicated, because it is divided into a number of small entrepreneurs: Suppliers of PS > Chicken Rearers > Pullet Rearers > Model Rearers > Mini Hatcheries > Chicken Rearers > Key Rearers.

The HYV chickens are sold by the Chicken Rearers to the smallholders at an age of eight weeks or produced by the smallholders (Key Rearers) themselves.

The DOCs (Day Old Chickens) are provided to the Chicken Rearers by either: 1) mini- hatcheries; 2) Government Poultry Farms; 3) NGO hatcheries; 4) private hatcheries; or 5) by the Smallholder herself by using the Desi as mother hens.

Table 3. Sources of Parent Stock (PS).

Sources of PS	Breeds	Replacement of PS	Customers
Government Poultry Farms, GPF	White Leghorn, RIR, Fayoumi	Reproduction of purelines	Model rearers
NGO-Hatcheries	Hybrids (Commercial PS)	Imported	Chicken rearers
Private Hatcheries	Hybrids (Commercial PS)	Imported	Chicken rearers through NGOs
Model Rearers	RIR males and Fayoumi females	Purchased from GPF	Chicken rearers through mini hatcheries
Key Rearers	Exotics and crosses with Desi	Purchased from chicken rearers or reproduction of own stocks	Other villagers

Development of breeding strategies

The development of the different sources of parent stocks has been driven by the demand of day old chickens. A breeding strategy was formulated in the mid 1990s based on a Central Government breeding farm planned to produce parent stock to Sonali chickens, a cross between RIR males and Fayoumi females and parent stock to produce a cross between Fayoumi males and commercial hybrids as the female line. The implementation of the breeding strategy has fallen behind the development and the NGOs had found other ways to satisfy the demand of day old chickens and this may not be the optimal solution for the end user.

A suitable breeding strategy for the smallholder concept is rather complicated. In the reproduction and multiplication links the hens are kept in confinement and fed with balanced feed. Consequently, egg production traits are the most important for a viable operation. However, the end user, the smallholder with ten hens, keeps the hens in semi-scavenging conditions and consequently such traits as scavenging traits and survival traits are the most important. A way to solve that, is the use of specialised breeds or lines, as shown by Moav (1966) in which the reproduction traits are conveyed through the female line while the traits important for the end product are conveyed through the male lines.

An experiment commenced in 1993 where different exotic hens were tested in semi-scavenging conditions. One of the breed combinations was a cross between commercial hybrid as the female line and an improved breed (Fayoumi, RIR or WL) as the male line. The hypothesis was, that use of commercial hybrids as parent hens would satisfy the multiplication links with respect to high egg yield while use of another breed such as males would satisfy the end user with respect to good scavenger and survival traits. Another breed combination was a cross between RIR-male and Fayoumi-female (SONALI), a combination known to have high performance values in the semi-scavenging system (Amber, 1986). A summary of the results is shown in Table 4.

The outcome of the experiment (Rahman et al., 1996) shows that the SONALI hens had the highest egg production and the lowest mortality rate. Although these performances were not significantly different from some of the combinations with hybrids as those of the female combination, it was decided to base the breeding strategy on production of SONALI hens. One of the reasons was that SONALI in several experiments had proven to be a superior combination.

A breeding strategy for the semi-scavenging concept was outlined by Jensen (1996a). ‘In general, breeding strategies in developing countries have focused far too much on the genetic potential of the breeds. It is stressed, however, that improved breed can never be a substitute for bad management.

Table 4. Performance of experimental hens reared in semi scavenging condition according to breed combinations.

Parameters	Breed combinations (Least square mean values) AB (Lohmann brown)	(Ax RIR) x Fayoumi	Fayoumi x AB	RIR x AB	RIR x Fayoumi	RIR x WLH	(RIR x Fayoumi) x AB	WLH x AB
1. Age of first egg (week)	34.5	32	32	34	33	32	32.5	34
2 Eggs/hen/year * (hen day)	140^{ab}	137^{b}	125^{b}	139^{ab}	156^{a}	128^{b}	141^{ab}	139^{ab}
Actual no. of eggs per hen (hen day)	86^{b}	104^{ab}	86^{b}	105^{ab}	119^{a}	97^{b}	86^{b}	99^{ab}
3. Mortality % (excluding predator loss)	22.14^{ab}	35.04^{b}	27.59^{ab}	32.64^{b}	15.98^{a}	25.21^{ab}	21.20^{ab}	22.88^{ab}
4. Mortality % due to predator	1.38	0.87	1.40	2.71	2.09	0	5.31	2.61
5. Supplementary energy Kcal/bird/day	146^{b}	122^{a}	136^{ab}	144^{b}	130^{a}	134^{ab}	146^{b}	135^{ab}
6. Supplementary protein (g)/bird/day	7.3^{b}	6.0^{a}	6.9^{b}	7.2^{b}	6.4^{a}	6.6^{ab}	7.1^{b}	6.6^{ab}
7. Supplementary feed cost (Taka)/bird/laying year	202.51^{b}	177.44^{a}	193.72^{ab}	203.18^{b}	184.20^{a}	190.62^{ab}	205.32^{b}	192.10^{ab}
8. Gross margin (Taka)/hen up to one laying year (Income–Cost)	134.66^{b}	169.83^{ab}	113.08^{c}	133.13^{b}	205.17^{a}	145.53^{b}	132.09^{b}	154.65^{b}
9. Egg production period (Months)	8.54	9.84	9.17	9.37	9.84	9.13	8.74	8.97

Rahman et al (1996)
Figures with same or no superscript in a row are not significantly different ($P<0.05$)
* Corrected for 12 months egg production period

Potential Breeding Strategy
Commercial Hybrids as Parent Hens

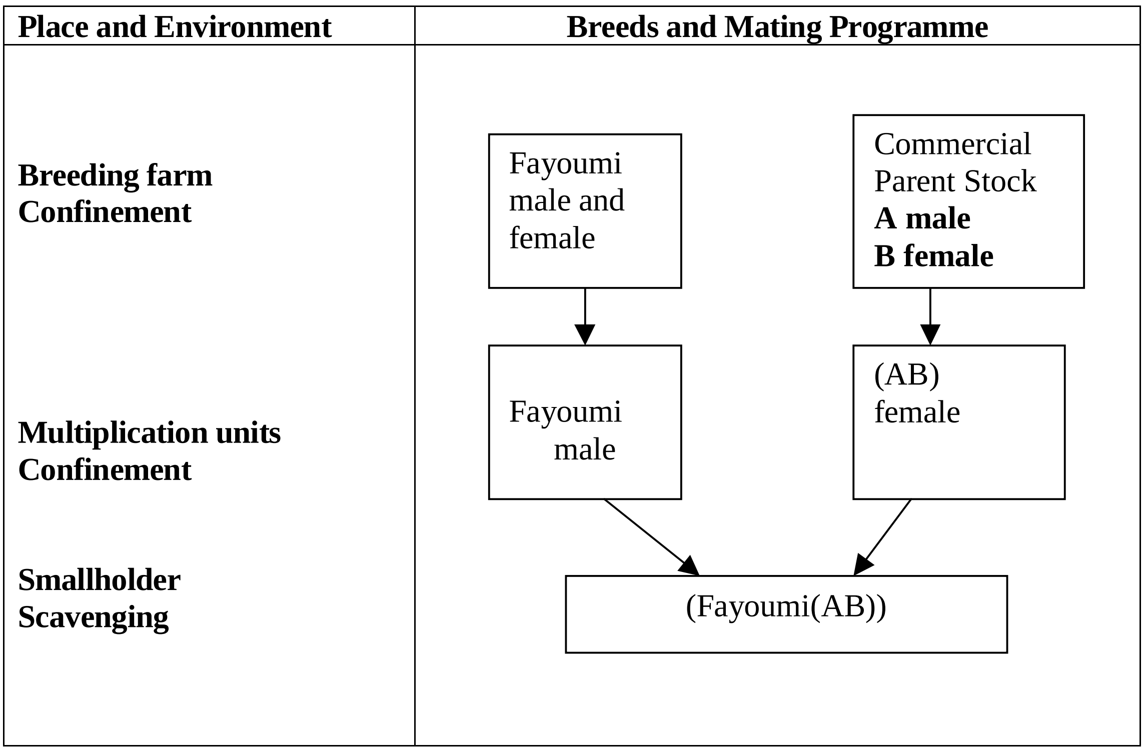


Table 5. Rate of lay, percent for pure-breed and crosses and the hybrid vigour.

Feeding system	RIR	Fayoumi	SONALI	Hybrid vigour
Free access, in confinement	46	49	50	+5%
Scavenging + 75 g supp.feed	19	20	33	+69%
Scavenging + 25 g supp.feed	12	10	18	+64%

Rahman (1996).

The objectives of a breeding strategy for the semi-scavenging poultry holdings are to:

1. Maintain breeding stocks with a genetic potential which matches the best smallholder management skills for producing eggs on the basis of a behaviour conducive to semi-scavenging conditions. Consequently, the management skills and not the genetic potential will be the limiting factor in improving the productivity.

2. Maintain the breeding stock under circumstances which give the best health security and produce parent stocks with a uniform antibody status in order to obtain the best immunity from the vaccination programme.

3. Have a multiplication and distribution system which optimises the financial results for the end users, in this case the smallholders take the productivity in the multiplication units into due consideration.

The semi-scavenging model is in fact an integrated production chain and all links involved shall be considered in the formulation of a breeding strategy. Breeders and chicken rearers, where the birds are kept in confinement and fed with balanced feed, must *inter alia* also be viable units. In reproduction links, the egg yield and feed efficiency are the most important traits, while at smallholder level, traits such as survival rate and scavenging behaviour are more important.

Indigenous breeds are developed and adapted to the local environment and do not produce eggs in confinement with free access to balanced feed. Consequently, they have lower productivity than the improved breed when kept in confinement when they are kept in multiplication units. However, a programme where indigenous breeds are used as parent males will not effect the viability of the multiplication units.

In Table 6 the production cost for producing day old chickens calculated for the breed combinations is shown: commercial parent stock, commercial parent hens used as grand parent stock (Hybrids), and Fayoumi.

Table 6. Cost calculation of Day Old Chicken (DOC) with different parent hens.

Assumptions	Fayoumi	Hybrid	Comm. PS
Price, day old PS, taka	30	40	200
Rearing, feed, kg	9	9	9
Laying feed, kg	46	46	46
Other cost, % of feed cost	0.4	0,4	0,4
Feed price, taka / kg	12	12	12
Survival rate, rearing, %	0.9	0,9	0,9
Survival rate, laying, %	0.9	0,9	0,9
Egg yield, number per hh	200	260	240
Ratio of hatching eggs	0.75	0,9	0,9
Utilisation of hatching eggs	0.95	0,95	0,75
Hatchability of egg set	0.75	0,75	0,75
Price for DOC, unsexed, taka	12	12	15
Price for table eggs, taka / egg	3	3	3
Cost calculation, per hen			
Day old PS	33.33	44.44	222.22
Feed	660.00	660.00	660.00
Other cost	264.00	264.00	264.00
Total cost	957.33	968.44	1 146.22
Production			
Number of eggs	200.00	260.00	240.00
Number of hatching eggs	150.00	234.00	216.00
Unutilised hatching eggs	7.50	11.70	54.00
Number of table eggs	57.50	37.70	78.00
Number of DOC	106.88	166.73	121.50
Income, taka			
Sales of DOC	1 282.50	2 000.70	1 822.50
Sales of table eggs	172.50	113.10	234.00
Total sales	1 455.00	2 113.80	2 056.50
Profit, taka per hen	497.67	1 145.36	910.28
Production cost per DOC	8.96	5.81	9.43

Note: The actual production costs may differ from this calculation, but the differences will be very close to the figures shown above.
By using hybrids as parent hens instead of commercial parent stocks, the overall cost will be reduced with three to four taka per DOC. Fayoumi and commercial parent stock have almost the same production cost.
Jensen(1996). Not published

The preliminary conclusions to be drawn are:

1. The semi-scavenging model developed in Bangladesh can provide an environment and management skills to utilise the genetic potential of breeds with a higher value than the capacity of randomly selected HYV breeds.

2. There is no rational behind use of commercial layers in semi-scavenging conditions at smallholder level. However, use of commercial hybrids as parent hens will enhance the viability of the rural parent farms and a combination of hybrid parent hens and a HYV male may be a viable solution for smallholders.

3. The SONALI (RIR x Fayoumi) breed has a remarkable high performance in semi-scavenging conditions compared with other breeds.

An appropriate breeding strategy may be the use of commercial brown hybrids as parent hens and a coloured improved breed as parent males. Even though the strategy may not be the optimal solution, it is manageable and can be applied until a better strategy has been developed. Furthermore, the proposed strategy provides optimum opportunities for parent farms to be viable operations, because the parent hens will have high genetic potential for producing hatching eggs with low feed costs when kept in confinement and provided with balanced feed. (This strategy is not applied in Bangladesh).

The main constraint in implementing the breeding strategy is the low level of biosecurity (conditions which minimise the health risk) on Government Poultry Farms intended to be used as multiplication units and with a central breeding farm as supplier of the parent stocks. The farms are not designed to use an all-in -all-out system and the hatchery is located close to the chicken houses. This problem has not been solved yet and in the meantime the NGOs develop their own ways of distribution chickens.

Present breeding plans

DLS is in the process of establishing a separate breeding farm operating as a grandparent farm for producing parents to SONALI chickens at six of the Government's hatchery farms.

There will be 2 500 Fayoumi hens and 500 RIR hens as grandparents. The grandparent population will be reproduced from the pure-breeds with some selection pressure on egg size and age at maturity.

Even though the breeding goals are defined, good scavenging and survival traits, a method to record such traits and use them in a selection index have to be developed.

Lessons learned

1. The research base for breeding activities related to semi-scavenging or scavenging conditions is very limited.

2. Government poultry farms are usually designed to carry out a number of activities and biosecurity in this respect has low priority.

3. A dissemination structure in which biosecurity has high priority is a must due to the direct link from breeding to all the end users. It is very difficult to integrate existing Government farms into such a system.

4. Politically it is difficult to implement a system in which due consideration is given both to the reproduction and multiplication links and to end users.

5. The reproduction links and the hatcheries are more powerful than the end users in setting the breeding goals.

6. Research institutions in the developing countries are not involved enough in developing breeding activities to be used in their own county.

7. To formulate and implement a breeding strategy is a long process and takes at least five years. Consequently, a dissemination system with high biosecurity has to be developed and implemented as the first step and simultaneously the breeding programme can be developed.

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Yak breeding programmes in China

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Introduction

The yak (*Bos grunniens*) is one of the most important species of livestock found in the Himalayas and on the Tibetan Plateau. Totalling about 15 million animals, yaks and yak-hybrid crosses provide multiple products for the subsistence and marketing of local communities (Miller *et al*, 1997). In fact, the yak is a unique animal, native to Central Asia and well adapted to the cold, high altitude environment where it is found. As such it is very significant to conserve and manage yak genetic diversity for sustainable pastoral development over a large geographic area.

Western Sichuan, the case-study area, is located in the most eastern region of the Tibetan Plateau and plays the most important role in the connection between the Plateau and the lowland of China both economically and ecologically. This Region has a long history of yak breeding with pronounced local economic characteristics. Following Qinghai and TAR (Tibetan Autonomous Region), Sichuan Province ranks the third most important province / region in China for yak breeding, where the number of yak amounts to 26 percent of the national total (Wu, 1997a).

Yak breeding and cross-breeding in Sichuan

Although the yak is indispensable across the Tibetan Plateau and neighbouring regions, this animal is a unique bovine with relatively low productivity. As a result, herdsmen have been adopting various means to improve yak productivity for years. Most significantly, herdsmen have developed methods of cross-breeding to produce yak hybrids. In the past few decades, several breeds of cattle with a large body and high productivity have been introduced into China's yak population.

Main Yak breeds

The different breeds of yak existing in high altitude areas have for a long time been selected by local herders. Owing to its multipurpose, yak not only has a very high value in terms of economics, but also in genetic resources. To date, two breeds (types) of yaks have been identified in

Sichuan, for example, Valley type (*Jiulong* Yak) and Plateau type (*Maiwa* Yak) (Cai, 1989; 1992), both of which are the main breeds involved in yak genetic improvement schemes.

Production system concerned

The sparseness and limitation of natural pastures and their geographic location contribute to the formation of mobile yak-keeping characters in the Tibetan Plateau. In general, with the seasonal alternation, the yak herds repeatedly often have to cover a large distance in search of foodstuff and water, which leads to the migration on seasonal pastures. Traditionally, yaks are reared in range systems with very low input level and are never housed even during the worst climatic conditions. These animals live entirely on natural pasture but occasionally the lactating animals are given barley flour with common salt, but are never accustomed to any concentrate ration. They graze in community. If enough herdsmen are available, the dairy animals are separated from the rest. Generally speaking, it appears (in the absence of actual intake of nutrients), that the animal has the special adaptability to live in areas of scarce feeding conditions without having a detrimental effect on their health.

Approximate number of animals concerned

In Sichuan, the yak population has shown an increasing trend in the last four decades, which has recorded an increase from 1.67 million to 3.97 million from 1950 to 1995, for example, an increase of 137.7 percent (Ao *et al*, 1988; SSB, 1996). The largest population of yak in Sichuan is distributed in the north-western counties, such as *Serqu*, *Dege*, *Sertar*, *Zoige*, *Hongyuan* and *Aba*, where the population in every county is more than 200 000 heads. Transgressing the borders southwards, there are seven counties where the population of yak is above 100 000. The percentage of yak hybrids in yak population increases with the rise of altitude and the role of livestock husbandry in agricultural production. More hybrids are found in areas with a greater relative difference of elevation (mountain regions) or agro-pastoral areas.

In *Hongyuan*, the centre where the *Maiwa* breed is distributed, there were 350 000 head of yaks (including hybrids) in 1995 (SSB, 1996), among which there were about 300 000 head belonging to the *Maiwa* breed. It is estimated that there was a total of 700 000 head of *Maiwa* Yak distributed in the north-western plateau of Sichuan. It is also the yak breed with the biggest population in China. At present, there are about 100 000 head of yaks in Hongyuan involved in the straight-breeding programme of Maiwa breed and 1 200-1 500 head of female yaks concerned with the cross-bred programme. The approximate number of another important breed, *Jiulong* Yak, is about 50 000 head, among which there are about 20 000 head of breedable female yak. There are only 600 head of yak bulls taken to other places for breeding or cross-breeding. Others are totally reproduced with the straight-breeding method.

Breeding goals and traits included

Generally speaking, from time immemorial breeding and cross-breeding of yaks have been practised with two main goals:

1) To have a type of improved or cross-bred animal which suits the harsh climate. With the expansion of yak from the original area, pure-breeding and cross-breeding began to be practised. For example, in order to suit the environments in mountainous regions, such as apparently vertical difference (steep gradients), diverse foodstuff (different herbaceous plants and feedings in different seasons), transhumance systems and inaccessibility, the '*Jiulong* breed' was selected around the Jiulong County which is called 'valley type'. In the north-western Sichuan the plateau has many morasses or semi-boggy areas, hill-shaped highlands with gentle slopes and broad valleys present in an open kind of topography. A little higher precipitation and humidity make the alpine and subalpine meadows predominated by dense grasses and sedges. Due to the open topography, the seasonal migration of nomads is more horizontal and yak tends to migrate freely. Bulls (even wild yak bulls at the beginning of this century) move from one area to another and mate with individual cows or even whole herds in neighbouring areas. In geo-ecological background and nomadic conditions, the '*Maiwa* breed' (plateau type) was selected.

2) To enhance the productivity of yak to meet the subsistent or marketing requirements. Owing to the difference of life-style, the purposes of breeding or cross-breeding are varied in different groups of pastoralists. For example, the yaks of the *Maiwa* breed are of relatively good milking capacity with high butterfat content of milk. These yaks are clearly multipurpose, being mainly used for milk and meat. On the contrary, the yaks of the *Jiulong* breed have good productivity in meat and hair and have been selected with meat, hair and draught in mind (Table 1). Presently, marketing requirements always dominate the objectives of breeding or cross-breeding. In the last few decades, owing to its big body size, high productivity and ideal adaptability to the mountain environment, the *Jiulong* Yak has been introduced to many yak-raising regions, such as Yunnan, TAR, Gansu and Qinghai, for straight-breeding or cross-breeding.

Approaches adopted for breed selections

In the regions where yak products are in great demand and sought after in the market place, it seems that herdsmen have acquired both the knowledge and skill to improve production traits. In Sichuan the indigenous knowledge of traditional yak breeding can be found popularly in pastoral societies, but most of them have not been described systematically. The system of selection in *Jiulong* is an exception, which has been sifted out and discussed in some literature (Cai, 1989; 1992; Cai and Wiener, 1995; Wu, 1998). Here only the traditional selection procedure used by herdsmen in the *Jiulong* area is reviewed briefly.

Table 1. Comparison of Typical Traits between Jiulong Yak and Maiwa Yak.

Items	Jiulong yak	Maiwa yak
Centre of distribution	Jiulong, southern Kangding (including Muli, Yanyuan, Mianning and Shimian)	Hongyuan, southern Zoige (including Aba, Songpan, Nanping and Zamtang)
No. of heads	50 000	700 000
History of selection	130 years	about 100 years
Colour of hair	black (most), black-white (a few)	black (most), as well as black-white, grey, brown and white
Horn	occurring in all yak	occurring in most yak
Body weight (kg)	400 - 700 (M); 200 - 400 (F)*	300 - 500 (M); 150 - 350 (F)
Height (cm)	130 - 140 (M); 110 - 120 (F)	120 - 130 (M); 100 - 110 (F)
Selecting purpose	meat, milk and hair	milk and meat
Dressing percentage (%)	50 – 60	50 - 60
Dressed carcass (%)	40 – 50	40 - 50
Milk yield during lactation (kg)	200 – 500	200 - 400
Butter-fat content (%)	5 – 8	6 -7
Hair yield (kg)	13 - 20 (M); 1 - 3 (F)	2 - 12 (M); 1 - 3 (F)
Packing capacity (kg)	60 - 75 **	70 - 100
Travelling distance with burden (km)	20 - 25	30

Source: Cai, 1990.
Note: * M = male yak; F = female yak.
** This number was measured with castrated yak (bullock).

1) Selection of male yak (bull)
In the *Jiulong* area, the choice of male yak is stricter than that of the female. The guiding principle for the herdsmen is to check the ancestors (parents) first and the bull second. The criteria of selection are summarised in table 2.

The selection of male yaks (bulls) in the *Jiulong* area is carried out in three stages. The first is pre-selection at the age of one-year olds. There is a second selection from among the first group at the age of two years and a final selection at the age of three or four years. Culled bulls are castrated and used for meat or draught purpose.

2) Selection of female yak (cow)
The criteria for female yak are simpler and mainly concentrate on reproduction. To summarise, the indigenous knowledge of herdsmen, can be expressed as “three elimination”, namely:

- eliminating the female yaks when they reach the age that should give the first-birth (four to five years old), but no calves are born;
- eliminating the barren or non-pregnant female yaks through three to four years;
- eliminating the female yaks that have not enough maternal instinct to look after the growth of their babies.

Table 2. Traditional criteria for the selection of Jiulong yak.

Ancestors (parents)		Bulls (themselves)
Female (mother)	Male (father)	
• high milk yield; • good conformation • (big body); • tame and gentle; • given birth twice to • calves	• rich and thick hair; • numerous descendants	• rough bases of horns and long distances • between them; • horns stretching outwards and widely; • broad forehead, muzzle and mouth; • thin and long lips; • thick neck, high withers and wide brisket; • wide and flat back, loin and rump; • straight forelimbs and curved hind-legs; • hairy tail and shrunken scrotum; • black coat or black with some white specks • on the forehead and at the extremities of the • body (e.g. legs, tail).

Source: Cai, 1989; Cai and Wiener, 1995.

Selection criteria

The defined purposes of selection in China aim at accelerating the speed of individual maturing and increasing growth rate. Strictly speaking, there was no systematic selection scheme carried out for yak to date (Cai, 1992). In order to promote the identification of yak breed, the selection criteria were drafted out at the end of the 1970s and perfected in the 1980s. In Sichuan the selection of *Jiulong* yak is concentrated on meat and hair (or downhair) and in *Maiwa* yak milk and beef (Table 3).

Table 3. Selection criteria for Jiulong yak and Maiwa yak in Sichuan.

	Items	Jiulong yak (Valley type)		Maiwa yak (Plateau type)
	Purpose	Meat and milk	Meat and hair	Meat and milk
Body size (cm)	Height (cm)	125 – 145	120 - 135	120 - 140
	Length (cm)	140 – 170	140 - 170	
	Heart girth (cm)	190 – 225	200 - 230	
	New birth	18 – 20	18 - 20	
Body weight (kg)	180 days (stop suckling)	100 – 120	100 - 120	115
	1.5 years old	200 – 250	210 -260	135 - 155
	Adult	350 – 600	370 - 630	350 - 600
Productive properties	Dressing percentage	above 58 %	above 60 %	60 %
	Dressed carcass (%)			50
	Milk yield (kg)	above 1 000	above 1 000	306*
	Butter-fat content (%)	6.2	6.0	above 6.5
	Hair yield (kg)	1.5 - 2.0	4 - 12	2 - 3

Source: Cai, 1992.
Note: milking once a day for 153 days.

Whether a pastoral community opts for pure breeding and/or cross-breeding depends not only on the actual environmental circumstances, but also on their cultural traditions. It is interesting that the distribution of the valley-type yak and the Plateau-type yak mirrors the traditional distribution of the Kham Tibetan and the Amdo Tibetan (Wu, 1998). The central area of Jiulong yak distribution has for many centuries been the homeland of the Kham Tibetan people. Traditionally, they chose pure breeding as the main method for selection and even today cross-breeding is rarely practised. This has to do with the topography of the area: high mountains with deeply incised valleys restrict the exchange of yaks. Only in the adjacent area where the altitude is lower and cultivated fields spread, some hybrids between yak and cattle (“*Pian Niu*’ in Chinese), making up ten percent of total heads of yak herd, can be found which are cross-bred with the purpose of draught.

The region of the plateau-type yak distribution is inhabited by Amdo Tibetan who are thought to be the descendants of the ancient Qiang people of northern China. Owing to its geographical accessibility, cross-border exchange or trading of yaks existed not only in the Amdo area itself but also between different ethnic groups. Moreover, bulls for breeding could easily be introduced from the adjacent areas suitable for crop cultivation.

The historical migration of nomadic tribes, including the Qiang, Tibetan and Mongolians, also introduced new yak breeds and promoted genetic exchanges (Wu, 1999). As a result, it is cross-breeding which is most often practised in this Region and hybrids are very common. In *Zoige* County, for example, the hybrids represent 20-30 percent of total head of yaks. Even so, in the original home of the *Maiwa* breed, the number of hybrids is still kept below six percent and straight-breeding is the principle mean for yak improvement.

Brief history of cross-breeding plan

The traditional selection methods for breeding appear to have produced, over a period of many centuries, an improved breed of yak which is highly regarded (Cai and Wiener, 1995). However, the development of pastoralism would need to encourage the herdsmen to pay more attention to the productive characteristics of yaks. In Sichuan the strengthening of yak productive potential usually entails genetic up-grading of indigenous breeds with high yielding exotic stock.

In the yak-raising area, the cross-breeding between yak and cattle (*Bos taurus*) can be dated back historically to at least 3 000 years ago, when Qiang people adopted these methods to reproduce '*Pian Niu*' (including '*Dzo*' and '*Dzomo*'). With the development of cultivation in the adjacent mountainous regions, the cross-breeding was increased and a wealth of experience accumulated. Through numerous tests and practices, the cross-breeding between cattle bull and yak cow is identified as the ideal method by herdsmen. Meanwhile, it is also found that male sterility exists within the hybrids (F_1), but the female hybrids (*Dzomo*) are able to reproduce. In Aba Prefecture cross-breeding is only carried out for two generations. The F_1 animals are called '*Pian Niu*' and F_2 '*Za Niu*'. The F_2 can be further divided into two kinds: '*Mao Za*', the progeny between male yak and *Dzomo*; '*Huang Za*', the progeny between male cattle and *Dzomo*.

In the last three decades many improvement schemes have been used to improve breeds of cattle of dairy, beef and/or dual-purpose type. The work has been facilitated with the introduction of artificial insemination (AI) and the use of frozen semen. The name given to the first cross between yak and exotic breed is 'Improved *Pian Niu*'. Viewing the improvement activities in yak cross-breeding, the results that have been obtained in Sichuan and the opportunities created for improvement are described as follows:

1) Eliminating backcrosses '*Za Niu*'. This is a traditional method to maintain the development of stock. Only the F_1 animals ('*Pian Niu*') are used for production (for example, not for breeding), and all of their progenies ('*Za Niu*') are eliminated. This practice aims at harvesting all milk from the F_1 cross-breed (*Dzomo* in Tibetan), strengthening the availability of hybrid vigour and preventing the degradation of hybrid

quality. The problem of this practice is that it is not appropriate for the poor herdsmen who only own a small stock of animals and thus refuse to cull out any backcrosses.

2) Culling out '*Huang Za*' (progenies of backcrosses with cattle) and developing '*Mao Za*' (progenies of backcrosses with yaks). In order to restore and develop the yak husbandry, in the 1950s and 1960s the Government encouraged pastoralists to adopt this method instead of killing all of the backcrosses. This plan was based on the fact that the progenies of backcrosses with yaks can keep the productivity of yak better than that of the progenies of backcrosses with cattle and the hybrid vigour degrades more slowly. This improvement activity stimulated the development of yak husbandry in Sichuan and the hybridisation and utilisation of hybrid vigour made further progress. Until the middle of the 1970s the number of yaks (including cross-bred progenies) in Sichuan increased from 1.34 in 1950 to 2.7 million in 1974. This strategy was accepted and widely adopted in the north-western plateau where there is a tradition for hybridisation. It should be mentioned that this method is also combined with the selection and culling of F_2 hybrids in order to control their proportion in stock. Only the strong progenies of backcrosses with yaks are kept for draught and also culled out when they are old. The yak bulls for cross-breeding are also used for straight-breeding in yak stock. The progenies of backcrosses with yaks are mainly used for draught or trading with farmers, the number is very limited in such a high altitude area. Pure breeding is still the main method for herders.

3) Introducing improved cattle breeds (bulls) and cross-breeding with yak. In order to further utilise the hybrid vigour, it is necessary to remove the defects of local cattle and increase the economic return of hybridisation. In the 1960s eight breeds of cattle, such as Simmental, Holstein Friesian, Charolais, Hereford and Shorthorn, were introduced. They were raised in some pastoral counties, such as Zoige, Aba, Hongyuan and Sertar, and further crossed with yak. In this way some F_1 hybrids ('Improved Cross-breeds', '*Pian Niu*" in Chinese) were obtained, whose properties were apparently better than those of local cross-breeds ('*Pian Niu*' in Chinese) (Table 4). Even so, however, the actual socio-economic benefits were not as high as it was hoped because the introduced cattle breeds could not adapt totally to the high-altitude conditions and nomadic grazing systems and lost their mating ability gradually. In Sichuan there were no more than 1 000 cross-bred progenies of the introduced improved sire (bulls) after 20 years and until the 1970s the 'Improved Cross-breeds' obtained this way were less than 500 head. Finally, the improved sires for cross-breeding purpose were almost extinct until the end of the 1980s.

Table 4. Comparison of the properties among Yak, 'Local Cross-breed' and 'Improved Cross-breed'.

Items	Yak	Local cross-breed Yak (f) × cattle (m)	Improved cross-breed Yak (f) × HF (m)
Height at withers (cm)	109.7 (f); 123.9 (s)	118.3 (f); 128.7 (s)	121.8 (f); 144.0 (s)
Body length (cm)	138.1 (f); 161.5 (s)	148.0 (f); 173.0 (s)	152.3 (f); 178.3 (s)
Heart girth (cm)	160.3 (f); 198.0 (s)	167.9 (f); 197.3 (s)	182.7 (f); 215.6 (s)
Cannon bone circumference (cm)	16.9 (f); 20.6 (s)	17.0 (f); 20.3 (s)	18.5 (f); 21.3 (s)
Adult weight (kg)	249.0 (f); 443.0 (s)	292.0 (f); 476.6 (s)	356.5 (f); 580.0 (s)
Weight of new-born (kg)	18.7 (7.5 - 27.5)	17.5	22.5 (14.5 - 25.5)
Dressing percentage (%)	53.7	52.7	52.0
Carcass percentage (%)	42.0	40.0	41.0
Daily milk yield during lactation (kg)	2.0	3.0	8.0
Butter-fat content (%)	6.3	6.0	5.3 - 5.5

Source: 1) CAI, 1989; 2) Annual report of *Longri*, Hongyuan County.
Note: f = female; m = male; s = steer (castrated male).
cattle = local cattle; HF = Holstein Friesian or (75 percent HF + 25 percent local cattle).

4) First cross-bred generation ("*Pian Niu*') for dairy purpose and backcross ("*Za Niu*') for meat purpose. From the beginning of the 1980s this improvement scheme has been implemented in western Sichuan. Its purpose was to raise the yield of milk with the cross-breeding between female yak and improved bulls of dairy types (e.g. Holstein Friesians), and the yield of meat with the cross-breeding between cross-bred F_1 and improved bulls of meat types. In this way all backcrosses were used for meat purpose which accelerated the turnover of bovine population. Owing to the increase in milk yield and economic return, this plan has been disseminated to a certain extent in pastoral areas. Until 1985 the number of 'Improved Cross-breed' for dairy purpose in this plan was about 3 000 head (Cai, 1989). However, it should be mentioned that this work was facilitated by the introduction of AI. The use of AI is and has been inevitably restricted to more accessible areas. Moreover, the expense to herdsmen, of using AI or having bulls of the improved breeds of cattle (as well as their poor survival) means that, except in a few localities, this plan cannot be carried out effectively without relatively high input from governments or development agencies. So far no herdsmen in case study areas have engaged in this practice with their own investment.

On-going cross-breeding programme

With the privatisation of rangeland in the 1990s, an integrated development programme was initiated. Combined with the infrastructural construction, such as the construction of settlements for nomads, sheds for animals and cultivation of hay meadows, the improvement of yak and increasing the economic benefits of animal husbandry have also been included in the framework. After considering the various methods adopted during the last few decades, a more practicable method was suggested and implemented. As the improvement of cattle has been largely carried out in adjacent mountainous farming areas for some years, the F_1 male cattle that are always culled and used only for beef may be used in pastoral areas for yak improvement. This kind of bull is more adaptable to high altitude and harsh environment than its present father, on one hand and on the other hand, has higher potentiality in dairy production than local cattle did. Furthermore, in this way, bulls for cross-breeding are easier to obtain, the expense is acceptable for pastoral households, economic return is higher and the offspring are more adaptable. The detailed process is shown in figure 1.

Dissemination and breeding structure

The geographic location of pastoral western Sichuan naturally provides the accessibility to the exchange of animals and their products among pastoralists in plateau and farmers in mountainous regions. Traditionally, the original cross-breeding activities were carried out by yak herders along the eastern fringe of the Tibetan Plateau, for example, the agro-pastoral areas. The introduction of cattle for cross-breeding with yaks, therefore, is in line with the traditional practice of yak herders. However, the difference

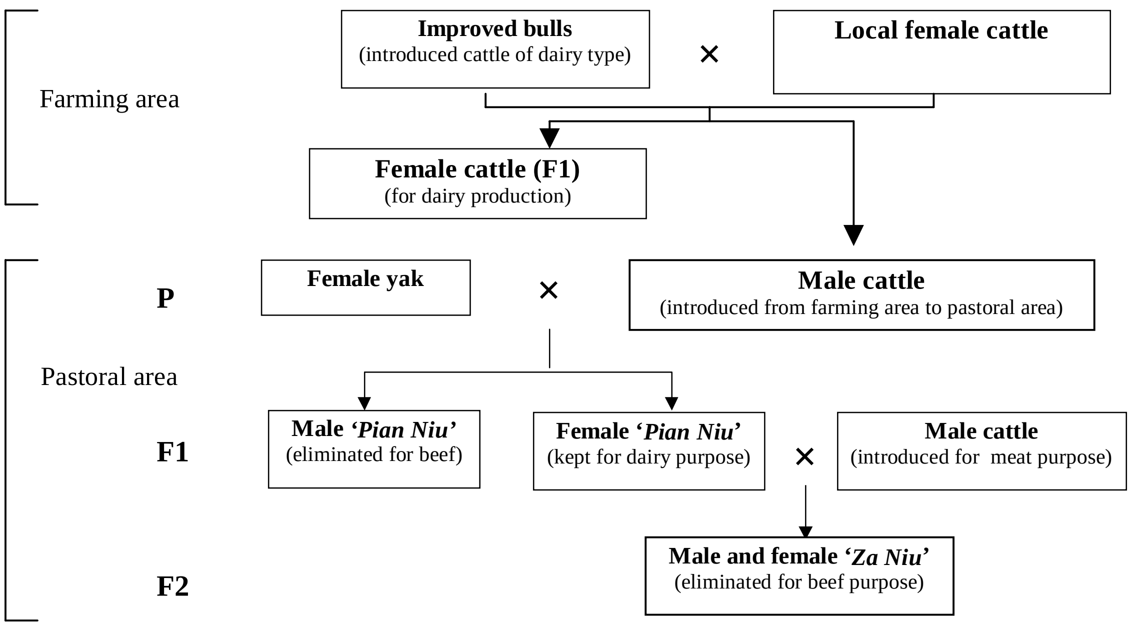

Figure 1. On-going cross-breeding plan.

between the on-going programme with traditional activities is that the introduced bull is an improvement on the pure local cattle, which may have greater potential for dairy production. On the other hand, it has stronger adaptability than the improved bull (such as Holstein Friesians) used in the last improvement schemes. Although the improvement programmes in both farming and pastoral areas are promoted by Government and development agencies, the local herders willingly accept this method due to its traditional and low expense. At the beginning of the 1990s a few bulls were introduced by institutions responsible for the technical support in the integrated development programme. With the demonstration in a few nomadic households, more and more nomads recognise the advantages of this practice. The introduction of bulls from farming areas is operated occasionally by individual herders themselves, step by step with the support of technicians and Government. Generally, an introduced bull is shared by a number of households having a joint investment.

Although the cross-breeds can provide more dairy products for the nomadic family, they still need more supplementary feeding during winter and spring. If herders want to keep the high productivity of hybrids, more attention should be paid to management. In general, the introduced cattle bull is raised separately in an enclosed pasture, which is close to a winter settlement of pastoralists and the hybrids are always separated from the yak herd. As the labour input is relatively high and the duration of the programme is short, the number of cross-breeds obtained in this way is only about 1 200 head in Hongyuan, the demonstration county and only make up 0.34 percent of the total yak stock.

Participation and technical support

Since the improvement of yak has been tested and carried out in western Sichuan for a few decades, abundant experiences both positive and negative have been accumulated. In the 1990s when the integrated development programme was implemented in pastoral areas, the Government was still the organizer, but experts from institutes, such as the Sichuan Rangeland Institute and Southwest Nationality College, gave technical support. At the beginning of the programme, the investment in the introduction of cattle bulls (male progenies of pure-bred foreign bulls with local cattle cow) from neighbouring mountain areas, was afforded by the programme, for example, from the Government. The experts are responsible for the demonstration in ten to twelve selected households in Hongyuan County. A series of training courses were conducted by technicians and herders from demonstrated families also worked as interpreters. Owing to its operational techniques, low investment and high economic benefits from milk selling, about 40-45 households were involved in this improvement scheme.

Main reasons for introducing the scheme and significant activities

Together with the traditional breeding goals mentioned above, looking for a breed with stronger adaptability to harsh environment and the marketing value are two major driving-forces for yak improvement. The purpose of cross-breeding initiated by the Government is, therefore, to combine some of the good qualities of the breeds being crossed and to anticipate the possibility that the performance of the crosses will exceed the average of the two parental types (in terms of heterosis or hybrid vigour).

Recent changes in production orientation from subsistence to more marketing in China drive the implementation of yak improvement. In Hongyuan County, one of the demonstrating counties for the integrated development programme, for example, in order to sell the surplus milk to the milk-powder factory located in the town, herdsmen need to have a breed with higher milk production. Traditionally, selling of dairy products is one of the most important sources for the income of local households including revenue for the Government, which has been reflected from the selection criteria of *Maiwa* Yak. Furthermore, one of the aims of the on-going integrated development programme is to promote the transformation of pastoralism from subsistence to marketing. With this original intention, the Government also needed to push forward the implementation of the yak improvement scheme in pastoral areas. Officials think that the situation of rangeland degradation could be changed through the increase of animal productivity, turnover rate of animal stock as well as the cultivation of artificial pastures. The development of hay meadows by every household provides the possibility to raise ‘improved’ yak hybrids individually. The limits of foodstuff in winter, labour in most households and seasonal migration of herds, however, still hinder the expansion of yak hybrids on a larger scale. Although the privatisation of the rangeland among nomadic households reduces the mobility of yak keepers, most households still adopt the traditional way for animal husbandry. The sparse and higher summer pasture cannot always provide enough foodstuffs to keep the high yield of lactating hybrids. The remote summer pasture is also far from the main road where the milk-powder factory collects milk from nomads. After the ‘settling down’ of nomads through the integrated development programme, the old people and children in the family always stay in their winter settlement all year round. They become the main labour responsible for hybrid raising with the help of women in the family during the lactation season.

Major challenging issues and future directions

Ways of improving yak productivity by selection, as contrasted to cross-breeding, might be thought to be of great importance to the people who depend on yak for their livelihood. Yak is an integral component of the socio-economic system of people in these remote areas. However, in the past and even in present times, several factors work against systematic breeding programmes.

Major challenging issues within Yak breeding and cross-breeding

At first, it was believed that yaks are still widely regarded, especially among Tibetan people, as a symbol of wealth, which is the main constraint for the genetic selection of yak (Cai and Wiener, 1995). Since the transformation from subsistence to marketing orientation is a slow process, the improvement of yak cannot be accepted widely in a short time, especially in remote areas. Furthermore, it is also impossible for the remote pastoral area to implement the cross-breeding programme where there is no effective market system for animal products and not enough foodstuff for animals.

Secondly, it was emphasised that an important reason why genetic selection by herdsmen or extension officers acting on their behalf, is hindered, is the absence of the necessary performance and pedigree records, although herdsmen will often claim to know the parents of the animal, especially bulls. In fact, the indigenous knowledge about breeding and cross-breeding has existed in pastoral societies for a long time and has functioned in a rational way. The only reason why it cannot be systematised and understood is that there is not enough technical capacity in these societies.

Thirdly, survival of yaks in a harsh, even hostile environment is of paramount importance, perhaps of higher priority than any single performance trait. In terms of selection for survival in these conditions, natural selection is almost certainly more effective than any current procedure devised by man (Cai and Wiener, 1995; Wu, 1997a). In addition, owing to the lack of sufficient knowledge on practical conditions including ecological, socio-economic and cultural, the activities or outcome of most projects for yak improvement which were coordinated by governments in the last three decades, cannot be sustainable.

Future directions

The improvement of yak in the high-frigid plateau is or will be inevitable and necessary, but it should also not be forgotten that yaks are reared in range systems and never housed even during the worst climatic conditions. The sustainable viewpoints cannot be omitted in any projects related to the development of the yak industry and all of the ‘modern’ techniques for breeding and cross-breeding cannot be introduced simply or directly without any practical evaluation (Wu, 1997b). Although the on-going cross-breeding scheme is relatively more successful than that carried out before (including the schemes mentioned in Section "Brief history of cross-breeding plan" such as eliminating backcrosses, culling out progenies of backcrosses with cattle and developing progenies of backcrosses with yaks, introducing foreign bulls to cross-breed with yak, and first cross-bred generation for dairy and backcross for meat), some aspects should also be improved if a sustainable approach is to be established, namely to:

- establish a small herd of pure yaks to carry out observations on performances in different systems of management. In this way the steady genetic features of different breeds may be characterised. It has to be admitted that yak to date, has better adaptability than any other hybrids in this harsh environment. The cross-breeding scheme cannot be expanded and / or it is not necessary to expand to the whole plateau. The systematic selection of yak breed and the *in-situ* conservation of a yak gene pool, therefore, must be carried out immediately, which will become an important basis for the sustainable development of yak husbandry;

- explore in depth the traditional strategies and indigenous knowledge of yak herders so that the best aspects of the traditional practices can be incorporated into modern improvement plans. Both cross-breeding and straight-breeding are important for pastoral development on the Tibetan Plateau. Technical support and investment should not only be limited to the field of cross-breeding, as the first purpose of the pastoralism in these remote areas should be subsistence rather than marketing in the forecasting future;
- conduct research on fodder and development of hay meadows for yak winter-feeding. If there is not enough foodstuff provided to yaks and / or their hybrids, the potential of milk, meat and hair production which is hoped for by development agencies, cannot be really elaborated;
- conduct research on the impacts of the marketing force on the improvement practices, breeding orientation and management systems. The forecast for the change of the marketing force and outlets is necessary for the steady and sustainable improvement scheme during the next five to ten years;
- raise the level of technical capacity through training and technical exchange in pastoral areas and to survey socio-economic problems associated with production or reproduction. The on-going privatisation in China has an impact not only on management of yak and land use patterns but also on the infrastructure and the direction of pastoral development. Any improvement scheme on livestock must be environmentally sustainable as well as politically sustainable (politically steady).

Conclusion

In the Tibetan Plateau many cross-breeding methods have been conducted in the last few decades, but few systematic schemes were implemented on the straight-breeding of yaks. Although the national selection criteria for yak breeds were set up in the 1980s, cross-breeding between yaks and cattle is still the only content involved in the most developed programmes. In operational opinions, straight-breeding should be largely promoted and the indigenous knowledge of herdsmen on yak selection should be combined into the future yak breeding programmes. Cross-breeding schemes should be limited to more favourable areas, such as agro-pastoral areas or the areas neighbouring in consideration of ecological adaptability of hybrids. The remote pastoral area should be dominated by yak stock when forecasting in the future. Even so, a cross-breeding scheme should not be expanded on a large scale until the technical capacity of local communities is enhanced so much so that they can master the techniques for more intensive management, more fodder could be provided to winter raising and enough market outlets could be made available for animal products.

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Appendix 1

A brief introduction to Yak

People always associate the high and frigid range on the Tibetan Plateau with the yak (*Bos grunniens*), because it is one of the most important species of livestock found in the Himalayas and on the Tibetan Plateau, as well as in pastoral areas of north-western China, Mongolia and southern Russia. Yak is the multipurpose high altitude large mammal belonging to the *Bovidae* family under the tribe ruminantia, and the only one species of bovines that can adapt itself to the physical environment of the Plateau. Man said: "Without yak it is difficult to imagine the situation of animal husbandry in the Qinghai-Tibetan Plateau." This implies that it is impossible to separate the yak production with the climate of the Plateau, alpine pastures and the daily life of the Tibetan.

Nomadic yak breeding sprang up in the Tibetan Plateau as a result of the adaptation of the pastoral communities with a producing economy to specific ecological niches created by the simultaneous effects of various natural geographic, socio-economic and historical factors. Traditionally yak breeding patterns can be interpreted as the result of adaptive responses of organisms and societies to current pressures and specific historical processes. Archaeological evidence indicates that the earliest domestication of yak, sheep and goats occurred in various locations in the Tibetan Plateau about 5 000 years ago (Cai, 1989). Originally an aspect of broad spectrum village subsistence and then specialisation in its own right, this technology becomes prevalent in the Tibetan Plateau and its adjacent territories.

In the Tibetan Plateau most of the places lower than 4 500 m are unsuitable for cropping, except for the few river valleys in the south and east. Therefore, the extensive areas of rangeland, with the area of 167 million hectares are available for yak grazing. In 1996, it was estimated that there were about 14.5 million yaks in Chinese territories (including yak-cattle hybrids).

Yak enjoys the rare distinction of being the only large mammal that dwells in-between 2 500 to 6 000 m with ease and simultaneously produces work and products. The natural habitat of yaks has some distinct characteristics, such as rarefied air and scanty grass resources. The diurnal temperature fluctuation is very wide at high altitude. High altitude pastures above 4 000 m almost remain inaccessible in the winter season due to snowfall. During this period the yak herds descend down to a lower altitude (always below 3 500 m) for the winter grazing, where few sunny days occur in the melting of snow and the grasses or shrubs are available for grazing by yaks. During the peak winters these areas also experience heavy snowfall but never remain under snow for a long period. Therefore, the features of the living area of yak are summarised as follows:

- high altitude (2 500-6 000 m);
- low temperature (annual mean temperature around and even below 0°C);
- great difference of diurnal temperature (above 15°C);
- low atmospheric pressure (below 110 mm mercury high); and
- alpine meadow, with dwarf shrubs but in good quality.

Yaks are endowed to live in the cold regions as they have some physiological and anatomical ramifications in comparison to other members of the bovine group. Since the result of natural selection of the special and harsh ecological environment, yaks have a very strong survival ability and form a serious function against the hard environment (Cai, 1989; 1992). Generally speaking, temperature is the single most important factor determining the distribution and stocking density of yak (Wu, 1997a). Yaks survive and perform adequately if the annual mean temperature is below 5°C and the average in the hottest month is not above 13°C. Subject to the availability of adequate grazing, the distribution and stock density of yak increases with altitude. However, altitude is of lesser importance than air temperature, because the relationship between altitude and latitude can be mediated through air temperature.

With the extensive rangeland, yak breeding remains important both for the subsistence of the majority of the rural population and for the entire economic system. In the absence of alternative opportunities for local employment of any significance, most people, mainly Tibetan, earn their livelihood from yak husbandry. For example, in western Sichuan the output value of pastoral livestock production approaches 54 percent of the Gross Agricultural Output Value (GAOV) as a whole. As extensive technical and economic reports mention, purchasing of animal products has generated no less than half the income since 1975. According to the statistics of the Provincial Animal Husbandry Bureau, 72 percent of milk, 45 percent of beef, 42 percent of bovines' skin and 34 percent of hair (including downhair) in 1995 came from the production of yak. Although the composition of livestock herds in different ecological regions are varied, yak is always an important means of subsistence and of productivity in all pastoral societies of western Sichuan, which contribute more than meat, milk and clothing materials. When associated with cropland they often contribute manure and traction. It is also common for yak to be used for transport and as a form of capital and security. In pastoral societies it may contribute blood to the diet and invariably it is used to build and maintain social relationships. Hides and skins are used for housing and water containers as well as for clothing and dung may be also used as fuel instead of manure. Different species perform different functions in different livestock production systems. The functions which yak fulfills in a given situation derive from interaction between environment, human need and custom.

Over the centuries, yak herders have bred yaks and developed numerous local yak types, often recognised as distinct breeds with different characteristics. In China ten types have been identified, which include *Jiulong* Yak and *Maiwa* Yak in Sichuan, *Zhongdian* Yak in Yunnan, *Tianzu* Yak and *Gannan* Yak in Gansu, Plateau Yak and *Huanghu* Yak in Qinghai, Alpine Yak and *Yadong* Yak in TAR (Tibetan Autonomous Region), and *Bazhou* Yak in Xinjiang (Cai, 1992). However, there is little scientific evidence available on the genetic variation that exists between these different breeds. The existence of different breeds may be the solution to developing a yak genetic conservation policy and new genetic programme for commercial yak raising

Different yak breeds exist, for the most part, in different areas where yaks are raised. To date, no proper genetic comparison has ever been made between these different breeds in terms of their performance and general attributes (Miller *et al*, 1997). It is not known to what extent the breeds differ genetically. All that is known is that they appear to differ in their general appearance. It is necessary, therefore, to measure performance, survival and reproductive capacities among the different breeds to determine how much one breed differs from another. Yak breed comparisons and the crossing of yak breeds could be very valuable for identifying yak genetic diversity and would provide a scientific basis for yak genetic conservation plans and, probably more importantly, for the development of improved breeding plans for yak herders to follow (Wiener, 1997). This could eventually lead to improvements in yak performance and hopefully even ensure the long-term survival of the yak and the unique yak-herding culture which it supports.

Cattle improvement project in the Kyrgyz Republic[1]

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Introduction

The case study of the Kyrgyz Republic in Central Asia is based on a very recent start to reintroduce systematic breeding in cattle after the transformation from large collective farms to small private farms. Some of the large farms have managed to transform themselves into collectively owned private farms. These farms have also managed to maintain valuable breeding stock which now becomes the basis to start systematic breed improvement in order to produce high quality semen to be used in the large number of small family farms throughout Kyrgyzstan.

Breeds

Alatoo

The Alatoo cattle breed is the main breed in the Republic. It was developed by complex cross-breeding schemes of local Kyrgyz cattle with Brown Swiss (BS) and Kostromskaya. Animals of this type are very similar to Brown Swiss, have a shorter body, deeper chest and lower implantation of the legs. The udder is well developed and the yield is in the range of ten to 15 kg of milk per day. Thanks to their productivity and their adaptation to the hot dry summers and severe winters of Central Asia, the breed is widely used in the Republic as well as in neighbouring countries. During the period of breed perfection, the Kyrgyz Republic exported 59 500 heads of young animals to other Republics of Central Asia, the Caucasus, Mongolia, Korea, China and Afghanistan. The level of improved (American) BS blood has probably decreased during the past seven years, as in this period there has been little use of BS semen. The population of Alatoo cattle in 1997 was estimated at 680 000 heads. The Alatoo breed is kept throughout Kyrgyzstan.

Kyrgyz Black and White Cattle

The Kyrgyz Black and White cattle (KBW) is considered to consist of three sub-populations: the original Aulieatinska breed, “holsteinized” Alatoo and “holsteinized” Aulieatinska. The highest density is in peri-urban areas of Chui oblast and Talas oblast. Kyrgyz Black and White cattle, though

[1]Supported by Kyrgyz Swiss Enterprise Development and Kyrgyz-Swiss Agricultural Project

not yet officially recognised, can be defined as a new breed group of dairy animals. Its genetic improvement can be pursued in a breeding programme similar to the one for Alatoo. The Aulieatinska breed was created in 1974 after cross-breeding of local Kyrgyz cattle with Friesian bulls. At dairy farm "Jergetalsky" (Talas oblast) productivity of cows was 3 900 kg of milk per lactation. From 1980 onwards "holsteinization" of Alatoo started in 26 collective farms with the purpose of increasing milk production. The population of KBW in 1997 was estimated at 170 000 heads.

Input levels

In principle, there are two types of cattle keeping systems in Kyrgyzstan:

- systems where the animals are housed year round. This is the more intensive system with normally large herds (500 to 3 000 animals, former collective farms) and located around larger industrial and urban centres;
- mixed systems with alternate stall-feeding and grazing in summer, or grazing altogether in summer on summer pastures and stall-feeding in winter. This system can be found in the newly established private farms as well as in some former collective farms.

The inputs for milk production vary from low to high. The sharp inflation which started in August 1998 put milk producers into difficulty: fuel prices went up drastically and milk prices remained approximately at the same level. The situation for medium scale farmers was similar. Small farmers do not use a lot of machinery in the production process. Fodder procurement is made manually which makes production costs lower.

Size of population

In 1997 the size of the Kyrgyz cattle population was estimated at 850 000 animals (680 000 Alatoo and 170 000 Black and White). Kyrgyzstan is divided into six oblasts (cantons): Chui, Osh, Jalal-Abad, Naryn, Issyk-Kul and Talas. Eighty-five percent of the territory is covered with mountains. Large cooperative milk farms are located only in Chui oblast, medium and small milk farms established in the process of reforms from 1991 are located in all oblasts. The cattle populations of the large cooperative farms amount to 3 000 heads.

Rationale of Cattle Improvement Project (CIP)

The Cattle Improvement Project was started on 1 January 1999. The Project activity involves six large farms, medium size private farm and 300 small scale farmers, cattle-keepers. The total number of cows is 7 000. Two thousand are involved in the "Animal Performance Recording System". The best breeding animals of the country are kept on the large farms, therefore the project aims at maintaining and improving the quality of the animals in these farms in order to use them afterwards as reproducers of genetic material for other regions of the country. All these farms have operational Artificial Insemination facilities. The project imports progeny tested bull semen for the insemination of the best cows with the purpose of producing good quality breeding bulls for the production of frozen semen or direct use in natural service. It is planned to initiate the improvement activity in the first stage in two oblasts of the country and to spread it afterwards over the whole country.

Main purpose and breeding goal

The main purpose of cattle-keeping is milk production. Some farms produce up to 18 tons of milk per day and sell it to milk processing units. The majority of small and medium farms sell milk on markets and use it for home consumption. Improvement of milk productivity is the most important aim. Imported Brown Swiss semen is used for the improvement of milk production of the Alatoo breed and imported Holstein semen for improvement of milk production of the Black and White breed. For the time being, real breeding work, performance recording, selection and nominated services, are carried out only on collective farms. These farms will produce the genetic material to be used by the small farmers. The majority of small farms, having 90 percent of the country's cattle population, at present do not improve the quality of their cattle through breeding at all. The breeding aims for milk traits for Alatoo and Kyrgyz Black and White are listed in Table 1.

Table 1. Breeding aims for milk traits for Alatoo and Kyrgyz Black and White cattle.

Trait	Alatoo	Black and White
Lactation yield	4 500 – 5 000 kg	4 500 – 5 000 kg
Fat content	3.8 – 4.0%	3.8 – 4.0%
Live weight	550 – 600 kg	450 – 550 kg
Milking speed	1.6 – 1.8 kg / min	1.6 – 1.8 kg / min
Udder index	42 – 44%	42 – 44%
Age at first calving	27 – 29 months	25 – 27 months

Breeding plans

From the 1950s onwards a large-scale programme for improving the local Kyrgyz cattle breeds has been carried out. Brown Swiss bulls were used for that purpose through artificial insemination. In the late eighties almost the entire cattle population was improved with Brown Swiss genetic material. In the eighties the programme of cross-breeding local Alatoo cows with Holstein bulls was initiated in Kyrgyzstan with the purpose of further increasing milk production. This programme involved 26 large breeding farms.

Today, only two large farms with predominantly Holstein crosses are still functioning effectively. These farms each keep approximately 1 300 milking cows which are Holstein cross-bred of different generations. The production level is approximately 4 000 kg per lactation.

Improvement with the Holstein breeding material was made mainly in the suburbs of the capital Bishkek and the lowlands, whereas cross-breeding with Brown Swiss was made over the whole of Kyrgyzstan.

The Government breeding policy aimed at large collective farms. In 1990 these farms had more than 85 percent of the cattle population. In 1987-1990 the annual average milk yield per animal on the collective farms was 3 100 kg.

The Central State Breeding Station produced frozen bull semen and had branches in all oblasts. In addition to the production of semen, the Station imported and sold high quality progeny tested semen.

The cows in the Government sector were inseminated artificially. Bulls were progeny tested.

Today the Government breeding system no longer exists. The large farms in five oblasts were reorganized into small private holdings where, at present, breed improvement activities in the narrow sense does not take place.

The Cattle Improvement Project being part of the Kyrgyz Swiss Agricultural Projects, combines six large cooperative farms, one private medium size farm and 300 small scale cattle holders. The aim of the project is to maintain the remaining breeding stock of the country and to improve its quality as well as to resume the production of bull semen for small milk producing farms.

New elements in the breeding programme

The Kyrgyz breeding policy for cattle aimed at dual purpose animals with emphasis on milk yield next to good daily gains for meat production. The Kyrgyz winters being long and hard and the summer feeding being based on high mountain pasture grazing, the fitness traits were important, though never explicitly bred for. The small scale cattle keeper will opt for an animal with a good (not maximum) milk production which can produce a reasonable amount of milk with the farm based fodder. Cultivated fodder and supplements (concentrates, minerals) will either not be sufficiently available or too expensive for quite some time to come.

Traits included in the breeding goal

At present the recording system is only geared towards milk yield and fat content. In addition, a body conformation scoring based on the linear description method is being developed for potential bull mothers and potential breeding bulls.

Selection criteria

The selection criteria are milk yield and fat content. At present a simple contemporary comparison method is followed. In addition, body conformation scoring (linear description for bull mothers and breeding bulls).

Dissemination of improved genetic material

Sale of bulls from breeding farms to villages for village herds and small holders. Sale of frozen semen of best bulls to cooperative farms and farmer associations. Sale of surplus good quality heifers from large farms to small holders.

Population structure

Looking at the entire cattle population, its composition can be defined as follows:
a) pure-bred Alatoo cattle;
b) improved Alaltoo x Brown Swiss;
c) Kyrgyz Black and White.

Farmer and Government involvement

Farmers invest mostly to improve milk production. Government support is no longer available. A Government resolution exists on providing breeding farms with subsidies, but in practice the farmers do not get any support from the Government.

Technical support

Milk recording and fat analysis. The Project carries out the milk performance recording of 2 000 cows. In four villages there are four milk recorders. Each of them visits 50 to 70 farmers per month. They measure milk quantity and take samples to determine the milk fat content.

AI services. In three villages AI points have been set up where farmers can bring their cows for insemination in the morning and in the evening. The project supplies semen, liquid nitrogen and other material to these points at cost price. The farmers of the villages have selected a person to work as an AI technician. The project renders support to the AI points in the large farms. For this purpose the project has provided new LN containers.

Training. The Project carries out the training for AI technicians and organizes exposure trips to Russia and Kazakhstan.

Main reasons for introducing the scheme

Cattle breeding is a traditional sector in Kyrgyzstan. More than 60 percent of the human population lives in rural areas. Milk production and sale of milk and milk products are a main source of income for those living in rural areas. Milk and milk products are prominently placed in the diet of the Kyrgyz population even among the poorer people. Meat is the main traditional protein product for the Kyrgyz population.

In agro-climatic conditions (average rainfall 400 mm / year) and topography with very large high altitude pastures (2 500 to 4 500 m), livestock production in Kyrgyzstan has played a major role in the past and will in the future. In livestock production Kyrgyzstan enjoys a comparative advantage in Central Asia, based on agro-climatic conditions, tradition and knowledge.

At present in Kyrgyzstan, there is a large untapped potential for more intensive livestock production.

Peculiarities of the programme

The programme attempts to bundle the still available know-how in breed development of the erstwhile collective and state farms and to assist the remaining cooperative farms to make their good quality genetic material available to a wider public by systematic breeding work. This work has to be based on principles of private enterprise and market economy.

Anticipated changes

In the near future the following changes with regard to breeding will be implemented:

- adoption of the newly developed breeding policy on a national level;
- establishment of farmer organizations to enable farmers to independently deal with breeding issues;
- design breeding plans at local level;
- simultaneously make efforts to improve the feed and fodder base and animal feeding (this issue is acute for farmers as the breed improvement activity undertaken at the moment will not solve the problem of low milk productivity alone);
- establish a breeder service company as a limited liability company based on principles of private enterprise and market economy.

Future outlook

The future of the two existing cattle breeds depends on the farmers themselves. There are regions in the country where milk sale is difficult. This hampers the possibility of breed improvement (for example remote mountainous regions). In contrast, the areas around cities and industrial centres are characterised by a high demand for milk and milk products. In such regions farmers will start to combine their efforts and will organize AI activities using frozen semen of breeding bulls (a demand driven programme). We are convinced that milk production in the coming five to ten years will become profitable not only in the suburbs but also in the rural areas which after all will be the driving force to the overall cattle breed improvement programme in Kyrgyzstan.

A village goat cross-breeding project in Maharashtra, India

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Introduction

The Nimbkar Agricultural Research Institute (NARI) was established with a private endowment as a registered public trust in 1968, in Maharashtra, India, with the objective of undertaking research in a wide range of agricultural activity to improve the quality and quantity of agricultural produce. The Animal Husbandry Division of NARI was started in 1990 with the aim of bringing about genetic improvement in local goats and sheep to increase their productivity and efficiency. A comprehensive project proposal to enhance the income of rural goat-keeping women in Phaltan taluka (shire) by improving the productivity of their goats was submitted in 1991 to a Government of India funding agency, the Council for Advancement of People's Action and Rural Technology (CAPART). This proposal comprised eight modules, out of which, CAPART agreed to fund two, e.g. cross-breeding of local goats and provision of goat health care under their scheme 'voluntary action in rural development.'
The mammalian species involved was goat.

The breeds of goat involved

Local goats not recognised as belonging to any particular breed, were cross-bred with bucks of the Sirohi breed from Rajasthan, Alpine x Sirohi and Toggenburg x Sirohi bucks.

The approximate overall input level of the production system concerned

Goat-keeping in south central Maharashtra where Phaltan taluka is situated, is a low input production system. The usual practice is for women to keep small flocks of one to three goats which are tied up in front of the house. There are some larger flocks of ten or more goats. The women take the goats out to the fields with them every day, tie them on the boundary of the field where they work and feed them weeds, grass and acacia or prosopis pods. Goats also get kitchen scraps and leftovers from family meals. Concentrates or oilseed cakes are fed occasionally after kidding. Sometimes goats are vaccinated against enterotoxaemia and haemorrhagic septicemia in camps specially organized by the Maharashtra Government department of animal husbandry. In recent times, private veterinarians have started practising in a lot of villages and goat-keepers avail of their services in emergencies. However, on the whole, there is hardly any expenditure on purchasing feed, medicines or other inputs.

The approximate number of goats

Thirty-four villages within a 15 km radius of Phaltan town formed the target area for the cross-breeding project. The estimated number of breeding does in these villages was about 15 000 and about 60 000 in Phaltan taluka. Thirty-one Sirohi, five Alpine x Sirohi and four Toggenburg x Sirohi bucks were placed in 34 villages; one per village with 200 to 500 local does and two in each of the six villages with >600 does each. These bucks had been selected on their own growth rates and their mothers' milk yields.

The local goats in the 34 project villages were targeted for improvement.

The approach through which the breeding goal was established

A preliminary survey of goat-keeping practices and economics in the villages near Phaltan showed that women rear goats for milk for home consumption and meat for sale. The kidded doe provides a little milk for the family after kids are weaned and the male kids are sold or slaughtered at the age of five to six months. Thus both milk yield and growth rates are economically important traits.

However, the village women goat-keepers generally do not keep a breeding buck. Most of the goats in the village are mated by the breeding buck specially reared by one goat owner. Little or no care goes into the selection of the breeding bucks. There is also a tradition to let buck kids loose as an offering to God. These bucks roam around and even graze people's crops and grow big and hefty. They then dominate the other bucks in the village and mate with the majority of the goats in the village. It is thus likely that generations of breeding bucks in a particular village hail from one individual with the possible consequence of severe accumulated in-breeding.

NARI thought that supplying breeding bucks of an improved breed for cross-breeding would reduce in-breeding and lead to genetic improvement.

A cross-breeding programme was preferred as selection would take too long to be effective and would need substantial facilities and funds that were not available. Moreover, cross-breeding at village level could be monitored readily because the cross-bred progeny would be easily distinguishable.

Choice of breed for cross-breeding

The Sirohi breed from Rajasthan was recommended by "the Central Advisory Committee for the development of sheep, goat and rabbit" for use in up-grading non-descript goats. The Indo-Swiss Goat Development and Fodder Production Project (ISGP), in performance recording of Sirohi goats from 1988-91, found their production potential to be much higher than reported earlier. They reported the average milk production of Sirohi does in village conditions to be 250 kg in 180 days. The average weights of male and female Sirohi kids at the age of six months were reported to be 19.6 and 18.6 kg respectively. The Sirohi and Sirohi cross bucks also fulfilled the local goat-keepers' criterion that the breeding buck should be large, e.g. weigh at least 40-50 kg. The Sirohi breed is from hot and arid Rajasthan and was expected to adapt well to a similar climate of the Phaltan area. Before the start of the village cross-breeding programme in 1991, NARI purchased 13 Sirohi bucks selected on their individual growth rates and their mothers' milk yields, ten Alpine x Sirohi and ten Toggenburg x Sirohi bucks from the ISGP. CAPART refused to fund the purchase of the cross-bred bucks which were therefore purchased with NARI's own funds. Twenty more Sirohi bucks were purchased from the Central Institute for Research on Goats of the Indian Council of Agricultural Research. Out of these 53 bucks, two Sirohi, five Alpine x Sirohi and six Toggenburg x Sirohi bucks had to be culled due to lack of libido and the remaining 40 bucks were placed in the villages.

The plan designed and followed to achieve the breeding goal

In each village, one or two families willing and able to maintain a breeding buck (with assistance from NARI in the form of supply of concentrates at 300 g per day per buck and complete free health care of the buck) were identified and an agreement was entered into between NARI and the head of the buck-keeper household. A breeding buck was then allotted to each such family. Each buck-keeper family was provided with chain-link fencing to make a pen for the buck and specially designed notebooks for recording the services given by the buck and the details of each goat serviced. Bucks were insured in the name of NARI to protect the buck-keepers against financial loss if the bucks were to die. Buck-keepers were allowed to charge service fees only at the normal rate in each village so as to induce goat-keepers to get their does bred by that buck. However, if a doe served by the buck returned to oestrus, another service would be given for free. Efforts to persuade the villagers to get rid of wandering bucks succeeded in some villages.

The plan to achieve the breeding goal did not differ from that actually followed.

Traits included in the breeding goal were liveweights/growth rates of kids up to six months of age.

The selection criteria followed: no selection was made.

The methods used for the dissemination of improved males/females

As indicated in the section entitled "The plan designed and followed to achieve the breeding goal", improved bucks were placed in the villages for cross-breeding of local goats. No efforts were made for the dissemination of cross-bred males and females generated in the course of the project.

The population breeding structure: Cross-breeding

Local goats maintained by village goat-keepers were cross-bred under the project. Breeding bucks were sent out to selected buck-keepers in the villages at the onset of the breeding season in late May. At the end of the major breeding season in December-January, when the number of goats exhibiting oestrus dwindled, if the buck-keepers had a shortage of feed, the bucks were brought to the NARI farm. In the next breeding season, these bucks were sent to different villages to eliminate the possibility of in-breeding even though some buck-keepers had strong personal preferences for the bucks they had originally kept. The goat-keepers who were given Sirohi goats (see the chapter "Government support"), were encouraged to breed these with the project's Sirohi bucks in their village and some well-grown Sirohi buck kids from such matings were purchased by NARI to replace aged bucks and those without adequate libido.

Farmer involvement

The active participation of a local farmer who cared for the buck in each village was an important factor in the acceptance of the scheme by goat-keepers and the success of the programme.

Levels of acceptance over time

The number of goats mated by the project's breeding bucks increased from 1 193 in the first year to 1 814 in the second year (a 52 percent increase) and 1 990 in the third year, a total of about 5 000 goats in three years. Increased acceptance of the project by local goat-keepers could also be attributed to the fact that the goat-keepers did not have to go far to obtain superior germplasm and they could see the cross-bred kids thriving in the same conditions as local goats. An important incidental benefit of the project was that goat-keepers became aware of the importance of weighing their goat kids and correlating the sale price with the kids' weights.

Government support

CAPART, a Government of India funding agency sanctioned a grant of Rs. 1 million over three years for the project but did not disburse the last instalment of Rs. 0.2 million.

The Central Institute for Research on Goats which is a Government institute, made 20 Sirohi bucks available for the project at a reasonable price.

It was a condition of CAPART that part of the funding for the project come from local Government agencies. NARI, applied accordingly to the Satara District Rural Development Agency for funds to construct a shed with feeder and waterer for the breeding buck in each village and to purchase goat Artificial Insemination (AI) equipment, microscopes for semen evaluation and veterinary first aid boxes for use in the villages. It was envisaged that these items would be handed over to the grampanchayat (village council) for long-term use for the benefit of the village goat-keepers. It is noteworthy that the Government has financial provisions to keep veterinary health care kits in villages and to distribute 'improved' goats and sheep to beneficiaries. However, in spite of constant correspondence with Government officers up to the highest level and frequent visits to the concerned offices, the Government realised its written financial commitment given to this project. However, the Maharashtra State Animal Husbandry Department provided enterotoxaemia and haemorrhagic septicemia vaccines free-of-charge for goat health camps organized by NARI, every six months in every village where a breeding buck was kept. Some drug companies provided small quantities of free dewormers for these camps.

In the third year of the project, NARI implemented a sub-project to provide additional goats to below-poverty-line families in five of the project villages. This was to help goat-keepers take advantage of the Central Government scheme of a 33 percent subsidy (50 percent to backward class households) on bank loans for income-generating activities to families from the list of those existing below the poverty line. (An annual income of US$200 per family is considered to be the poverty line.) Since good goats were not available in large numbers locally, NARI purchased Sirohi goats from Rajasthan and 125 goats were distributed to women beneficiaries under the Government scheme.

Type and nature of technical support, including extension, involved

Farmer support. Two veterinarians were hired, who visited each project village one morning a week to deliver a week's concentrate supply for the bucks, monitor the health of the bucks and provide free medical treatment to the bucks, if necessary, and to any sick goats in the village. They also brought back the records of services given by the bucks and ironed out any problems encountered by the buck-keeper and goat-keepers. This regular communication link was necessary and useful;

Research and development. The veterinarians were entrusted with the task of visiting all the goats served by the NARI bucks in the week in which they were due to kid and recording the date of kidding, the number of kids born, sex and birth weights. Thereafter, they recorded the liveweights of all cross-bred kids every month until they were sold for slaughter or up to the age of six months. For comparison, liveweights of contemporary local goat kids were also recorded;

Training. Ten groups of ten women goat-keepers each were given a three-day training course in goat management with funds from a Central Government scheme. These courses were held at an agricultural science centre in the adjoining district. Some women clearly benefited a lot while others, mainly the illiterate ones, did not gain very much from the training.

The main reasons for introducing the scheme

i) The activity of goat-keeping provides supplementary income to poor rural families and produces much-needed animal protein. Genetic improvement of goats has been neglected by the Government;

ii) Breeding bucks were provided to some villages where there were no breeding bucks and goats had been taken long distances to be mated;

iii) Goats are usually reared in small numbers and individual goat-keepers do not keep breeding bucks. In most, but not all villages, there may be one or two breeding bucks. These are not changed for years. There is, therefore, a high probability of severe accumulated in-breeding. The cross-breeding scheme was introduced to counter the in-breeding;

iv) Sirohi bucks selected for growth rates and mother's milk yield and crosses of Sirohi with the Alpine and Toggenburg breeds, were introduced into the local goat population under this project. The expectation was that cross-breeding with these bucks would lead to increased productivity of the cross-bred progeny through additive genetic effects and heterosis.

The most significant activities and design peculiarities that enabled the scheme to be initiated and maintained over time

They are:

1) Technical factors:

i) the scheme fulfilled a need of village goat-keepers and they approved of the physical characteristics of the breeding bucks;

2) Operational factors:

i) NARI was highly motivated to bring the scheme into practice and was able to ensure active participation of village goat-keepers;

ii) The supply of feed and veterinary care for the bucks, freedom to charge fees for buck services, vaccination and deworming facilities made available to the village goats and other incentives including insurance of the bucks, all played a positive role in the initiation of the scheme as well as its maintenance over time.

3) Policy factors:

i) In the present goat-keeping scenario in this part of Maharashtra, only a relatively simple and unsophisticated breeding scheme is practical; such as the supply of bucks whose offspring can be readily identified.

There is no sophisticated recording system in place at the goat-keeper level and a selection programme would be too long-term and would require funds and facilities which are not available.

Changes that should be made to the design and operation of the scheme to make it more successful and reasons for suggested changes:

1) Economic evaluation

An economic assessment of the activity of goat-rearing comparing the use of local bucks with improved bucks, should be made. However, this is difficult to carry out because goat-rearing is a part-time activity using family labour, inputs and outputs are not quantified and the age at sale / slaughter of the goat kids produced is not likely to be optimum because it depends on considerations such as the family's need for cash in an emergency;

2) Estimates of heterosis

It is important to know the relative importance of heterosis and additive effects in order to make a decision about whether to continue cross-breeding the local goats with bucks of the chosen breed or cross or to 'up-grade' by backcrossing or to create a synthetic. In this project, no estimates of heterosis could be obtained from the data on the progeny produced. It was not possible to create a sufficiently large female population of the buck breed-type in the same (village) conditions. Efforts should therefore be made to produce sufficient numbers of backcrosses (both by crossing the cross-bred kids with local bucks and Sirohi / Sirohi cross bucks) and F_2 level crosses by doing *inter se* mating, to get an estimate of heterosis for this set-up;

3) The ISGP reports the average litter size of the Sirohi, Alpine x Sirohi and Toggenburg x Sirohi to be in the range of 1.05 to 1.07 whereas the local goats have an average litter size of 1.63. It is likely that the cross-bred female progeny of local goats would have lower prolificacy than the local goats. Prolificacy is an essential element of an efficient meat production system and this factor will need to be included in the choice of the crossing breed. Unfortunately this was not considered a priority for this project.

Future directions for development in design, operation and policy

There is a serious shortage of goat meat in India which is reflected in the rising prices of goat meat over the last 15 years. After the experience of the first cross-breeding project, NARI imported the Boer breed of goat which is selected for meat production performance in southern Africa, in order to assess its potential for the improvement of goat production in this area of India. These trials have started and initial results are promising. As the number of pure Boer bucks with NARI is small, artificial insemination has to be used to implement cross-breeding. This adds a further complication to the system but demand for Boer semen from local goat-keepers is good. There is also a large demand for Boer crosses from all over the State which can be sold for breeding at substantially higher prices than local goats.

Available estimates of genetic change in the population due to the scheme

Liveweights of 1 972 local and cross-bred kids were measured on spring balances and recorded from the age of one month to six months. At six months, only 805 of these kids were still available for recording due to continuous sale of kids. These liveweights were analysed by Harvey's least squares analysis of variance. Results are shown in Table 1. Liveweights of kids reared to six months were also analysed separately to see if only the slow growing kids had been retained to that age. However, this was found not to be the case. The decision to sell a kid was more a function of the family's need for cash rather than the liveweight of the kid.

There was thus a moderate increase in the growth rates of cross-bred kids with the same feeding and management as the local kids.

Most of the male cross-bred kids were sold or slaughtered while some of the female cross-bred kids were kept and reared by the goat-keepers. Their performance was assessed with the help of a questionnaire and it was found that 64 percent of the goat-keepers surveyed were completely satisfied with the reproductive and milking performance of cross-bred does and rated it better than that of local goats while the remaining 36 percent felt the cross-bred females did not come up to their expectations.

Table 1. Least square means of liveweight (kg) from one to six months of age of different genetic groups of village goat kids. (The numbers in brackets denote the number of observations available).

Genetic group	One month	Two months	Three months	Four months	Five months	Six months
Local	5.2 ± 0.2^A (189)	7.4 ± 0.4^A (171)	9.4 ± 0.5^A (156)	11.5 ± 0.6^A (116)	13.0 ± 0.8^A (87)	14.7 ± 0.9^A (42)
Sirohi x Local	5.4 ± 0.2^A (1 337)	7.9 ± 0.3^A (1 321)	10.1 ± 0.5^A (1 292)	12.4 ± 0.6^B (1 088)	14.1 ± 0.7^B (878)	15.7 ± 0.7^A (580)
(Alpine x Sirohi) x Local	5.8 ± 0.2^B (335)	8.7 ± 0.4^B (337)	11.5 ± 0.5^B (321)	13.4 ± 0.6^C (275)	15.1 ± 0.7^C (242)	15.1 ± 0.8^A (160)
(Toggenburg x Sirohi) x Local	5.2 ± 0.2^A (111)	7.5 ± 0.4^A (107)	9.9 ± 0.6^A (100)	12.5 ± 0.7^B (82)	14.2 ± 0.8^B (64)	16.5 ± 1.1^B (23)
Significance of the effect of genetic group	$P < 0.01$	$P < 0.001$	$P < 0.001$	$P < 0.001$	$P < 0.01$	Not Significant

Means with different superscripts differ significantly ($P < 0.01$).

The survey was made in the middle of the third year of the project when data on only the first kidding of the cross-bred does was available. More than 90 percent of the does surveyed gave birth to single kids. However, it is difficult to say whether this was an effect of their father's genotype since local goats usually have single kids in their first kidding.

Problems encountered

1. Absence of libido in some bucks and variation of libido in others were major problems. It is uncertain whether any treatment is effective in such cases and the buck-keepers always considered it a prestige issue. Five of the ten Alpine x Sirohi, six of the ten Toggenburg x Sirohi and two of the 33 Sirohi bucks bought originally had to be culled at different stages of the project due to lack of libido.

2. Butchers in the area spread propaganda that the meat of cross-bred kids is not as tasty as that of local kids and offered lower prices for cross-bred animals. NARI then suggested to the goat-keepers that they slaughter a couple of cross-bred kids themselves to see if they could note any difference in the taste of the meat. Goat-keepers were convinced that the meat tasted the same and then insisted on getting the same price for cross-bred kids.

3. Some goat-keepers held a superstitious belief that if a suckling kid was weighed, the mother's milk would dry up. Initially this presented some problems for weighing kids, but this was gradually overcome.

The project was intended for three years with the hope of extension, but CAPART seemed to have other priorities. NARI kept the project going for another year with its own resources and with the buck-keepers' support but finally the project ended after four years. However, this project has provided a framework for an effective breeding programme when individual units are small and spread out over a large area.

Cattle breeding programmes in India

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Cattle in India were primarily raised for milk and draught. The focus is currently on improving their milk production potential. This is in view of reduced requirement of draught animal power due to mechanisation and the need for more milk due to increasing demand.

Cattle are generally maintained on agricultural by-products and crop residues with some grazing and little grain supplementation. The average holding size is one to three animals per household. The majority of the cattle are still managed under low inputs with only a few being raised under intensive management. Dairy cooperatives at village level for milk marketing have been established. In some areas these cooperatives are being used for delivering inputs and performance recording. Medium to large sized herds of cross-bred cattle have also arisen in the periphery of large towns and cities, mainly for supply of milk. Little or no information on the performance status of cattle breeds in their native environment is available. AI coverage is less than 20 percent and the AI services are available mostly at fixed places. Improvement in cattle production is also directed through feeding, generation of marketing facilities, advisory services and veterinary aid.

Breeding policy and programmes

To begin with the cattle breeding policy was to improve the milch and draught breeds through selection and the local cattle through up-grading. Herds of pedigreed cattle of various indigenous breeds were established for production of superior bulls for use in up-grading and improvement of indigenous breeds in their breeding tracts. The local cattle have poor growth rate (100-150 g per day), late sexual maturity (age at first calving, 60 months) and low milk production (less than 500 kg per lactation). The lactation milk yield in some of the breeds like Sahiwal, Red Sindhi, Tharparkar, Rathi and Gir is about 1 500 litres and in all other breeds is below 1 000 litres. Although some increase in milk production through up-grading of local cows with improved indigenous breeds was obtained, the impact of these programmes was limited because of reluctance from farmers to castrate scrub bulls and due to non-availability of sufficient number of good pedigreed bulls of improved indigenous breeds. Other limitations of the up-grading programme were, the low yield levels of the improver breed used, long generation interval in indigenous breeds and five to six generations needed to up-grade the level of improver breed. As local cows are the core of our action plan, indigenous breeds having lactation milk yield of more than 2 000 kg, need be to be used in up-grading programmes. Bulls with such potential are rarely available. Progeny testing programmes on organized farms for some important indigenous breeds were also initiated for testing bulls for milk production using 300 cows and ten bulls in a breeding cycle of 18 months. This system also failed to make any impact.

Considering the need for rapid increase in milk production, cross-breeding of local cattle with exotic breeds in hilly regions and in urban areas around industrial township was started in 1961 as a matter of policy with the provision that bulk of the exotic inheritance should come from Jersey; Brown Swiss and Holstein may be tried on a limited scale. Subsequently, breeding of Holstein was allowed in areas which could support higher milk production. In hilly regions, use of Brown Swiss and Red Dane was recommended with exotic inheritance between 50 and 75 percent.

Cross-breeding work on scientific lines was initiated between 1910 and 1930 in various institutes and military farms. Between 1960-1970, planned cross-breeding experiments were initiated to answer some questions about the choice of exotic breeds and the level of exotic inheritance to be introduced through cross-breeding. Simultaneously, cross-breeding work in field conditions was initiated under bilateral aided projects focussing on synthesis of high yielding cross-bred strains of cattle.

Analysis of some of the well designed pure-breeding and cross-breeding programmes have been made to assess their impact including identifying their strengths and weaknesses and are used as input for re-designing the breeding programmes to make them more effective for bringing about faster genetic improvement in cattle productivity.

Selection within indigenous breeds

Analysis of selection schemes for milk yield in the indigenous breeds revealed that genetic gains, in general, were negative or insignificant and had large standard errors. Genetic gain in milk production in a closed Hariana herd at a Government Livestock Farm at Hisar, which had been under selection for over 20 years, was estimated to be 10 kg or 1.5 percent of average first lactation milk yield per year. Although, the bulls used were selected from high yielding dams on the basis of pedigree and type, the progeny test information in retrospect indicated most of them had poor milk potential transmitting ability. Similarly, analysis of data of the Tharparkar herd at the National Dairy Research Institute, Karnal (1936-1971), where young breeding bulls were selected on the basis of their dam's milk production, revealed that genetic gains in first lactation milk yield though insignificant were negative. The environmental trends were also negative. The milk production over the years in fact declined from 2 199 kg in 1936 to 1 443 kg in 1971. The genetic trends in 305 day first lactation milk yield in Sahiwal and Hariana herds in Uttar Pradesh were estimated to be 5.04 ± 0.48 and –0.82 ±0.26 kg/year, respectively. The negative genetic gain in the Hariana herd could be due to the use of bulls of inferior genetic merit, lack of systematic breeding plan and little or no culling of low producers. These selection studies suggested that final selection of bulls for intensive use for artificial breeding should be based on progeny test information only. Small herd size and use of few sires and few daughters per bull were the major limitations of these selection schemes. Non-existence of semen freezing facilities at some of these farms also contributed to the failure because by the time bulls became available after testing, they were too old to produce enough semen. There was hardly any culling of females on the basis of milk production in these herds.

In order to overcome the problem of small herd size, linking of the farms/herds of the same breed was adopted to increase the population size. Accordingly, progeny testing programmes for Sahiwal, Hariana and Angle breeds by associating the existing herds were initiated. The programme for Sahiwal was started in 1978 and involved testing of six to eight bulls/cycle using an approximate herd size of 700 breedable cow's spread over seven farms. A total of 33 bulls were used for progeny testing. Examination of the breeding value of the first two sets of bulls revealed that genetic superiority in the first and second set of bulls ranged from -0.2 to 9.5 percent and -15.6 to 12.9 percent, respectively. Bulls in a set were spread over four years which is too long a period. Only 25.4 percent of the breeding bulls produced freezable quality semen. The trait may be breed specific as Sahiwal bulls are lethargic in nature and many of them had poor libido. This would, however, call for raising four times the bulls required for semen production.

The programme for Hariana and Ongole breeds was started in 1986 and involved the recording of a minimum 12 female progeny for milk and five progeny per bull for draught. Averages of age at first calving, first lactation yield, first lactation length and first calving interval in various herds ranged from 44 to 61 months, 732 to 1 044 kg, 208 to 280 days and 15 to 17 months in Hariana cattle and 37 to 60 months, 407 to 778 kg, 179 to 261 days and 16 to 23 months in Ongole cattle. Surprisingly, milk production in first lactation of cows in the central unit both for Ongole (407 kg) and Hariana cows (790 kg) was lower than the associated herds (638-778 kg). This was perhaps due to the fact that more emphasis was placed on physical breed characteristics while selecting cows from the field for central units. Preliminary evaluation of Ongole bulls for first lactation milk yield revealed that the progeny average for milk yield of bulls having more than ten daughters ranged between 437 and 495 kg. At the rate of one percent genetic improvement per year, around 80-100 years would be needed to double the milk production. The major limitations of these programmes are (1) very long generation interval, around 15 years in Ongole; and (2) low milk yield of the two breeds. This project will answer the nature of the relationship between milk and draught and is being pursued with this focus only, although it is known that the two traits are negatively correlated.

Policy of pure-breeding in indigenous cattle breeds did not show any significant improvement due to non-availability of proven sires, lack of extension support and absence of breeder organizations / programmes for each breed. In view of focussing on improving yield levels of local cows through up-grading with selected indigenous breeds and conservation and improvement of indigenous cattle breeds, a large number of bulls of indigenous cattle breeds are needed to be produced use through AI or natural service to support breeding programmes of up-grading of local cows and selective breeding in defined breeds. Accordingly, breeding programmes to produce quality bulls for important indigenous milch breeds, for example, Sahiwal, Rathi, Gir and Tharparkar, need to be strengthened by networking the existing herds and involving farmers' animals in the breeding tract into a breed improvement programme. This is a difficult target and the costs are rather high.

Cross-breeding

Cross-breeding experiments have been undertaken both in the institutional herds and in field conditions to answer questions like superiority of exotic and indigenous breeds, level of exotic inheritance, non-additive genetic variance for milk production, genotype x environment interactions and synthesis of new breeds using cross-bred populations. Holstein, Ayrshire, Jersey, Guernsey, Red-Dane and Brown Swiss breeds have been used in cross-breeding. The information on the crosses generated has been analysed in relation to questions raised and results reported by a number of workers. Results are mostly available on two breed crosses barring a few planned experiments where three-breed crosses were also produced.

The results of various cross-breeding experiments have clearly demonstrated that increase in milk yield in cross-breds over the indigenous breeds was two to three fold. Friesian was the breed of choice for higher milk production. Jersey crosses had some advantage of early maturity and better reproduction but on over all merit, they were inferior to Holstein crosses. The ranking of the exotic breeds based on milk production was Holstein, Brown Swiss, Red Dane and Jersey. The exotic inheritance between 1/2 and 5/8 was most ideal for growth, reproduction and milk production and that grades with higher exotic inheritance had comparatively higher mortality and more reproductive problems than halfbreds. Differences among the Friesian crosses with various improved indigenous breeds (Sahiwal, Red Sindhi, Gir, Hariana) on military farms were insignificant thus suggesting that superior zebu breeds have nothing different to contribute in cross-breeding. The decline in milk production from F_1 to F_2 generations on account of interse mating attributable to heterosis was small. The large decline in some of the experiments was due to poor quality of cross-bred bulls used.

Indo-Swiss project

The Indo-Swiss Project in Kerala started in 1963 with the objective of developing a multipurpose breed for milk, draught and meat through cross-breeding of local cattle with Brown Swiss bulls. The project envisaged cross-breeding of local cattle with Brown Swiss bulls to produce halfbreds. These halfbreds were bred *inter se* and to Brown Swiss bulls to produce 1/2 and 3/4 grades. The 1/2 and 3/4 grades produced were crossed reciprocally to generate foundation population of 5/8 grade which were subject to interse-mating and selection and were called Sunandini. The origin of Sunandini can be traced to importation of 22 Brown Swiss bulls and 45 cows between 1964 and 1967. Subsequently, semen from 11 more bulls was imported. The major component of zebu in the Sunandini breed is the local non-descript cattle; although some attempts were made to introduce Sahiwal, Gir and Kankrej into the population. Halfbreds produced through mating of local cattle with Jersey, Holstein and American Brown Swiss bulls now also form part of the Sunandini population. From the multipurpose breed, the focus is now on breeding Sunandini solely for milk and the present policy is to have exotic inheritance around 50 percent from Friesian/Brown Swiss.

The average adult Sunandini cow at 48 mth weighs around 375 kg while Sunandini bull weighs 574 kg. Averages for age at first calving, service period and calving interval in Sunandini cows in the nucleus breeding stock were 32.2 + 0.19 months, 148.2 + 3.08 days and 424.5 + 3.32 days. There is scope for reducing the service period. The first laction milk yield was 1 914 + 27.8 kg with fat percent being 3.97 + 0.02. The milk yield increased over the lactations and was 3 024 + 68.8 kg in the fourth lactation. Average age at first calving in recorded cows was 42.17 + 0.07 months. First standard lactation in recorded Sunandini cows increased from 1 480 kg in 1983 to 1 830 kg in 1991. The average annual increase is 2.9 percent which is both genetic and due to improved management.

The progeny testing programme to estimate the breeding value of cross-bred bulls based on milk recording of farmers' cows was started in 1977 and proven bulls are being used to produce young sires for extensive use through AI. The project has a well established field performance recording system and excellent bull rearing and semen freezing facilities. Some of the problems facing the progeny testing programmes are:

i) long generation interval (around nine years);
ii) poor reproductive performance of cross-bred bulls, only 27 percent of bull calves contributed to semen production;
iii) large variation in management practices;

iv) tracing accuracy of parentage of calves born; and
v) difficulties in performance recording because herds are small and scattered. The data revealed that only 14 percent of the progeny of AI resulted in completed first lactation.

It is important to mention that between 45 and 73 percent of the cross-bred bulls up to six years of age were culled on account of poor individual semen mortality, poor or no libido, aspermia / oligospermia while those between four and 19 percent were culled due to other reasons. These data suggest that a much larger number of cross-bred males need to be produced to select the required numbers to be put to the progeny test so as to have reasonable intensity of selection. Herd size with farmers varied from one to three cows. Milk recording was done once a month and records used for predicting 300 day milk yield. A genetic model with effects like AI centre, sire of cow, type of dam, month and year of calving, age of cow and sex of calf explained only 21 percent of the variation in milk yield. Lower variability accounted for due to the model was attributed to small herd size. It was suggested that animals should be grouped into herds according to feeding / production level, which is impractical.

The major problem is that there is no selection intensity on the male side as the number of bulls tested is hardly sufficient for semen production required by the State. There is no improver herd which is well defined. The only selection intensity available is through selection of young bulls who are progeny of proven bulls. The progeny testing programmes in this situation have little relevance.

All India Coordinated Research Project (AICRP) on cattle cross-breeding

The Indian Council for Agricultural Research (ICAR) initiated a large cross-breeding project on five locations, for example, HAU, Hisar, IVRI, Izatnagar, JNKVV, Jabalpur, MPKVV, Rahuri and APAU, Lam using Jersey (J), Brown Swiss (B) and Holstein-Friesian (F) as exotic breeds and Hariana, Gir and Ongole as indigenous (L) breeds. The objective was to produce halfbreds (FL, BL, JL) and 3/4 grades with two exotic breeds and test them for growth, production and reproductive efficiency with the possibility of developing them into breeds suitable for specialised dairy farming. The Hariana breed at Hissar and Izatnagar and Ongole at Lam were crossed with all three exotic breeds while Gir units at Jabalpur and Rahuri used two exotic breeds, for example, Friesian and Jersey. Breeding of Brown Swiss to Jersey halfbreds and Jersey to Brown Swiss halfbreds was later discontinued. Accordingly, the number of 3/4 genetic groups was reduced from six to four at Izatnagar, Hissar and Lam and from four to three at other units. It was also decided that halfbred females should be disposed of as soon as the targetted number of 3/4 grades was produced. This was done to accommodate the required number of 3/4 genetic groups as the carrying capacity of each unit was not more than 400 adults and followers.

Evaluation of results revealed that there were significant differences among the three halfbred groups and that FL were superior to BL and JL halfbreds. The best genetic group at all the locations was the FL. There were little or no significant genetic group differences among the 3/4 grades for important economic parameters. It was thus suggested that FJL and JFL and FBL and BFL should be merged and FJL and FBL sires be used to breed the merged groups. FL and 3/4 merged groups after interbreeding should form the foundation herd for developing new strains of cross-breed dairy cattle. Furthermore, interbreeding among halfbred and 3/4 grades would provide answers to one of the major questions regarding breeding of cross-bred populations. It was also decided that genetic evaluation of FL and 3/4 grades should be made on the basis of overall economic efficiency. The project was wound up in 1986. The knowledge gained from this experiment was used for synthesis of cross-bred dairy strain using Friesian x Sahiwal cross-breds (around 24 000 breedable females) available at military dairy farms. At the end of the experiment around 547 breedable females in FL, 971 in FJL + JFL and 702 in FBL + BFL groups were available in the project. These populations were large enough for synthesis of cross-bred strains. Unfortunately, this option was not pursued.

The technical programme of the project has undergone frequent changes. The production of a target number of halfbreds in a given time frame was seriously affected due to poor reproductive efficiency of indigenous breeds used. Against the assumption of 30 female calves from 100 indigenous cows, only 15 were produced in the project. The halfbreds and 3/4 grades were produced at different times and were not contemporaries. Three-quarters were produced at a time when there were more constraints both in terms of physical facilities and inputs and this also affected their performance. The comparison between 1/2 and 3/4 grades needs to be made with caution. The decision to remove the halfbreds after producing requisite number of 3/4 grades eliminated the possibility of contemporary comparison of 1/2 and 3/4 groups.

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Cross-breeding of Sahiwal and Red Sindhi with Brown Swiss was initiated in 1963 to evolve a new dairy breed Brown-Swiss breed famous for its high milk yield, better heat tolerance and draught capacity was chosen. Semen of bulls with a progeny test index between 6 000 and 7 000 kg of milk was used. The interse mating in these crosses was practised for three generations and cross-breds were named as ‘Karan Swiss’. Cross-breds were about 5-6 kg heavier at birth and had higher growth rate than Sahiwal/Red Sindhi. The age at first calving, service period and calving interval were much lower and milk yield higher in Karan Swiss than Sahiwal/Red Sindhi. The 305 day first lactation yield was higher in F_1 (2 859 + 34 kg) than in F_2 (2 183 + 84 kg) and F_3 (2 296 + 46 kg) crosses. The large decline in F_2 crosses was mainly due to non-selection of F_1 cross-bred sires. About five to six sires per set were tested. Each set of bulls was used over three to five years which is too long a period. The breeding cycle should have been restricted to 18 months even if it meant reducing the number of bulls to be tested. Analysis of sire indices indicated that genetic superiority of bulls ranged from –22.1 percent to 13 percent, -9.1 percent to 20.9 percent and –23.2 percent to 8.7 percent in sets 1, 2 and 3, respectively. The 305 day first lactation milk yield in Karan Swiss cows in general showed an increase from 2 427 kg in 1981 to 3 312 kg in 1993 while thereafter a large decline was noted. A large decline in milk yield between 1992 and 1997 was due to the fact that 80 percent sires used in the third set were below the herd average. Deterioration in management during this period was also responsible for the decline. Only 31 percent of the cross-bred bulls donated good quality semen. Apparently 69 percent of the selected bulls did not even enter the test. This would call for the numbers to be raised at least three times, to achieve the required selection intensity.

A large reduction in number of cows (adults) has taken place over the years (207 in 1981 to 59 in 1998). This was due to higher annual culling rates in heifers / adults due to poor reproduction (18.2 percent) and low milk yield (7.4 percent). The conception rate in Karan Swiss cows was also low being 39.4 percent. Heavy mortality (47 percent) up to six months during 1992 and 1998 also led to depletion of the herd.

The semen of Karan Swiss breed was used in cross-breds in the ORP area of NDRI, Karnal. The institute neither developed a performance recording system nor extended a sire testing programme in the field. The field testing programme should have in fact been started after F_3 generations were produced at the institute. Such an approach was the only viable alternative to enlarge the base of the Karan Swiss breed and their further improvement through selection.

Analysis

The breeding objective in dairy cattle was to increase milk production through up-grading of local cows, selection within indigenous breeds and cross-breeding mostly of local cows with various European and American dairy breeds to produce cross-bred grades for commercial milk production and to evaluate them for their suitability in a tropical environment. Comparisons among various breed groups have mostly been made on the basis of individual first lactation and lifetime traits and these together have not been used to study the overall merit of a given genotype. Criteria like feed cost / unit of milk production and profit / cow / year have not been used to define breeding goals. Information on breeding and health parameters of non-descript cows, defined indigenous breeds and cross-bred cattle in field conditions is hardly available. These data need to be generated to devise breeding programmes for improving cattle productivity.

India according to the 1992 livestock census, had 63 million breedable cows, of which 6.4 million were cross-breds and 56.3 million indigenous (approximately 8 million defined breeds and 48 million non-descript cows). Apparently, a large number of quality bulls of defined indigenous breeds would be needed for breeding indigenous breeds and up-grading large proportion of local cows. Breeding programmes did not show any significant genetic improvement in cattle productivity because of non-availability of proven bulls. Programmes therefore for production and testing of bulls of indigenous breeds and cross-breds shall have to be strengthened. The emphasis should be to develop breed societies, introduce performance recording and link the existing breeding farms and farmers' animals into the breed improvement programme for milk. The cross-bred populations should be synthesised into a breed development programme with performance recording and sire testing as an integral part of it. In view of limited performance recording and long generation interval in indigenous breeds and cross-breds in field conditions, MOET should be used for production and testing of sires. The bull production programmes should be coordinated at national level.

The progeny testing programme in field conditions has its own limitations. Between 75 and 80 percent of cross-bred female calves identified and registered were lost before completing first lactation. Herd size is very small and it is not possible to produce contemporaries for accurate sire evaluation. A large number of cross-bred bulls (40 to 70 percent) are eliminated on account of poor semen quality, poor or no libido, aspermia / oligospermia and other reasons. These data suggest that a much larger number of cross-bred males need to be produced and raised to select the numbers required for progeny testing in order to have a reasonable intensity of selection. Similar data on male reproductive efficiency of indigenous breeds need to be generated. The generation interval which was eight to nine years in cross-breds and 12 to 15 years in indigenous breeds needs to be further reduced to achieve higher genetic gain per year.

Genetic models using field records explained 16 to 21 percent of variation in milk yield. Poor accuracy of sire breeding values resulted from errors due to no correction for sire's age, exotic inheritance of the cross-bred dam, large differences between herds and small herd size. Developing appropriate methodologies for standardisation of field records for sire and cow evaluation should therefore, be a priority.

Recommendations

Genetic progress in indigenous and cross-bred herds with a population size of 200-300 breedable females and eight to ten bulls is not possible even in institutional herds for reasons of high mortality, poor growth and poor reproduction, etc. The only alternative is to have large field programmes of performance recording with progeny testing as an integral part of it to support breed improvement.

Culling in cows is not possible due to economic and religious reasons. Selection pressure for increasing milk production, therefore, mainly comes from sire selection. Breeding programmes to produce quality bulls should be strengthened by networking the existing herds and involving farmers' animals in a breed improvement programme. Test and improver herds should be clearly defined.

Reproductive efficiency in indigenous breeds is rather low in a low input environment. Around 15-20 female calves are born per year per 100 cows in the field. These data should be used while developing breed improvement programmes, for indigenous breeds.

A minimum of 40 daughters per bull spread over four to six locations would be essential for evaluating a bull for milk yield with reasonable accuracy. With only around 20-25 percent of total female calves born and registered completing the first lactation in field conditions, 320-400 cows should be allotted to each bull to have around 40 recorded daughters for first lactation milk yield.

In view of limited success in performance recording and a long generation interval in indigenous breeds and cross-breds in field conditions, MOET should also be used for production and testing of sires.

Problems of culling of a large number of cross-bred bulls due to poor semen quality, libido and freezability, need to be looked into. Two to three times the number of cross-bred bulls needed should be produced to have the requisite number of bulls for semen production. The data on male reproductive efficiency of indigenous breeds, which is scanty, should also be generated immediately.

Appropriate methodologies for use of field records for sire evaluation should be standardised.

Buffalo breeding programmes in India

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Introduction

The major objective of this paper is to describe the genetic improvement programmes implemented by the National Dairy Development Board (NDDB) in buffaloes in six districts in Gujarat and outline the experiences gained in designing, running and sustaining breeding programmes that are relevant to developing breeding strategies in low to medium input production environments in developing countries.

The NDDB has initiated a comprehensive programme of milk recording and genetic improvement of animals referred to as 'Dairy Herd Improvement Programme Actions (DIPA)' in a few selected districts where the infrastructure of artificial insemination has been well established. The first DIPA programme was started in 1987 by the Mehsana District Cooperative Milk Producers' Union in the Mehsana district for selective breeding of Mehsana buffaloes. Later, in 1989 the Kheda District Cooperative Milk Producers' Union initiated a DIPA programme in the Kheda district for up-grading of local non-descript buffaloes with Murrah bulls. In 1992 another four cooperative unions namely the Sabarkantha District Cooperative Milk Producers' Union, Baroda District Cooperative Union, Panchmahals District Cooperative Unions and Surat Cooperative Milk Producers' Union in collaboration with the Sabarmati Ashram Gaushala (SAG) initiated a similar programme for up-grading the local non-descript buffaloes with Murrah buffalo bulls in their districts. These district milk cooperative institutions are farmer-owned organizations collecting, processing and marketing milk of their member producers. In 1998-99 these six cooperative unions together collected and processed on average 3.2 million litres of milk a day. These organizations also provided technical input services to their member producers, like artificial insemination, cattle feed, fodder seed and veterinary health care. DIPA programmes are integrated with the other services provided by the unions for enhancing milk production. Before details of the DIPA programmes are provided, it may be worthwhile to know about the buffalo populations that are intended to develop in these six districts.

Target population

All six districts have proportionately more buffaloes than cows (see Table 1). About two thirds of the total breedable animals are buffaloes. Buffalo milk production constitutes about 70 percent of the total milk produced in these districts.

In Gujarat, buffaloes are primarily kept for milk production, but they also provide meat. They are not used for draught power. They provide manure which forms an important source of organic matter to the soil increasing productivity of soil in a sustainable way. Dung is used as fuel for cooking and it constitutes the major fuel supply for many farmers in rural areas. Dung is also used for production of biogas which provides an alternative to fuel wood in rural areas. Buffaloes are considered to be more efficient converters of poor quality roughage than cattle.

Table 1. Number of buffaloes, milk production, AI coverage and DCSs under DIPA in six districts.

Particulars	Mehsana	Kheda	Sabar	Baroda	Panch	Surat
No. of villages	1 093	970	1 395	1 651	1 908	1 185
No. of households in ‘000	550	643	325	567	463	629
Breedable Females in ‘000:						
Buffaloes	362	413	261	20 2	231	140
Cows	113	102	112	111	177	98
Predominant Buffalo Breed	Mehsana	ND	ND	ND	ND	ND
Other		Surati	Mehsana			Surati
Milk prod.in ’000 tons / year						
Buffalo	437	374	213	157	141	115
Cow	125	137	81	65	61	56
Total DCSs	984	985	1 556	884	1 107	917
DCSs under AI	435	863	313	420	550	448
DCSs under DIPA	33	50	30	35	30	40
% recorded buffalo population	4	6	3	2.5	2	3

DCS: Dairy Cooperative Society; ND: Non-descript buffaloes

More than 70 percent of households have animals. Farmers have one to five animals. Very few farmers will have more than five animals. Farmers in villages live near to each other in conglomeration, and hence, they learn from each other and often follow common management practices. Buffaloes are largely maintained on crop residues and agricultural by-products and supplemented with green fodder and concentrate. They are mainly looked after by women. The production systems followed could be categorised as low-to-medium input systems.

Breeds involved

The Mehsana district has predominantly Mehsana buffaloes, while the other five districts have non-descript buffaloes or non-descript buffaloes crossed with either the Murrah, Mehsana or Surati. A brief description of these breeds is given below.

Mehsana

The Mehsana breed arose from crosses between Surti and Murrah breeds. The home tract of this breed is the Mehsana district in Gujarat and they can also be found in the adjacent districts of Sabarkantha and Banaskantha. Mehsana buffaloes are also found in the Ahmedabad and Gandhinagar districts and in Bombay. These buffaloes are black in colour with white markings on the face or a white switch are not preferred. These are considered disqualification for the breed. Their horns are short and initially they assume a sickle shape similar to the Surati breed, but later turn upwards and form a curve similar to the Murrah buffaloes. Compared with the Murrah, the Mehsana has a longer body. Mehsana buffaloes have a reputation of being persistent milkers and regular calvers. Lactation yields of Mehsana buffaloes vary from 1 500–2 000 litres. Elite Mehsana buffaloes produce more than 3 000 litres in one lactation.

Murrah

The Murrah is the most popular breed in India. These buffaloes originate from the Rohtak, Hissar and Jind districts of Haryana and the Napha and Patiala districts of Punjab State in North India. The buffaloes have spread to many parts of the country for commercial production. Murrah bulls are extensively used for up-grading local non-descript buffaloes and have been used in many countries including Brazil, Bulgaria, China, Egypt, Italy, Malaysia, The Philippines and Thailand, etc. The average lactation yields of Murrah buffaloes in institutional herds have been reported to be between 1 500 and 2 000 litres. Some elite buffaloes in their native tract produce more than 3 000 litres.

Non-descript buffaloes in these districts are mostly crosses of the Mehsana, Murrah and Surati breeds. They produce between 1 000 to 1 500 litres in one lactation.

DIPA Programme

Need for initiation of DIPA programme

As seen in table 1, the cooperative unions have established village level dairy cooperative societies in more than 90 percent of the villages in their respective districts, except the Baroda and Panchmahals district cooperative unions which have covered about 60 percent and 70 percent of villages, respectively. These cooperatives unions collect more than 90 percent of the milk available for sale by farmers from the villages where village dairy cooperative societies have been established. These districts already have very large buffalo and cow populations. As each district in Gujarat has a dairy cooperative union, it is common understanding among unions that every dairy union will only collect milk from its own district. It was therefore imperative to each of these cooperative unions that unless they plan to increase the productivity of buffaloes and cows in their district, they would not be able to expand their business. The DIPA programme in fact was initiated by these unions primarily to increase the productivity of cows and buffaloes in their district.

Breeding goals

Indian consumers prefer milk with high fat percentage. A number of milk products are made from milk. Milk and milk products are an essential part of the diet across regions, age and income groups and in rural and urban areas. A variety of sweets (with very high fat percentage) made from milk, are considered valued products and are widely consumed. The village level dairy cooperative societies pay the producers on the basis of volume or weight and fat content. These trends are likely to be continued and it is expected that milk with a high fat percentage will continue to be preferred by the Indian consumers for many years to come. High volume and high fat percent or high kilo fat production are therefore considered as the key goals for improving productivity of buffaloes.

Breeding plan design

The core breeding strategy adopted for the genetic improvement of buffaloes in all six districts is progeny testing of buffalo bulls involving farmers in selected villages. In the Mehsana districts, a straight-breeding strategy has been adopted to improve the Mehsana buffaloes of the district. In the Kheda district, a strategy of cross-breeding of local non-descript buffaloes with the Murrah breed has been implemented. Here the plan is to use Murrah bulls obtained from the Murrah breeding tract in Punjab and Haryana for two generations and then follow the strategy of straight-breeding in the resulting up-graded buffalo population as in the case of the Mehsana district. A similar breeding strategy has been planned in the third programme jointly implemented by the Sabarkantha, Baroda, Panchmahala and Surat milk unions and the SAG.

The core design adopted in all three programmes is depicted in figure 1. A set of ten to twenty bulls are tested every year. About 30-50 villages, each village having 200-300 breedable buffaloes, are selected for the programme in each district. This means, about 6 000 to 10 000 breedable buffaloes in each district or two to six percent of the total breedable buffaloes are selected for the programme. This population is referred to as the recorded population of the DIPA programme. At present, 40 percent of villages overall in the six districts have facilities for artificial insemination. This means about 0.65 million buffaloes constitute the target population which is intended to be improved through the DIPA programmes. The cooperative unions have planned to increase their AI service to about 70 percent of villages in the next five years. The base population therefore will increase to some one million buffaloes in another five years.

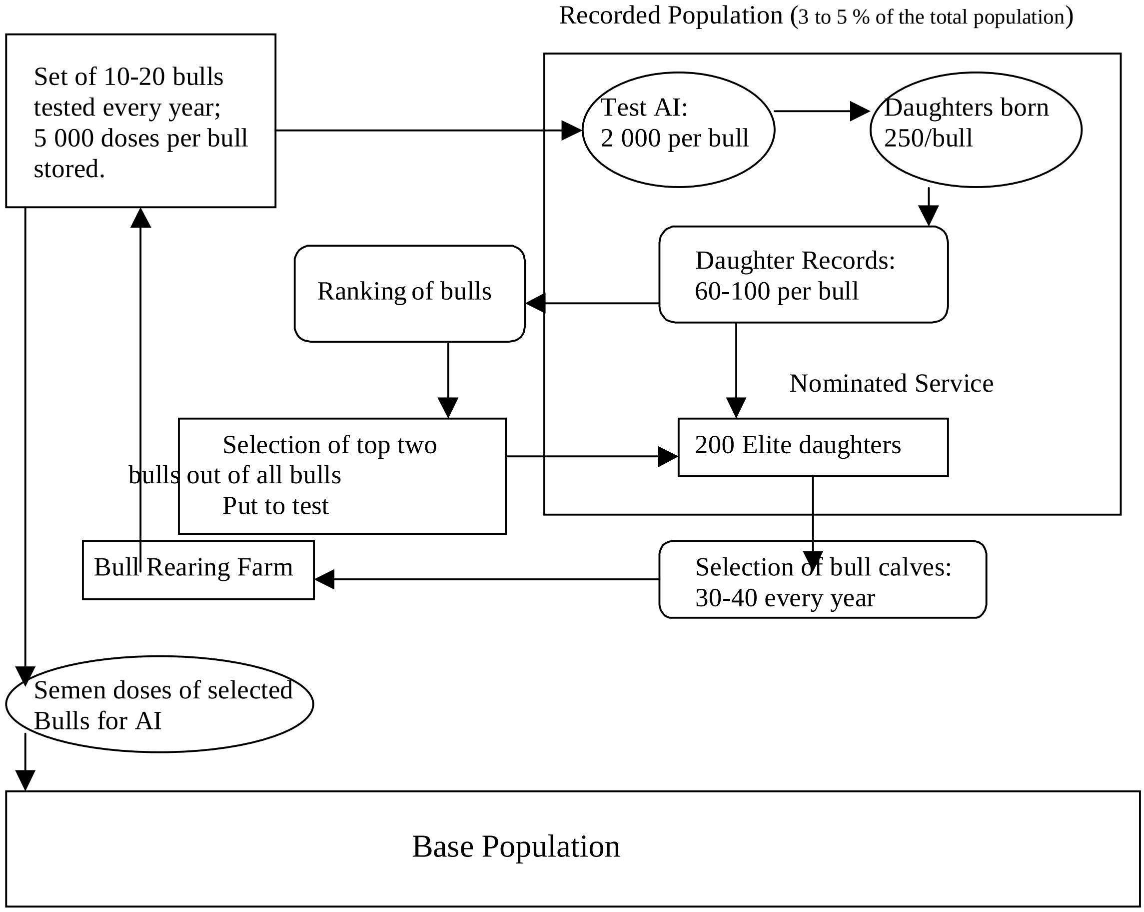

Figure 1. Breeding Plan of DIPA Programme.

Some 2 000 semen doses per bull are distributed in DIPA villages in a way that the number of daughters born to all bulls tested in each village across all DIPA villages would more or less be equal. To achieve this, a bull wise semen distribution schedule is prepared. Semen doses of all bulls tested are distributed each month. Each DIPA village gets semen doses from only one bull. Semen doses of different bulls are used in each DIPA village every month and it is ensured that within a year, the maximum of bulls tested are used in each DIPA village and across all DIPA villages. This ensures production of daughters of bulls tested in most villages and in all months. Apart from test doses, a minimum of 5 000 doses per bull are stored till progeny test results of bulls tested are available. The stored doses of some top bulls are later used for a nominated service to produce the next generation of bulls.

When any village is selected for a DIPA programme, all breedable buffaloes of that village are eartagged with a plastic eartag having an eight-digit number. All eartags are supplied by the NDDB to ensure that no number is repeated. The last digit of an eight-digit number written on the eartag is a check digit derived from the other seven digits. While registering buffaloes under the programme, information on breed type, number of lactation completed, in milk or dry and age or date of birth is collected. When a registered buffalo is brought for insemination at the village society for insemination, it is inseminated with a semen dose from the semen doses of a particular bull supplied to that society for that month. If any buffalo has not been eartagged, it is eartagged at the society. At the time of insemination, information on date of insemination, number of service bull, batch number of semen dose and inseminator code is recorded. Pregnancy diagnosis is carried out once a month in every society by persons employed by the dairy cooperative union. At the time of pregnancy diagnosis, the code number of the person who carried out the pregnancy diagnosis and date and result of pregnancy diagnosis are recorded. When registered, buffalo calves, date of calving, sex of calf and any genetic defect observed are recorded. Every female calf born is eartagged.

Every female calf born under the programme is followed during growth. As an incentive to farmers participating in the programme, all farmers having a female calf born under the programme are given five bags of cattle feed (350 kgs feed) over a period of one and a half years. Cattle feed to farmer is supplied in five to ten instalments. At the time of supplying the next instalment of cattle feed, the weight of the calf is estimated by measuring length and heart girth by the visiting supervisor who decides, based on weight gain, whether the next instalment of cattle feed is to be supplied to the participating farmer. Apart from providing an incentive to farmers, the practice of feeding an equal amount of cattle feed to all calves born has reduced to some extent, management differences followed by different farmers and helped in identifying true genetic differences.

When daughters are in heat they are inseminated and three to four months later they are pregnancy-diagnosed and when they calve, their calving details are recorded. Each daughter born under the programme is milk-recorded once a month, morning and evening, by the village level inseminator who is paid for every milk recording. Milk recording is done by a measuring jar. At the time of milk recording a sample is taken in a sample bottle for fat testing. Fat testing is done in the village at the society building. Every village dairy cooperative society uses fat testing equipment for testing fat content in milk supplied by farmers in order to decide the price per litre to be paid to farmers. Milk payment to individual farmers is made on the basis of volume or weight and fat test. Monthly milk recordings of each daughter are continued until it completes its lactation.

All events of the programme starting from registration of dams, their insemination, pregnancy diagnosis and calving, birth details of female calf, body weights of calf, insemination, pregnancy diagnosis, calving and monthly recording of milk and fat test for whole lactation of daughters born, are all recorded through the Management Information System

(MIS-DIPA) developed for the programme. Data collected on a monthly basis in different formats are processed at the Union's headquarter and many reports are produced to evaluate the performance of buffaloes, villages, bulls, inseminators, supervisors, etc. Since farmers have just one or two animals, information like animals to breed, animals to examine for pregnancy diagnosis, animals to calve, animals to dry off, animals crossed more than three inseminations per conception, etc., generated through the MIS-DIPA is not of great relevance to an individual farmer. They in any case have all the information and any such output does not provide any additional information. However, when output is produced for all farmers within a village comparing performance of each individual farmer with all other farmers, the comparative performance report becomes very informative and provides very valuable information to each individual farmer to evaluate his own performance and adopt improved practices followed by better performing farmers. An action list for a village taking into consideration all animals of the village, is also produced. For a village, village comparative performance reports become very valuable. Poor performing villages can find out why the performance of their village is poor in relation to others and can jointly decide together what they need to do to improve overall performance of their village. All such outputs are produced in the local language and are displayed in the dairy cooperative society so that all farmers can see their performance in relation to others when they come to deliver their milk to the society. Reports are also produced for supervisors and inseminators which help in evaluating their performance.

Bull performance reports are produced for evaluating the performance of all bulls tested with respect to conception, milk production and fat percentage of their daughters. Bulls are ranked on the basis of breeding values estimated using sire model employing the best linear unbiased prediction method (BLUP). Right now breeding values are estimated using the following model:

$$Y = Wa + Xb + Zc + e$$

Where:

Y= an observational vector consisting of 305 days standard first lactation milk yield of daughters,
a= effect of age at first calving assumed to be a continuous variable,
b= a vector of village-year-season effect,
c= a vector of random sire effects,
W, X, Z= are known matrices, and
e= a vector of random residual effect.

Traits included in the breeding goals and method used for dissemination of improved genetics

Under the DIPA programme, at present, information on conception, age at first calving, standard lactation yield and fat percentage have been collected for bulls on the basis of their daughters' performance in the field. As mentioned earlier, breeding values of bulls for milk yield are estimated using sire model employing BLUP. As more records will be available and genetic parameters will be estimated more accurately, a multi-traits animal model would be employed to estimate breeding values of both males and females together.

As shown in figure 1, the genetic progress in the target population has been planned to be achieved through selection of sires to breed sires, selection of dams to breed sire and selection of sires to breed replacement stock. Higher genetic gain on the sire to sire path has been sought to be achieved through increasing selection intensity of sires to produce sires by putting more and more bulls under test programme, increasing accuracy of selection of sires by producing as many daughters as possible per bull and in as many villages as possible by systematic semen distribution schedule and reducing the generation interval extent possible by putting sires to test as early as possible. On the dam to sire path, the higher genetic progress is planned to be achieved through increasing selection intensity of dams to produce the next generation of sires by increasing as many buffaloes as possible under recording and through increasing accuracy of selection of dams by having at least two lactation records. Once bulls are obtained through nominated mating using the top ranked progeny tested bulls and elite recorded bull mothers, some selected bulls after they complete their test mating are used for artificial insemination in the base population, buffaloes of villages having artificial insemination facilities which are not part of the recorded population. Thus, a gradual genetic progress occurs not only in the recorded population, but also in the base population.

Results achieved so far

The DIPA programme in Mehsana was started in 1987. So far seven batches in all 95 bulls have completed their test mating. The semen doses of the eighth batch are being distributed. The overall simple average standard 305 days first lactation yield of daughters born under the programme was 1 946 litres based on 2 846 observations. The progeny test results of the first four batches or 60 bulls based on more than 30 records per bull are now available. All new batches of bulls that are tested are now obtained from the field using top bulls and the top elite recorded daughters in the field. The DIPA programme in Kheda was started in 1989. So far 57 bulls have completed their test mating and another 16 bulls are being tested. The average simple standard 305 days first lactation yield of recorded daughters was 1 481 litres based on 1 106 observations. The progeny test results of the first two batches or 29 bulls are available. At present, bulls are obtained from the Murrah breeding tract based on recorded dam yield.

Still one more batch of Murrah bulls is planned to be used. There after bulls will be obtained from the Kheda district using top bulls and elite recorded daughters in the field. The joint milk unions and SAG DIPA programme was initiated in October 1992. So far 50 bulls have completed their test mating and another ten bulls are being tested. The daughters of the first two batches are recorded. In another six months time, progeny test results of the first batch will be available based on more than 30 records per bull. The average lactation yield of daughters which have completed their lactation was 1 738 litres based on 77 observations.

Table 2. Status of DIPA programmes.

Set No	No. of Bulls	AI / Bull	Daughters Born / bull	Daughter complete Lact / bull	Avg. 305d 1st lac. Yld
1. DIPA by Mehsana Union, since 1987					
1	13	1 714	195	52	1 960
2	20	1 392	135	34	1 910
3	12	2 716	262	58	1 924
4	15	1 493	162	21	2 013
5	12	1 831	163	33	1 962
6	12	1 031	86	5	2 005
7	11	1 604	88		
8	12	1 768			
2. DIPA by Kheda Union, since 1989					
1	13	5 032	345	42	1 478
2	16	4 844	337	35	1 484
3	17	5 011	363		
4	11	11 069			
5	16	5 878			
3. DIPA by Sabar, Baroda, Panchmahals and Surat Unions and SAG; since 1992					
1	10	1 914	254	7.7	1 738
2	10	2 017	237		
3	10	2 074	240		
4	10	2 262	244		
5	10	2 463	214		
6	10	2 240			

Farmers and Government involvement

The DIPA programmes have been implemented by the respective farmer owned dairy cooperative unions under the technical guidance of NDDB. There is no involvement of the State or the Central Government in the programme. Each DIPA programme was initiated with the financial support of NDDB. NDDB met all the cost of implementation of the programme for the first five years. After five years of implementation of the programme, a separate corpus fund for each of the three DIPA programmes was created with the contribution from respective unions and the NDDB. Each programme at present meets its costs from the interest earned from the long-term investment of the corpus fund and does not depend on any external agency for funding. If the cost of implementation of the programme in any particular year is more than the interest earning, the additional cost is met by the respective dairy cooperative union. Farmers do not pay for recording. The fact that the Mehsana Union has been running the DIPA programme now for almost 12 years, the Kheda Union for ten years and the other four unions for six years, it indicates that the programme has been well accepted by the farmers and will be continued by farmers themselves for many years to come. No legislation has been formed so far for implementation of the programme. From the experiences gained, however, NDDB has been planning to evolve standards for recording of all DIPA activities and a mechanism to ensure that all participating agencies adhere to the standard set.

Technical support

A Management Committee with a representative from each union and the NDDB oversees the implementation of the programme and provide necessary technical guidance. This Committee meets every three months and reviews progress made and takes decisions on implementation aspects of the programme. It approves budgets and reviews expenditures. A separate investment committee with a representative from the union and NDDB decides on the investment of the corpus fund. Apart from this, NDDB provides all help in running and modifying the software used for data processing and generating required information. NDDB also helps in analysing the data and estimating breeding values. NDDB organizes regular training programmes for inseminators, supervisors and officers involved in implementation of the programme for updating their skills and knowledge.

Activities and design peculiarities that enabled the DIPA programme to succeed

The key design peculiarities and activities that have enabled the DIPA programme to succeed are briefly described below.

Implementation of all activities by a single organization

The DIPA programme in each district is implemented by the respective district cooperative milk producers union. It is integrated with other activities implemented by the union. Each participating union is a large dairy cooperative organization that collects milk from village cooperative societies, processes collected milk into milk and milk products and pays village societies for their milk. It organizes farmers at the village level to form independent village dairy cooperative societies managed by farmer representatives. All such village level cooperative societies in a district federate into a district cooperative union. A board of directors mainly elected by the chairman of village cooperative societies, manages the district cooperative union. At the village level, the village cooperative society collects milk twice daily from milk producers and pays on the basis of weight or volume and fat test. The milk collected by the village level societies is bulked in cans that are collected by the union twice daily at a pre-specified time. The milk collected by the union is processed into milk and milk products. Processed milk is sold by the union, while the products are sold by the Milk Marketing Federation. All milk unions in Gujarat are federated to the Gujarat Milk Marketing Federation. The union also provides all inputs like cattle feed, fodder seed, veterinary health care service and artificial insemination services to farmers.

All DIPA activities beginning with the registration of farmers and their animals, insemination (AI) and pregnancy diagnosis of animals (PD), recording of AI, PD and calving, monthly recording of milk yields and testing of fat content, supervision of recording, measuring weights of calf and distribution of cattle feed, collection and processing of data, providing feed back to farmers and societies, estimation of breeding values and selection of bulls and bull mothers for production of the next generation of animals, and dissemination of superior genetic material to the large population of the district through the creation of the AI network within the district, are carried out by the same organization. More coordination is ensured when all activities are carried out by a single organization than when they are implemented by many organizations.

Participation of farmers in the programme

Although, the participating farmers did not initially understand what benefits the recording system would bring to them, they carried out whatever was asked of them by union officials as they trusted the Union and their village cooperative society. However, the following four activities implemented under the DIPA programme further boosted their interest and increased their faith in the programme.

- *Incentive to farmers in the form of cattle feed for female calves born*: for every female calf born under the programme, five bags of cattle feed (about 350 kgs feed) were given to farmers to feed the calf over a period of 18-24 months. This initially provided sufficient motivation to farmers to participate in recording activities. However, it helped the programme in many ways. The early feeding of concentrate to buffalo calves ensured good growth. Many buffalo female calves grew well, they matured early, came in heat early, conceived early, calved early and gave much more milk. Many buffalo heifers calved in less than 30 months. This also increased the market value of their animals considerably. Thus, supplying cattle feed to farmers provided the first major impetus to the programme and many farmers came forward to participate in the programme. It also to some extent reduced the differences in management of calves and greatly helped in resolving the problem of treating a village as a herd in a smallholder situation;

- *Providing village level performance reports*: comparing their performance with other farmers in the village was additional valuable information to participating farmers. Such information greatly helped them to improve their existing feeding and management practices;
- *Organization of calf rallies*: every year at least one calf rally is organized in each DIPA village wherein participating farmers bring the calves born under the programme and compare their calves with others. Farmers from neighbouring villages also participate in such rallies. Talking to visiting farmers the participating farmers realise that the value of their animals has considerably increased. This provides further incentives to participate in the programme;
- *Farmers' DIPA Programme Monitoring Committee*: in some districts a Farmers' DIPA Programme Monitoring Committee has been formed with a few selected chairmen of the DIPA village dairy cooperative societies. The Committee meets every three months in different villages and explains to farmers the importance of the programme. They also take responsibility to ensure that cattle feed supplied to farmers is fed to female calves born under the programme and not to others. They also take responsibility to supervise milk recording and improve quality of data collection, and also provide feed back to officers implementing the programme.

Financial independence

Each DIPA programme has created a corpus fund with a contribution from the union and the NDDB. At present the programme meets its expenditure from the interest earned from the long-term investment of the corpus fund and does not depend on any external agency for funding.

Development of local software for monitoring of the programme and decentralizing data processing

The NDDB developed its own software for processing data and generating information for all participants of the programme. Since software was locally developed, all changes required in the software could be made locally and the system became increasingly more relevant for the users. All data processing activities were totally decentralized from the beginning which helped in the rapid processing of data and provision of information to farmers and others without delay.

Back-up support by the NDDB

A national organization like the NDDB provides all technical and policy support to DIPA programmes. The NDDB also provided initial financial support and created a corpus fund for each programme. The NDDB organizes review meetings for evaluating the performance of each programme and stimulating enthusiasm among the implementing officers of the unions. It also organizes regular training programmes for inseminators, recorders, supervisors, data processing personnel and project managers to update their skills and knowledge. The NDDB gathers the data together and provides valuable feedback to all participating agencies. It centrally estimates and circulates breeding values to all concerned. This kind of support from a central organization helps in maintaining and sustaining the programme for a long time.

Changes envisaged in the operation of the programme

In the next five years all six districts will have a similar base population. It is envisaged that after five years, all three programmes will be jointly operated and each bull tested will be evaluated with more daughter records spread over many villages across many districts. In this way both the intensity and the accuracy of selection of bulls could be raised. Over a period of time more villages will be added in the programme and more buffaloes will be recorded. This will also help in increasing intensity of selection of bull mothers for producing sires. At that stage the breeding value estimation will be carried out centrally by the NDDB and will publish a common sire directory.

Many village societies are now computerising their operations at village level. It is envisaged that very soon it will be possible to process the data collected under the DIPA programme directly in the village and the information required by farmers for management of their animals will be generated in the village itself without delays. Participating farmers would be able to update their files in the society and obtain the necessary outputs in their own local language.

The data generated under the programme will later be used not only for management decision of participating farmers and genetic improvement of local buffalo populations, but also for planning of breed improvement efforts in other parts of the country. Superior bulls produced under this programme will be used in breed development in other parts of the country. Some elite recorded buffaloes of these programmes were recently exported to Thailand. In the future, semen doses of progeny tested buffalo bulls and bulls and buffaloes born using progeny tested semen will be exported to many other countries.

It is a little early to estimate the genetic gains in the target population due to the programme, but in the next four to five years, it will be possible to make precise estimates of genetic change and the benefits the participating farmers gained from the programme. It would also be possible to carry out a cost-benefit analysis of the programme and record the benefits such programmes bring to the participating farmers in particular and to the dairy cooperative unions and the nation in general.

Field performance recording of cross-bred dairy cows in Kerala (India)

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1. Introduction

The State of Kerala located in the south western part of the Peninsular of India is one of the smaller states (provinces) of India (38 863 km²) with a population density of 810 / km², which is among the highest in the country. This has led to a situation whereby the per capita availability of cultivable land is among the lowest in the country (0.1 ha). Due to the relentless pressure on land, as a natural sequel, agriculture has been preferred over animal husbandry in the traditional farming system of the State. Dairying was being resorted with the purpose of serving only as a supporting activity by providing milk for domestic consumption and manure. The agro-climatic conditions prevailing in the State can also be termed as being hostile to dairying (hot and humid climate almost throughout the year, scarcity of feed and fodder, prevalence of tropical diseases, high rainfall and mineral depletion). All these factors resulted in the formation of a small non-descript type of cattle that was hardy, resistant to disease and adapted to the prevailing climatic conditions. However, the milk production potential of these animals was very low (about 400 kg per lactation). Even in well managed conditions they only yielded up to a maximum of 800 kg per lactation with an adult body weight of about 250 kg.

2. Cattle breeding programmes

The origin of a systematic cross-breeding programme of the State can be traced back to the advent of the bilateral project, for example, the Indo Swiss Project Kerala (ISPK) in the year 1963 in Mattupatti, which evolved later into the Kerala Livestock Development Board (KLDB). The main objective of the project was to develop a new breed of cattle through cross-breeding and selection. The concept of the Key Village Scheme which ultimately resulted in the formation of the Intensive Cattle Development Project (ICDP) during the late 1960s under the Animal Husbandry Department and the introduction of lay inseminators under the Dairy Development Department during the 1970s resulted in rapid and substantial growth of cross-breeding activity through Artificial Insemination (AI) in the State. Changed food habits coupled with an ever-increasing population increased the demand for milk, which was a scarce commodity. This prompted the policy makers to take serious note of the situation and to try and improve the quality of the animals with respect to milk production. As a step in this direction, a definite cattle breeding policy was formulated. The implementing agencies were identified and entrusted with specific tasks aimed at the improvement of the quality of the animals with respect to their milk production. Today, 70 percent of the cattle in the State are cross-breeds. The milk production and per capita availability of milk have registered vertical growth during the last two decades (Figure 1).

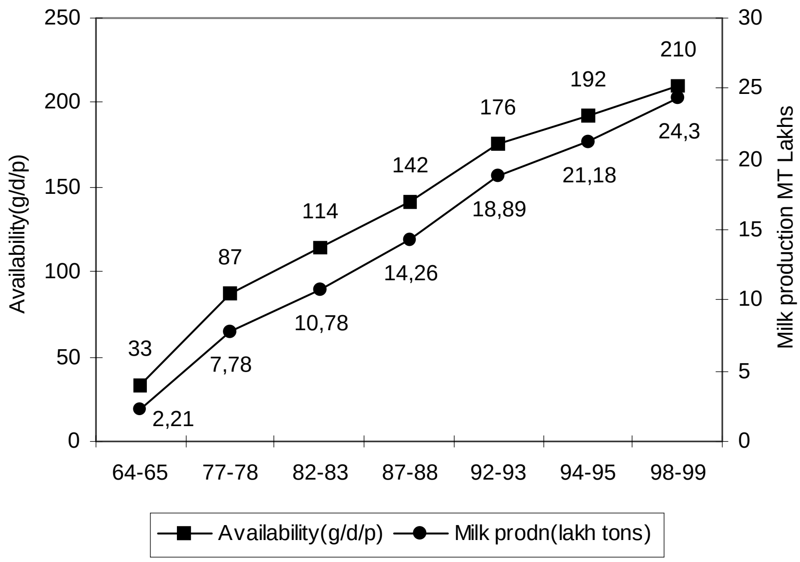

Figure 1. Milk Production and per capita availability, 1964-65 to 1998-99.

The analyses of milk production in the past have shown that nearly 73 percent of the increase has occurred due to the increase in productivity of the cross-bred cows. The challenge ahead is how to maintain and further improve the milk production potential in an environment, which is altogether hostile to dairying. With the bull being virtually more than half the herd in an AI based breeding operation, it was fit to begin a sire selection programme simultaneously. The KLDB during the year 1977 with the financial assistance from the Government of India started a programme for the field progeny testing of bulls used in the breeding programme based on field performance recording of their female offspring.

3. Field Performance Recording (FPR)

The KLDB being the agency responsible for the production and distribution of frozen semen required for AI operations throughout the State, believed it correct to change the then existing system of bull selection which was based exclusively on the pedigree, to that of a more scientific and reliable method based on the performance of the daughters (progeny testing programme). It was thus decided to have field performance recording, which can fit into Kerala conditions.

With low importance given to dairy-based agriculture, individual animal identification, the basic requirement of a recording system, was absent. The practice of recording the production / reproduction / management levels offered to the animals, was virtually non-existent. At this juncture, it is worth mentioning that in the prevailing situations, there were no compelling reasons for such a system to be put into practice from the point of view of the farmers. The absence of a cattle breeding policy was also one of the main limiting factors.

3.1 Design of field performance recording and selection of area

Field performance (FPR) recording systems available in the temperate countries were very advanced, thus preventing a repetition in Kerala conditions. The not so advanced stage of development of the dairy sector, lack of qualified recorders to man the sophisticated systems of performance recording, inadequacies in the information levels of the livestock farmers, etc., were other factors contributing to the difficulties faced to set up a FPR system.

While designing the system, the inverse relationship between the rate of genetic progress and the number of traits for which selection is practised was kept in mind. Developing the recording system was an evolutionary process. Thus the initial system applied had only those criteria / traits which could be measured easily and were absolutely essential. To begin with, a herd book system for individual identification and recording the pedigree and milk production details, was introduced. As it was difficult to establish and successfully run such a system in its entire state, it was thought more practicable to identify areas with a higher concentration of cross-breds and to implement the system in these areas. A well established AI system in these areas was a major factor that led to such a decision making process. The areas from four districts representing a cross-section of the three geographic zones of the State, (coastal, midland and high ranges) and qualifying in respect of the above-mentioned criteria were selected and performance recording was started. The FPR initially had three major elements, namely, herd book registration, growth and development recording and milk recording. The organization of FPR is illustrated in Figure 2.

3.2 Herd book registration

The female calves born in the identified areas are brought to the herd book after permanent identification using metal eartags. These female calves are followed up on a regular basis until their death, sale to areas outside the operational zones or first calving, whichever comes first. The process has been a continuous one for the past two decades. To date a herd book of 88 000 animals has been created and is being maintained

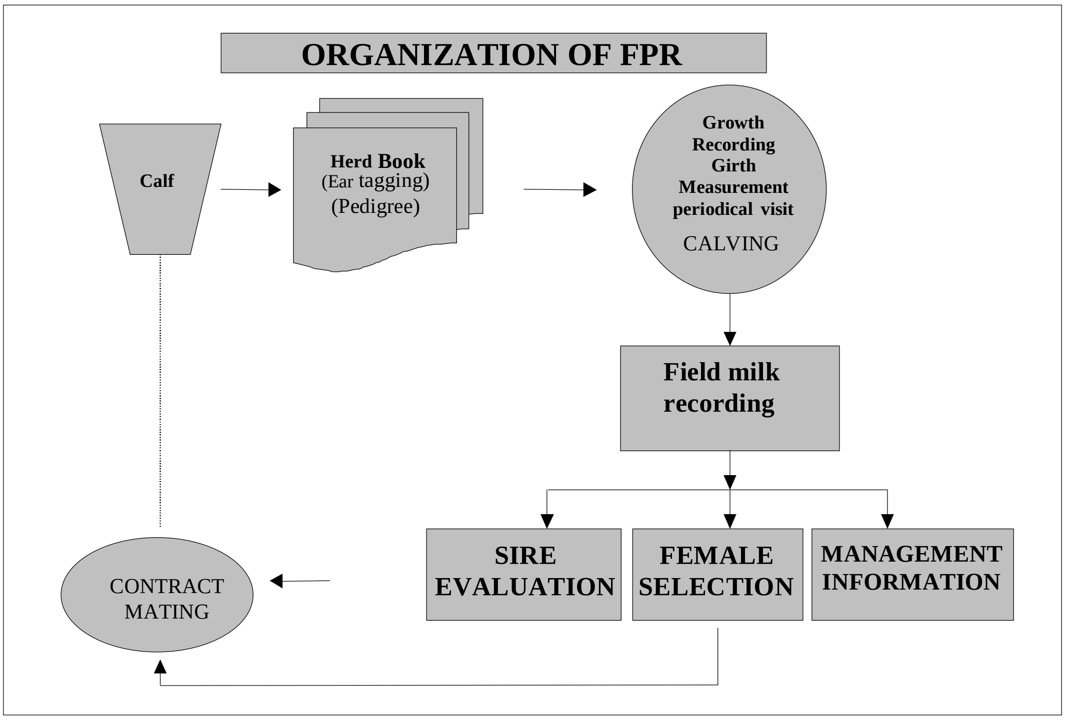

Figure 2. Organization of FPR and application in a Breeding Programme.

using a computer programme (Table 1). In order to motivate the farmers to cooperate with the on-going programmes, a farmer beneficiary programme like supply of mineral supplements, de-worming medicines, etc., is carried out. This programme is covering all the animals included in the FPR scheme. A subsidised insurance programme for the animals is also being operated in collaboration with an insurance company. The animals so followed up will be inducted into the field milk recording programme after calving, if it has been sired by a test bull.

3.3 Measurement of growth and development

The FPR is updated regularly by incorporating possible additional records on the performance of these animals with respect to their growth by way of girth measurements carried out by the milk recorders at regular intervals. Scoring based on management factors like housing, hygiene, etc., is carried out once during the initial stage of the first lactation (survey date) by the supervisors of the KLDB. On the date of survey, the feed and fodder used for feeding the animals together with their quantities, are also recorded. Based on the nutritive value of these feed ingredients, the DCP and TDN value of the feed fed to the animal is calculated. Also the TDN and DCP requirement is calculated based on the milk yield obtained on the day nearest to the survey date, 350 kg adult body weight being taken as a constant for the calculation of the maintenance ration. This being a recent

Table 1. Female calves registered under the herd book programme.

Years	No. of animals registered	Cumulative total
Upto 1991	42 318	
1991-92	7 049	49 367
1992-93	5 508	54 875
1993-94	6 606	66 481
1994-95	6 490	66 971
1995-96	4 889	71 860
1996-97	5 519	77 379
1997-98	5 222	82 601
1998-99	4 414	87 015

addition to the field milk recording programme, further streamlining of the system is required in order to draw meaningful conclusions on its effects on production and productivity of the cross-bred dairy herd.

3.4 Field milk recording

The monthly milk recording system is the most widely accepted one within the FPR system. To carry out the milk recording of cross-bred cattle in the selected areas, the following possible options were tested:

a) Official milk recording. Appointing qualified personnel as regular employees and using them for milk recording.
b) Own recording. Where the farmer does the recording himself;
c) Contract recording. Where part-time milk recorders are engaged on a contract basis.

Before ultimately resorting to the third option, the other two options were studied carefully. Due to the administrative and prevailing socio-cultural situation, the first two options were not found to be suitable. Considering the factors like high cost involved, small herd size with scattered distribution, the need to have a relatively larger population in the recording programme and the need to integrate the performance recording into the progeny testing of cross-bred bulls, it was thought appropriate to engage part time milk recorders on a contract basis. These recorders were recruited from local areas.

The animals registered in the herd book and those calved in the selected area, are entered into a field milk recording system (FMS) and their milk is recorded at monthly intervals (AM / PM recording) with samples for fat content analysis. A maximum of ten recordings per cow per lactation is made. From the recorded milk yield, the lactation yield is estimated by applying the method of "centering date". The results obtained are brought into the herd book. The result of the field milk recording is given in Table 2.

Table 2. Details of cows enrolled for milk recording under field conditions.

Years	No of cows under milk recording Enrolled	Completed
Upto 1987-88	28 149	19 123
1988-89	3 642	2 877
1989-90	2 729	2 610
1990-91	2 823	2 140
1991-92	3 600	2 464
1992-93	2 608	2 946
1993-94	3 049	1 955
1994-95	2 713	2 428
1995-96	2 658	2 178
1996-97	2 715	2 399
1997-98	2 508	2 380
Total	57 192	43 700

From the total cows enrolled, 1 521 are yet to complete milk recording. Therefore it can be seen from Table 2 that only 78 percent of the cows milk recorded complete the programme. This can be attributed to high rates of migration of animals during lactation, mostly sales to other areas.

The average first standard lactation yield in the performance-recorded area over the years is given in Table 3. It is observed that the lactation yield has registered a steady increment over the years. The increase amounts to 3.4 percent over the base year of 1983, which is commendable in the given situation. This improvement is made possible due to the synergetic effect of genetic improvement of the cross-bred cattle and the overall improvement of animal management.

4. Constraints of FPR in Kerala conditions

With the dairy animals in Kerala having a scattered distribution and belonging to small holder agricultural farmers following a diversified farming system, meticulous follow-up of these animals is a highly labour intensive process. Initially the farmers were reluctant to cooperate as they feared official interventions and application of food adulteration laws. A milk recorder can only record two cows in a day because animals being recorded are widely scattered since most households keep only one lactating cow. Cattle migration from the recorded to outside areas aggravates the problem. Farmers do not fully recognise the importance of

Table 3. Average first standard lactation milk yield of crossbred cows (kg).

Year	n	Yield Mean	s.d.
1983	1 627	1 480	481
1984	1 763	1 640	539
1985	1 865	1 669	511
1986	1 943	1 691	570
1987	1 987	1 726	530
1988	2 196	1 749	546
1989	1 988	1 796	564
1990	2 039	1 796	569
1991	3 017	1 833	560
1992	1 700	1 960	621
1993	1 823	1 985	598
1994	1 897	2 046	618
1995	1 827	2 134	604
1996	2 072	2 194	710
1997	1 565	2 191	621

FPR in respect of production, reproduction and management parameters. Although the actual milk recording is a part-time job, often a full day has to be devoted because the milking takes place twice a day, early morning and evening. The lack of adequate remuneration to the recorder due to financial limitations is a contributing factor and obstacles the successful operation of the whole system. Another major hurdle is the inter-departmental relation. The AI, maintenance of breeding records and identification of the farmer and the cow are the responsibility of the Government Department while the FPR is under the KLDB. This at times, results in difficult access to records. The frequent transfer of personnel, changes in policies and programmes of these departments, etc., also influence the efficiency of FPR The recorded animals are owned by a large number of farmers spread across a large area and the accuracy of the records is influenced by the enormous environmental variation.

The cost of the FPR and selection is fully met by the Government and the farmer meets only part of the AI cost. In other words, the improvement resulting from FPR is partially subsidised. Typically, the entire cost of FPR, selection and consequent improvement must be built into the AI system. Due to the small herd size and associated low profit margin, the entire cost of FPR cannot be absorbed in full by the AI industry. This problem is typical to low input output dairy systems.

5. Policy implications

The FPR in Kerala is well integrated with a sound breeding and selection programme. The benefits derived are:

- All the bulls used for AI are progeny tested and selected based on FPR of daughters or young bulls out of nominated mating between proven bull and elite bull mothers;
- The elite cows of the farmers are identified by applying FPR. A contract mating system is developed between the KLDB and the farmer. The male progeny born out of such mating is purchased by the KLDB while the farmer retains the female;
- The bulls selected on the basis of progeny testing and cows selected on the basis of FPR are mated to produce the next generation of young bulls. The semen of these bulls is used for AI. Hence the genetic merit accrued in the nucleus stock is disseminated to the general population in the field through AI using semen from young bulls resulting from nominated mating of selected sires and dams. The elite cows are inseminated using semen of proven bulls. It can therefore be seen that the sole means of disseminating the improved stock is through AI;
- It allows effective interaction between the farmers and KLDB resulting in mutual benefits;
- Individual farmers receive benefits like mineral supplements, insurance, etc.;
- The production data generated is extrapolated to estimate the production in the State;
- The data is used for the formulation of livestock policies and programmes for wider application and benefit of the farming community as a whole;
- The feed back of information on production and reproduction enables the farmer to follow proper breeding and feeding practices;
- A designated elite cow is often the pride of the farmer, which elevates his position in the farming society. On the other hand, an identified and recorded cow often fetches a higher price on the market and is easily sold.

Lessons learned

FPR can be employed as an effective tool for monitoring the performance of livestock owned by small holders provided it is adapted to the local situations. To make the program successful the participation at all levels,(farmers / institutional / inter-institutional) has to be ensured. Part time recorders under the official / semi-official agencies will be more practical than full time recorders or farmer recording in small holder situations. It remains to be difficult to attract part time recorders due to the low remuneration payable. Proper identification of the animal, high migration of the animal from the recorded area, follow up at various level high cost of recording etc., are the problems to be addressed.

6. Summary and conclusions

The KLDB has been implementing a FPR of cross-bred dairy cattle in a small holder situation since 1977. The programme employs part-time recorders to record information on breeding, feeding and management in field conditions. The FPR is well integrated with a breeding and selection programme of bulls and cows for genetic improvement. The data shows that an annual progress of 3.4 percent is achieved. FPR helps the policy makers in formulating policies and programmes for wider application and benefit of the farming community. The individual small holder farmers benefit through increased production, fringe benefits through contract mating and by using the data for management support. Lack of sufficient numbers and motivated recorders remains the greatest problem. Alternative systems of farmer recording did not succeed. Further research and development is needed to perfect the system to be made applicable in identical situations elsewhere.

Village breeding programme for local breeds of duck in Indonesia

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Introduction

Duck farming, mainly for egg production, has been part of rural life in many regions of the Indonesian Archipelago, as a component of an integrated traditional farming system. It provides significant additional income to the farmer household, especially during the dry season when the food crop farming activities are low. In the past, duck farming was generally considered only as a side activity, but in recent years it has played a more important role in the overall farming system as the major source of income to the farmers' family, in many rural areas. However, the farming practices are still mostly traditional and extensive, based on a herding or scavenging system except in a few cases.

The definition of duck breed / strain in Indonesia is basically based on geographical locations. As a result of geographical isolation for centuries and preference for various traits in different areas, some breed / strain differentiation may have taken place. Duck population often assumes local names and distinguishing characteristics may or may not reflect genetic differences in production traits. Hetzel (1986) has reviewed various Indonesian breeds / strains of ducks. The Muscovy breed is distributed throughout Indonesia and is primarily used as a natural incubator. The Alabio breed is native to South Kalimantan and is phenotypically different from other breeds and very uniform in appearance. In Java, there are two major breeds with large distribution, Tegal and Mojosari breeds, however, are very similar in appearances except for the colour tone of their feathers, Mojosari being darker brown than Tegal ducks. An analysis of protein polymorphisms was conducted on selected duck populations in Indonesia and Japan (Tanabe *et. al*., 1984), as cited by Hetzel (1986), and the results showed that the Indonesian local ducks have medium distance from one another.

In his paper, Hetzel (1986) stated that in Asia, particularly in Indonesia, duck occupies a unique ecological niche in that it is traditionally closely integrated with other forms of plant and animal production. There is, therefore, a need for caution when so called improvement programmes are undertaken since the implications of any change in the production system may be far reaching. However, the pressure is on to improve the efficiency of duck production where possible. There are two alternatives available for the genetic improvement programme, under closed and intensive management or under open and traditional extensive systems. Although the intensive management system has started to gain popularity in recent years, the majority of the duck population is still under extensive system and the so-called “Village Breeding Programme” should be conducted in this environment.

Following the definition by Solkner, Nakimbugwe and Valle Zaratte (1998), village breeding programmes are carried out by communities of smallholder farmers (villagers), often at subsistence level. The availability of feed for the animals is far from optimal with large seasonal variations and variations between years. The pressures from diseases may be high. The level of organization is low, hierarchical structures with good flow of information between levels of hierarchy can not always be assumed to work. Data recording in the sense used by animal breeders in the developed countries will often be missing. We shall see that the situation with our programme of duck breeding in Indonesia does not quite fit the above description, the organizational structure is very clear and this helps significantly in data recording.

Duck production system in Indonesia

The duck population in Indonesia has steadily increased over the years, with a current population of more than 30 million. Generally, there are three basic types of production systems. The herding system was, in the past, the most commonly used practice in which ducks were herded from one place to another following the period of rice harvest in the area. However, this system is gradually disappearing, particularly in Java, due to the intensification programme of rice cultivation which does not give a chance for the ducks to be herded into the rice fields. The scavenging system represents the majority of the production system in rural areas. In this semi-intensive system, the ducks are kept roaming freely around the house or village to feed themselves during the day and then return home in the evening and receive additional feed in confinement. The fully confined system is the third type of production system being practised more and more by larger farmers. In this intensive system, feed is fully provided by the owner from the locally available feed ingredients.

In order to accelerate the development of the duck industry in Indonesia, the Government has promoted a production scheme in which duck farmers are encouraged to form a cooperative group or to develop a partnership with a large company serving as the nucleus farm in a Nucleus-Plasma Scheme. Under this scheme, the cooperative unit or the nucleus company provides all the production inputs and collects all the products for marketing, while the farmer members serve as the production units in coordination of the group. Within this production system, all farming practices by farmer members can be accommodated, the efficiency of production can be increased from being a larger operation and production risks are distributed among all members. The major implication of the implementation of this scheme is the large opportunity for the development of a breeding flock following a proper breeding programme especially designed for the group and other farmers as well. Under this partnership system, a village breeding programme should have greater success for the benefit of small farmers who are allowed to continue to participate in the development of the industry.

Breeding programme

Before the programme was commenced, there was virtually no genetic improvement programme for local breeds of duck in Indonesia. The production of ducklings was and is still being handled by hatchery units in villages which rely mainly on collecting the hatching eggs from farmers in the area. Therefore, it is very difficult to implement any breeding programme aiming at genetic improvement. However, the demand for better quality final stocks in enough quantity is always increasing, due to the popularity of duck farming and duck products as an alternative to improved breeds of chicken which are imported from other countries and getting more and more expensive. In response to this situation, the coordination of the production system under group management or the Nucleus-Plasma Scheme were enthusiastically accepted by many duck farmers.

Among the three major local breeds, Alabio, Tegal and Mojosari ducks, the programme is using Tegal breed as the most popular breed and with the largest population (about 8 million) in Java. At the experimental station, the production level of this breed is on average about 65 percent egg production within a one-year period, i.e. 235 eggs annually. This level is actually quite satisfactory in terms of economical feasibility for a small to medium size farm. However, the main problem in the productivity of this breed and of other local breeds as well, is a rather low consistency of egg production. The local breeds of Indonesian ducks still retain their “moulting” characteristics, during which they shed part of their feathers and stop laying eggs. This moulting behaviour may happen after nine to 12 months of production but it may also happen much earlier, four to five months of production which is during their production peaks.

The breeding goal was to improve the consistency of production, at 60-65 percent egg production and between 4 to 4.5 Feed Conversion Ratio. The selection criteria are 65 percent or more of three-month egg production and without moulting before nine months production and the ducks are fed 165 g / head / day of dry feed. In setting the breeding goal there was no economic values assigned to these objectives, and the selection was based on independent culling levels. Five hundred female ducks were kept in individual cages and mating was conducted through artificial insemination. This programme is being implemented in the nucleus farm.

The results of selection from each generation are distributed to the plasma farmers directly in the form of day-old-ducks and each farmer receives between 200 to 400 female ducklings to be raised as layers or 400 male ducklings to be raised and sold at four-months old as meat. These stocks are provided to farmers as final stocks while the breeding programme continues to improve the parent stocks

The foundation stock had an average of 67.3 three-month egg production and the selected group had an average of 81.3 eggs with a selection differential of about 14 eggs. The selection intensity was 30 percent and the selected parents were mated to produce 500 offspring for the next selection. The egg production of the first generation still continues to be recorded. It would have been more desirable if the selection differential were larger in order to expect a larger response to selection. Also, the variability is very large and this is mainly due to the small flock size. For a village breeding programme in which many environmental factors are not fully under control, the initial population should have been larger.

Initially, the programme was supported financially by the Government through the Research Institute for Animal Production. The plan and design were set up together between research scientists and the staff of the nucleus farm. Meanwhile, the development of the Nucleus-Plasma Scheme is supported and supervised by the Indonesia Agribusiness Foundation which is a semi-Government organization, as a pilot project in the development of duck farming as a business activity.

Despite the difficulties and problems in the breeding programme aimed at genetic improvement, the production process keeps running from the production of day-old-ducks by its own hatchery unit, raising growers and distributing layers to plasma farmers. The number of plasma farmers is still small and keeps building up. When the number is large enough and the activity covers a larger area the breeding programme will not only be conducted in the nucleus farm but also involve plasma farmers in an open-nucleus breeding system. This way, the dissemination of breeding results will be faster and the nucleus farm will be released from some of its weight in carrying out the breeding programme.

The combination between a Nucleus-Plasma Scheme in the production system and the open-nucleus breeding scheme is the most significant feature of this programme. It promises success in carrying out genetic improvement to local breeds underlying village conditions, in which farmers are directly involved at the low to medium input levels.

Future directions

Research results showed that heterosis by environment interaction exists in some domestic animals (Sheridan, 1981). This phenomenon should be utilised in a breeding programme in a sub-optimal environment such as in Indonesia, because a stressful environment may increase the degree of heterosis in a cross-breeding programme (Prasetyo and Eisen, 1989). The utilisation of heterosis by environment interaction in a breeding programme involving two or more genotypes may be used as a tool in genetic improvement as well as in conservation of genetic resources particularly for those involved in the programme (Prasetyo, 1996). This concept is very appropriate to be applied in the village breeding programme such as for the local ducks in Indonesia, in which the production system is under sub-optimal environment. The combination of within breed selection and cross-breeding between breeds/strains in producing final stocks will be developed in the future.

In terms of within breed selection, the breeding population size will be increased in order to increase the selection intensity and thus we can expect a larger selection response. This can only be achieved when the size of the group is getting larger and the production capacity has increased. Funding from national or international donor agencies would be greatly appreciated in order to guarantee the success of the programme.

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Buffalo breeding programme in Thailand

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Buffalo production in Thailand

Buffaloes (*Bubalus bubalis*) in Thailand are classified as swamp type. Practically all swamp buffaloes are raised on rural smallholder farms where mixed crop-animal farming systems are prevalent and buffalo form an integral part of the farming system. The swamp buffalo on smallholder farms primarily provides a source of farm power for tillage and transportation and a source of manure for fertiliser, while sale of old buffalo for cash becomes a family long-term saving.

The most common places where buffaloes play a prominent role are in rice production areas. Draught power from the swamp buffaloes is commonly used in lowland rainfed rice production systems, while irrigated rice cultivation usually employs farm machinery. Upland rice and other crops also utilise swamp buffalo power wherever available.

The swamp buffalo production on smallholder farms in village conditions is characterised as complementary to crop production, making use of non-marketable farm products and marginal lands, utilising available family labour, requiring minimal cash input and simple and traditional technology. It is generally non-market oriented production, and is subject to a relatively low degree of risk. In general, attention is not given to obtaining a high rate of output of meat from the swamp buffaloes because other products and services are more important in the small farm systems. In general, the small farm buffalo husbandry can be described as follows.

Village farmers usually utilise marginal land areas available in the village such as paddy fields, scrub forests on upland areas, highway shoulders, rice bunds and communal grazing lands for buffalo and cattle grazing. In general, buffaloes depend mainly on rice straw and stubble; other crop residues, such as corn stover and cassava or kenaf leaves may also provide substantial sources of roughages, especially during the dry season. Generally, concentrate or mineral supplements are not given to animals. There are generally no cash inputs in buffalo raising and most tending is done by family labour, i.e. children, women and the old.

Due to high slaughter rates including illegal slaughter, scarcity of farm labour and grazing areas, increasing use of small two-wheel tractor and lower market price of buffalo (as compared to beef cattle), the number of buffaloes in Thailand had declined at the rate of 3.8 percent annually during 1984 to 1994 (Chantalakhana, 1996). In 1985 there were 5.25 million buffaloes but in 1998 only about two million buffaloes remained in Thailand. Besides, the average mature body weight and size of buffalo have also decreased in the past decades due to castration of larger buffalo bulls for farm work at about one and a half years of age, while larger females were often sold for slaughter.

National buffalo selective breeding programme

Breeding goal and purpose

Due to the lack of a national buffalo breeding improvement programme and apparent decline in genetic quality of the Thai swamp buffalo, the Department of Livestock Development (DLD) of the Ministry of Agriculture and Agricultural Cooperatives (MOAC) and Kasetsart University (KU) developed a joint project to improve buffalo production through breeding selection since 1975 with the support at the beginning of the programme from the Rockefeller Foundation (Thailand). Also in 1971 the Director-General of the DLD and his technical adviser from West Germany were very keenly interested in improving buffalo productivity and were encouraged by the FAO Livestock Specialist in Bangkok at that time. The breeding programme, however, was only partly implemented until 1980 when performance testing was carried out.

The breeding goal was to select superior buffaloes for draught and meat since most farmers in rainfed areas keep buffalo mainly for draught power and sale for meat purposes. The following traits were selected to be used as the main selection criteria.

1) At weaning:
   - 240 day adjusted weaning weight (AWW);
   - pre-weaning average daily gain (pre ADG);
   - general appearance.

2) At the end of testing:
   - average daily gain (test ADG);
   - two-year adjusted weight (2 AW);
   - height;
   - general appearance.

The breeding goal and selection criteria, as well as other technical details, were decided and revised, when necessary, by a joint national committee which was appointed and chaired by the DLD. The details of breeding and testing schemes established by the committee and presently being carried out, are shown in figure 1.

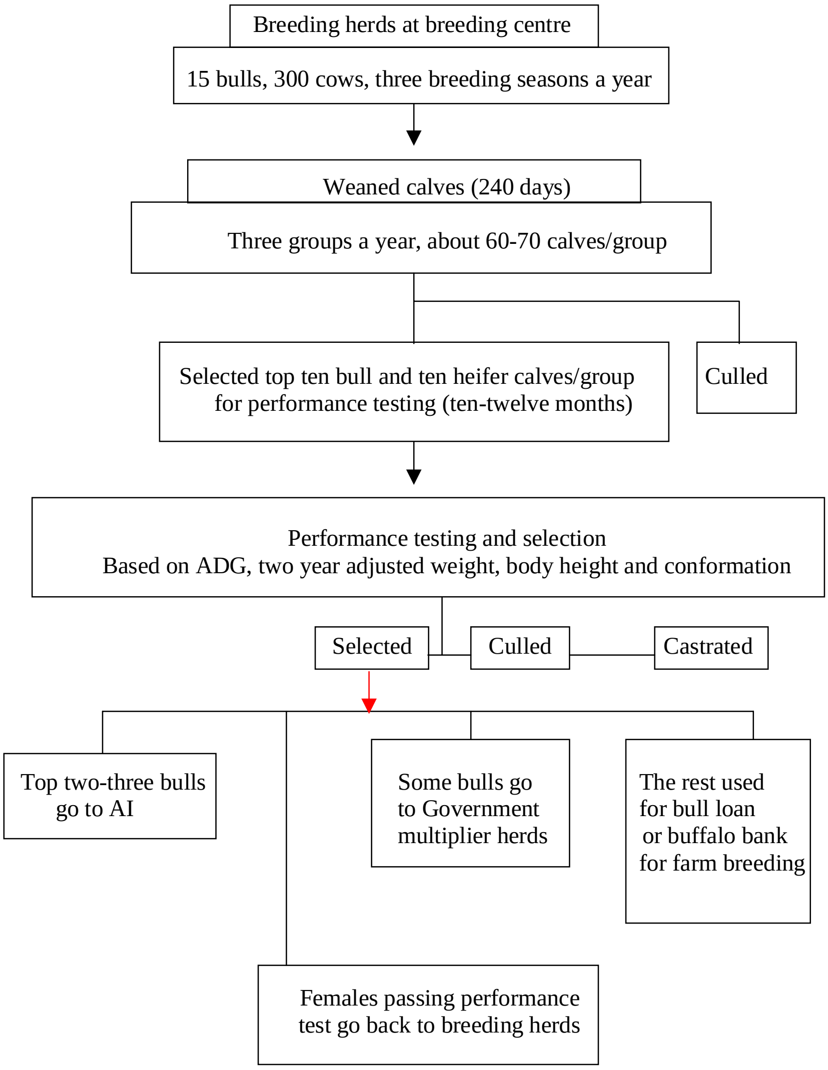

Figure 1. Breeding and testing scheme.

Collaborative agencies and their contributions

1) The DLD provides and maintains all breeding animals at Surin Buffalo Breeding Center (Northeast Thailand), and carries out performance testing at Lamphyaklang Livestock Station (260 km from Surin).
2) Kasetsart University provides technical inputs and research support, including the carrying out of data collection and analysis at an initial stage of the project.

At a later stage other institutions such as Chulalongkorn University, Khon Kaen University, etc., joined this project which has been expanded in its objectives to cover a wider range of disciplines such as health, reproduction and nutrition.

Breeding and testing schemes

As shown in figure 1, superior breeding buffaloes, 15 bulls and 300 cows, are kept at Surin Buffalo Breeding Center (DLD). These breeding stocks were originally selected both from Government stations and private farms. Single-sire herds are managed in three breeding seasons, using one bull to about 15 to 20 cows. During each breeding season about five single-sire herds are used. Feeding is based on grazing in pasture during the day (one acre per animal). Each herd is confined to a loose pen at night. During the rainy season grass soilage is used to feed animals in the barns. Hay, silage, rice straw plus one to two kilograms concentrate supplement per head are used during the dry season (usually January to May) when pasture becomes limited.

About 60-70 weaned (240 days) calves are produced during each breeding season. Only ten top bull calves and ten heifers are selected for performance testing based on their AWW and ADG. The selected animals are then transported to Lamphyaklang Livestock Station (DLD) for performance testing for ten to twelve months. The duration of performance testing is relatively long in order to allow the animals to express their genotypic performances on a low level of feeding. The animals are fed mainly on grass pasture plus a minimal concentrate supplement. The feeding regime used for performance testing of buffaloes is being kept at a level close to that practiced by small farmers in order to minimise possible influence of genotype by environmental interaction when the tested bulls are used on smallholder farms in villages.

After one year of performance testing buffalo bulls are selected by the joint national committee based on the selection criteria mentioned earlier. The animals passing the test will be used for breeding purposes as follows:

- top two or three bulls used for AI;
- next superior bulls may be used in multiplier herds in Government stations if needed;
- the rest could be used in a bull loan programme, buffalo bank programme or sold to farmers for breeding purposes.

So far, at least one thousand male buffaloes have been tested and about half of them passed the performance testing. Approximately 40-50 bulls were used for AI by the DLD. The rest were used in other DLD buffalo breeding stations as well as in villages through Government extension programmes.

The selected heifers will be used as a replacement in breeding herds at Surin. Culled animals will be sold for meat.

The use of superior buffalo genetic stocks in a nation-wide breeding programme was shown by Intaramongkol (1998) in figure 2. Below is a brief summary of a national buffalo breeding plan.

1) Since only one breed of swamp buffalo exists in Thailand, the selected tested bulls are used in the nation-wide breeding programmes. It should be noted that there are a number of swamp buffalo of white coat colour (about three to five percent) but the black or grey animals are preferred by farmers, therefore only black or grey swamp buffaloes are used in the national breeding selection programme. As shown in figure 2, the top bulls are used for the AI service to smallholder farms (base population), while some top bulls are used in multiplier herds such as

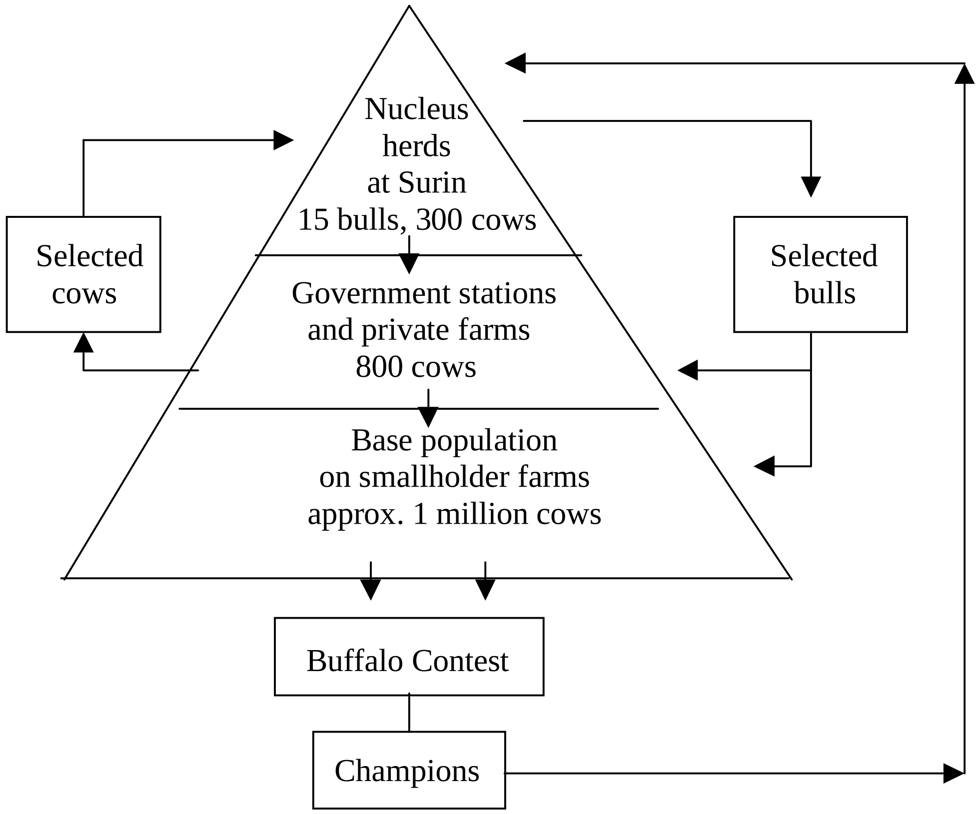

Figure 2. National buffalo breeding programme.

that in Government stations and a few private breeding farms. Some remaining tested bulls may be sold for breeding purposes to farmer groups such as bull service or bull loan group in rural villages.

2) Some number of selected females with good breeding records may be used as a replacement in the nucleus herds when needed. Some surplus cows from the nucleus herds may also be sold to farmers.

3) In order to encourage farmers to pay more attention to buffalo breeding, every year since 1994 the DLD organizes the National Buffalo Fair presided by the Minister of Agriculture and Agricultural Cooperatives and attended by farmers from all over the country. Buffalo contest is one of the main features of the Fair, in which champion bulls and prize-winning females are identified and may be sold to the DLD for breeding in the nucleus herds or multiplier herds.

Some results of buffalo breeding

Intaramongkol (1998) summarised some growth performance traits of buffaloes as resulted from breeding selection at Surin Buffalo Breeding Center as shown in table 1. It can be seen that the 240 day WW had increased from 121 kg in 1983 to 167 kg in 1995 with a genetic trend of 0.135 kg per year, the pre-weaning ADG increased from 459 g per day during 1983-1989 to 555 g in 1995 with a genetic trend of 2.073 g. For the animals subjected to performance testing the 2-yr AW (adjusted weight) increased from 268 kg in 1983 to 317 kg in 1995, while post-weaning ADG increased from 408 g in 1983-1989 to 410 g in 1994, but fall to 295 g in 1995 due to certain health and management factors. The height at wither of buffaloes at the end of the test increased from 118 cm for the first group to 124 cm for the 30th group (Konanta and Intaramongkol, 1994).

Topanurak (1992) used buffalo data at Surin Buffalo Breeding Center to estimate heritabilities of growth performance traits and reported as follows (see Table 2). It was found that the heritability estimates ranged from low to high. The growth traits of animals tested were highly influenced by genetic factors, while the pre-weaning traits were low to medium in genetic influence.

Table 1. Growth performance of Thai swamp buffaloes at Surin Buffalo Breeding Center.

Traits	<1983	1983-1989	1990	1991	1992	1993	1994	1995	Trend P[1]	Trend G[2]
Birth weight, (kg)	28.4 (144)	30 (1 373)	30 (209)	28.4 (111)	29.9 (200)	30.3 (187)	31.9 (193)	30.6 (77)	0.026 kg/yr	0.084 kg/yr
240-d WW, (kg)	121 (96)	141 (990)	150 (194)	146 (170)	138 (190)	156.3 (200)	152 (146)	167 (159)	1.105 kg/yr	0.135 kg/yr
ADG/g	-	459 (990)	504 (194)	481 (170)	456 (190)	522.6 (200)	484 (146)	555 (159)	5.314 g	2.073 g
2-y AW, (kg)	268 (21)	355 (339)	354 (59)	377 (38)	394 (40)	368.4 (56)	356 (39)	317 (36)	-	-
Post ADG, g	-	408 (380)	392 (60)	441 (40)	469 (40)	416.5 (56)	410 (39)	295.8 (36)	-	-

Note: Figures in parentheses are the number of observations.
[1]P = Phenotypic, trend.
[2]G = Genotypic trend.

Table 2. Heritability estimates of some growth traits of swamp buffalo.

Traits	Heritability	S.E.	Number of observations
BW	0.23	0.10	1 429
240-d	0.09	0.05	1 126
2y AW	0.60	0.25	437
Pre ADG	0.06	0.05	1 126
Post ADG	0.75	0.10	437

Possible improvement of current breeding programme

In order to increase the effectiveness and the efficiency of the present buffalo breeding programme, the following suggestions were offered for appropriate action.

1. Increase the size of the nucleus herds in order to increase selection intensity. The number of cows, if possible, should increase to 600 instead of only 300, and the number of bulls can increase proportionately. The performance testing of females can be terminated in order to allow more bulls to be tested.
2. Promotion for wider use of AI in buffalo ought to be supported. At present less than one percent of buffalo cows are artificially inseminated due to lack of interest among farmers.
3. More efficient systems of animal recording, data collection and analysis need further attention. Responsible personnel require more training in animal breeding and statistical analysis in order to carry out the jobs more efficiently.
4. Concerning performance testing, it is recommended that some number of bull calves sampled from smallholder farms ought to be tested along with the selected bull calves from the nucleus herds in order to check occasionally whether genetic superiority has been really attained through present breeding methods.

Future changes in the breeding goal

As mentioned earlier, the present breeding goal has been based on selection of buffalo for draught-and-meat purpose, in which height as well as body weights are selected using low-input feeding regimes. However, due to increase in beef demand and use of farm mechanisation as well as some other changes in socio-economic conditions of some small farm sectors, it is foreseen that part of buffalo production in Thailand will be oriented more towards commercial beef production. Therefore, the goal of buffalo selection should be based primarily on meat or meat-and-draught purpose. This may mean that the primary aim of selection should focus more on beef production traits and the feeding regimes should be formulated towards fattening operations but based on the use of locally available crop by-products or cheap carbohydrate sources such as cassava chips or cassava hay.

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Small ruminant breeding programmes in Greece

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Introduction

Small ruminant husbandry is the most important branch of the Greek animal production, contributing about 49 percent of the total output of animal production. In Greece about 9.2 million sheep and 5.9 million goats, which correspond to 50 percent of the total goat population of the European Union, are raised (Loukeri, 1996).

As the majority of sheep and goats are raised in mountainous and marginal regions of Greece, the productivity of these animals is low. However, in these regions sheep and goat production plays a substantial economic, social and ecological role by keeping the remaining inhabitants in the villages and contributing to the conservation of the environment (Boyazoglu, 1999).

Description and analysis of existing breeding programmes

Species involved

The species involved are sheep and goats. The evolution and distribution of the different types and breeds of sheep in Greece are the result of developments and changes that have taken place over the past thirty years. The uncontrolled cross-breeding between the different breeds and the unplanned extension of artificial insemination have played a major role in the disappearance of certain smaller breeds and in the diminishing number of the pure-bred mountain populations. The major segment of the sheep population in Greece belongs to the Zackel type, which is found all over the country and is characterised by the long tail and the coarse wool. A second group is the Ruda type, mainly found in Macedonia, Thrace and on some Aegean islands and characterised by finer and more uniform wool. A third group consists of the semi-fat-tailed type found on East Aegean islands (Hatziminaoglou *et al*., 1985; Boyazoglu, 1991; Zervas *et al*., 1991).

The great majority (90 percent) of the goat population belongs to the various indigenous types, which are characterised by a strong constitution, good fertility with a relatively lower milk production and low reproduction capacity. The local goat breeds represent today about 4.5 million animals in 200 000 herds. Among the different varieties of the local breeds, Skopelos is attracting the most attention. A small percentage of the population consists of pure-bred imported goat breeds such as Malta, Zaanen, Toggenburg and Damascus breeds and their crosses with the local animals (Hatziminaoglu *et al*.,1985 and 1995).

The breeds involved

Genetic improvement programmes are applied to the following sheep breeds:

- mountain breeds: Boutsiko, Sfakia;
- plain breeds: Karagouniko, Serres, Frisarta; and
- island breeds: Chios, Lesvos, Kefallinias and Zakynthos.

As far as the goats are concerned, a genetic improvement programme is established for the local Skopelos breed.

Approximate overall input level of the production environment of the production system

Seventy eight per cent of sheep and 91 percent of goats are raised in low input production system in the mountainous and marginal regions of the country. These species, which are naturally adapted to the optimal use of poor and marginal regions in difficult grazing conditions, play a major role in the rural economy of these regions (Loukeri, 1996).

The sheep population in Greece is characterised by a great variability in husbandry practices. Sixty per cent of all flocks contain 1-50 ewes indicating that sheep raising is of complementary importance to other agricultural production branches.

The main production systems are the:

- extensive system with transhumance, which is applied to the mountain breeds Boutsiko and Sfakia;
- extensive or semi-intensive system without transhumance, which occasionally involves the Boutsiko and Sfakia breeds, the plain breeds, Karagouniko, Serres and Frisarta and occasionally the island breeds Chios, Lesvos, Zakynthos and Kefallinias; and
- intensive system which mainly concerns the Chios, Lesvos, Zakynthos and Kefallinias breeds and occasionally the Karagouniko, Serres and Frisarta breeds.

Very extensive husbandry systems with or without transhumance are applied to the local goat breeds, usually raised in the regions of the country where existing conditions prohibit sheep husbandry. The local Skopelos breed is kept in a semi intensive and intensive system (Ligda *et al*., 1997; Georgoudis and Baltas, 1998).

Approximate number of animals concerned

The total number of flocks and animals recorded in each of the above-mentioned breeds is presented in table 1.

Table 1. Sheep and goat milk recording in Greece: Populations, number of recorded animals and herds.

Species and breeds	Total population	Recorded animals (Percent recorded)	Total flocks/herds	Recorded flocks/herds (Percent recorded)
Sheep breeds* *(1999 data)*	535 800	54 112 (pure-bred) 56 798 (total)	8 645	657 (6.2%) 677 (7.8%)
Mountains of Epirus (Boutsiko)	10 000	1 380 (13.8%)	300	10 (3.3%)
Sfakia	73 000	6 780 (9.3%)	1 050	64 (6.1%)
Karagouniko	200 000	15 467 (7.7%)	3 210	278 (8.7%)
Serres	38 000	6 636 (17.5%)	670	66 (9.9%)
Frisarta	27 800	6 380 (22.9%)	835	80 (9.6%)
Chios (pure-bred)	<7 000	5 398 (77.1%)	350	45 (12.9%)
Chios (up-graded)	100 000	2 686		20
Lesvos	180 000	9 982 (5.6%)	2 230	94 (4.2%)
Kefallinias		1 550		11
Zakynthos		639		9
Goat breed*		8 357		103
Skopelos *(data from 1999)*	*7 000*	4 347 (62%)		45
Local		3700		46
Zaanen		646		7
Alpine		657		6

Improvement is targeting the entire breed or only a sector

The genetic improvement targets only the sectors of the breeds, which are being performance recorded. A specific plan for the dissemination of the improved genetic material to the rest of the population has not yet been initiated.

Approach through which the breeding goal was established

The total population of ewes and goats in the country is milked and about 90 percent of this milk is transformed into good to high quality cheeses. Ôhe average prices of ewe and goat milk are higher than that of cow milk. The relative values are 40-70 percent and 35-50 percent higher than the price of cow milk for ewe and goat milk, respectively (Table 2). On average 60 percent of the total income comes from milk production and 40 percent from lamb or kid meat production, which in Greece are traditionally slaughtered at a liveweight not above 14 kg. Taking into account the above parameters, the breeding objective was defined as the improvement of milk production and as having lamb / kid as a by-product.

Table 2. Milk marketing for small ruminants (adapted from F. Vallerand, 1997).

Market prices of milk	Cow	Ewe	Goat
Milk composition			
% fat + proteins	7.8	11.0	7.5
Index	100	140	95
Relative prices	100	200-250	130-150
Comparative Advantage	0	40-70%	35-50%

The plan designed and the plan actually followed

To meet the above-mentioned breeding goal, pure-breeding programmes for sheep and goats were introduced with mass selection based on individual identification of the animals and milk recording. The selected males are used mainly by the farmers for the up-grading of their flocks and a part of them are sold as breeding animals to other farmers inside and outside of the recorded population. This programme is applied in general to all breeds being milk recorded. In addition a promising target was set up concerning the application of a progeny-testing programme for the Karagouniko sheep breed. An attempt was also made for the establishment of a progeny-testing scheme for the Skopelos goat.

The breeding programme for the Karagouniko sheep breed included a nucleus of 18 000 ewes raised in 270 private flocks. The total population of the breed in the plains of West Thessaly is about 200 000 animals. The relevant Animal Genetic Improvement Centre collects the milk recording data for further processing. By the end of the lactation period, information on the total milk production of the flock and of each ewe separately is provided to the farmers who can make decisions regarding the culling of the animals and the renewal of their flock. Using mass selected and progeny tested rams as described in the following description, the farmers produce the replacement lambs for their flock.

A number of rams selected from the superior ewes (based on milk production) from the best flocks of the nucleus are performance tested in a progeny-testing scheme that was initiated in 1986. The best four or five controlled rams, selected on their daughters' performance, are used in planned matings with exceptional ewes. The rest rams that are not selected remain in the Artificial Insemination Centre for two more years and their semen is used for the fertilisation of low or medium producing ewes (Georgoudis *et al*., 1995).

A similar scheme was designed in 1990-1993 for the Skopelos goat breed but some major difficulties interrupted the attempt.

The breeding programme applied to the Frisarta sheep that is referring to 6 380 ewes, includes the selection of the rams on their dam performance and their body conformation. The females for replacement are selected based on their dam milk production and their own records.

A different approach is followed for the Chios sheep breed where an attempt is made to establish a pyramidal selection scheme with multi-trait selection in the nucleus. The nucleus includes 500 Chios ewes raised in the Agricultural Research Station in Chalkidiki where, a rotational mating system to avoid inbreeding has been applied since 1980 (average rate of inbreeding: 0.013) (Gabriilidis *et al*., 1996). The following traits are included in the breeding goal: commercial milk production, litter size and average litter weight at weaning. The rams are used in the nucleus for only one mating period and every year are selected on the total merit index. During the next period the rams together with male lambs are sold for the up-grading of the commercial flocks (Ligda, 1999).

At what stage did the diversion occur?

The goals set up in the initial phases of the genetic improvement programme were proven to be too ambitious, as problems concerning financial and human resources were not taken into consideration at first.

Breeding goal

For all breeds the breeding goal is the same and consists of commercial milk production. Economic studies that were carried out were used as general directions for the definition of breeding objectives.

In the nucleus flock of the Chios breed in the Agricultural Research Station of Chalkidiki, multi-trait selection is applied. The traits included in the breeding goal are the commercial milk production, litter size and average litter weight at weaning.

Selection criteria

In all existing breeding programmes, the selection criterion is the total commercial milk yield of the animals, which corresponds to the total amount of milk produced after weaning of the lambs / kids at 42 / 60 days, respectively.

The selection in the nucleus flock of the Agricultural Research Station of Chalkidiki is based on the total genetic merit calculated by the application of a multi-trait animal model, which includes commercial milk production, litter size and average litter weight at weaning (Ligda, 1999).

Dissemination of improved males and/or females

As it was mentioned previously, the dissemination of the improved genetic material is realised by selling males and / or females directly by the farmers. The Ministry of Agriculture through the Genetic Improvement Centres occasionally supports this. The Agricultural Research Station of Chalkidiki of the National Agricultural Research Foundation, sells rams and young males and females to the farmers with pedigrees, approved by the Ministry of Agriculture.

Breeding structure

The breeding system applied is pure-breeding (straight-breeding). The size of the nucleus flocks being milk recorded was simply determined by the available financial and human resources. The application of a three-tier pyramidal selection scheme for the Chios sheep is being developed.

Farmer and Government involvement

The organizations involved in the on-farm performance recording are: The Ministry of Agriculture, Directorate for Inputs to Animal Production with five regional Animal Genetic Improvement Centres and the recently established Breeders' Associations, which will be subsidised by the Ministry of Agriculture until 2006. Performance recording on the Agricultural Research Stations is supervised by the National Foundation for Agricultural Research, which indirectly receives financial support from the Ministry of Agriculture (Baltas, 1995; Georgoudis and Baltas, 1998).

Technical support

The technical support to the breeding programme is provided by the Ministry of Agriculture, the regional Animal Genetic Improvement Centres and specialised scientific personnel employed by the Breeders' Associations. The country's agricultural universities support the scheme with computer facilities, software for processing the collected data and scientific methodology for the genetic evaluation of the recorded populations.

Reasons for introducing the scheme

The main reason for introducing and maintaining the scheme was the improvement of milk production of the local breeds. The authorities of the country also use the data collected for planning their activities.

Significant activities initiated

The Ministry of Agriculture is in charge of the organization and operation of milk recording and herd bookkeeping, but it is intended to totally involve the newly established cooperative organizations, under the supervision of the Ministry (Baltas, 1995).

Significant activities maintained

Recently, milk recording has been carried out more systematically on a larger scale and within the framework of a more specific genetic improvement programme per animal species and breed. A number of milk recorders have been employed, but they were not enough to cover the needs of the milk recording programme. Furthermore, close cooperation has been established between the competent services of the Ministry of Agriculture and the country's agricultural universities.

What changes should be made?

The direct involvement of breeder associations or farmer organizations in performance recording and in maintaining the breeding programme is necessary for the secure and continuing implementation of the programme. Such an involvement pre-supposes the increase of the support and services provided to the farmers, otherwise the farmers will have no motivation to participate in such an organization. To date, the feedback to the farmers has consisted of information on milk recording and some information on the lambings (number of lambs born). However, it is important to extend the data collected to information on reproduction traits, economic indexes, health and functional traits, in order to use this information on the management, feeding and health care of the flocks.

It is also important that the computer output is clear and the farmers can understand and interpret the results for the benefit of their flocks.

Changes in the traits included in the breeding goal have to be considered. Some traits to be studied are milk composition, somatic cell count and udder morphology. The redefinition, after extensive study of the production and marketing system of the breeding objectives, which may not be the same for all the breeds concerned, is necessary.

Future directions

The farmers should financially contribute to the milk recording programme, in contrast with the previous periods when the Ministry of Agriculture granted them considerable premiums to join the recording and genetic improvement scheme, in order to prove that the previous changes regarding the kind of support and information to farmers should be established.

Research is also directed to the introduction of simplified recording methods to reduce the cost of milk recording. Another objective is the application of pyramidal selection schemes with breeding nucleus for specific breeds.

Estimates of genetic change

Results from the application of the multi-trait animal model in the nucleus of the Chios breed showed an annual genetic improvement of 2.9 kg of milk yield per lactation, 0.3 lambs per 100 lambings and a slight decrease of the average litter weight of 3 g, which is counterbalanced by the increase in litter size (Ligda, 1999).

Estimates of genetic change due to the application of the breeding programme are not available because of the lack of information concerning the ancestors of the animals. However, from the results of the Genetic Improvement programme, the milk production of the Karagouniko breed, has reached 167 kg, an increase from 121 kg at the beginning of the implementation of the programme. The average milk production of regularly controlled Frisarta ewes, during the years 1990-93, is 220 kg (Ministry of Agriculture, 1995; 1997a). The milk yield of the Boutsiko breed, in the Research Station in Ioannina increased to 150 kg from 100 kg, after selection had been applied in the Station (NAGREF,1996). Results concerning the milk production of eight Skopelos goat herds that have participated continuously in the National Genetic Improvement Programme for at least nine years, showed an increase in milk yield from 240 kg to 340 kg (Ministry of Agriculture, 1997b).

Conclusions

Summarising the experiences gained during the period of the application of the Genetic Improvement Programme for small ruminants in Greece, the following can be concluded, from the technical, operational and policy points:

Technical

The projects have been implemented without detailed technical description and clear breeding goals. There was no specific plan for the dissemination of the improved genetic material. The technical and financial support offered by the Ministry of Agriculture was not in accordance with the demands of projects of such dimensions.

Operational

The implementation of the projects were interrupted several times because of lack of finance, which mostly inhibited the ability to hire personnel for milk recording. The collaboration with farmer organizations and breeder associations has only recently been established. Moreover, the collaboration with the Artificial Insemination Services was poor.

Policy

There was no specific plan for the genetic improvement of the local breeds by pure-breeding. For many years the introduction of many foreign breeds for the improvement of the local population was supported, which in conjunction with the extended cross-breeding between the local breeds, resulted in extended and undefined cross-breeds.

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Breeding strategies for the Mediterranean Modicana cattle breed

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Modicana cattle breed

The cattle breed investigated in this case study is the Modicana breed reared only in Italy, in Sicily. This wine-red colour breed has Podolian roots and like other Podolian derived breeds has blood group factors indicating a probable affiliation with zebu. Modicana derived from other Podolian root breeds, like the Apulian Podolian and Chianina, and from dark-red Podolian of Illyrian type and maybe from some other cattle of Central Europe arriving in Sicily through the many invasions suffered by the island in the last centuries.

Modicana pure-breed has three varieties:
1) the Modicana of the lowland or Modicana Olivastra, representing the best developed and most common type;
2) the Mezzalina, living in the hilly region; and finally
3) the Montanara that lives in the mountainous areas. This variety is the least developed.

At present the most important production of the breed is milk. Meat is less important. Modicana produces meat mainly through cross-bred calves progeny of Modicana cows mated with beef bulls. In the past, the breeding purpose was mainly for milk yield and working. Development of agricultural technology caused disappearance of working as a breeding purpose. Milk yield average for cows belonging to the herd book is 2 786 kg for first lactation, 2 961 kg for second lactation and 3 122 kg for third and higher lactations. The average lactation length is 250 days. The averages for all lactation fat and protein percentages respectively are 3.58 ± 0.37 and 3.46 ± 0.17.

Modicana is highly resistant to anaplasmosis, piroplasmosis and tuberculosis. Performances of Modicana, relative to other cattle breed, are good in fat and protein percentages in the milk. On the other hand, the Modicana breed has low performance in terms of milking. Overall the performances, in relation with the environment where the animals are bred, are relatively good, with good resistance to disease and high utilisation of poor pastures and by-products. Modicana does not have the desirable characteristics for producing meat as pure-bred, daily gain performance and quality of the carcass are poor. The skeleton is solid and big. Dressing percentage in young animals is about 53-54 percent and of adult individuals is about 45 percent for cows and 50 percent for bulls. Body size is medium to high with adult males weighting from 900 to 1 000 kg and adult females from 550 to 600 kg, height for adult males and females is, respectively, 155 $\pm$ 5 and 140 $\pm$ 5 cm. Morphology of the animals is not desirable either for milk production or for meat production. The wide spread technique of hand milking caused disagreeable udder morphology. Modicana has good maternal attitude, being able to produce calves in environments where no other breeds could.

At present Modicana lives in the mountainous and hilly regions of Sicily. Milk yield of Modicana is less than half of the average yield of the cosmopolitan breeds living on the island today. The possibility of using good quality semen from Modicana sires was denied by the complete absence of a semen market as a consequence of the former selection scheme with no bull progeny tested.

The number of animals is not well defined. In 1989 it was estimated at about 80 000 Modicana cows with only 4 360 registered in the herd book and milk recorded. Nowadays, the population size is decreasing, while the number of the registered cows is growing: 6 067 recorded animals on 338 farms. The average number of animals is 18 per farm. Most of the farms are in the class between 11 and 20 cows, with 63 percent of the farms having less than 20 cows and only 16.6 percent of the farms with more than 30 animals.

Modicana production system

Modicana is a cattle breed that is competitive only in areas where pasture productivity is very low, those areas are also the poorest in Sicily. In other zones more productive breeds are currently bred. In the last century people emigrated from the poorest zones of the island. Furthermore, many farms were abandoned and a large number of Modicana cattle were lost.

Nowadays in Sicily, Holstein Friesian is present mainly in the best territories, the Ragusa Province and the plain of Catania, where the Modicana breed used to give the highest production. Some herds of Brown Swiss are also present. In the rest of Sicily most of the cattle bred are Modicana, both as pure-bred and as cross-bred.

As only a few farms have milking machines, most of the farmers still hand-milk. Many farmers still milk cows leaving calves close to the mother, because it is believed that otherwise cows become difficult to milk. Recent research showed that the presence of the calf is not significant in milking and in the daily milk production of Modicana cows. A positive influence was instead found on lactation persistency.

Selection schemes applied

The history of the breed shows that over time many different attempts have been made to improve productivity. All of them have failed. Between 1864 and 1867 a disease killed most of the cattle reared in Sicily. Brown Swiss animals were imported to the island to help restore cattle population and to improve milk yield, mainly by cross-breeding Modicana cows. The Modicana breed was at that time mainly used for draughting and secondly for milk. Cross-bred animals were less resistant to the severe conditions present in Sicily about one hundred years ago. Furthermore, the cross-breeds were less capable of working. For this reason the project was a complete failure. To re-establish a bovine population adapted to the Sicilian environment, farmers were obliged to back-cross to Modicana, obtaining a new type of Modicana with still some portion of Brown Swiss genes in their genotypes.

A subsequent plan to improve milk yield was made about fifty years ago to again cross-breed Modicana cows with Red Danish and Holstein Friesian bulls. This plan was not organized by any regional or local policies, but only by private intentions. This effort also failed because the cross-breeds were not adapted for working and for pasturing in the less productive meadows of the island. At that time animal power was also loosing its importance. Pure-bred Holstein Friesian and Brown Swiss were imported to Sicily to use the more productive meadows. As a consequence Modicana was mainly confined to the worst territories of the island and the numbers of Modicana animals reduced. After the Second World War many farmers left the worst territories of Sicily to live in the main cities or away from the island. The result of this social change was that many farms rearing Modicana animals closed down.

The cross-breeding approach of Modicana with beef cattle began in 1975, mainly with Charolais bulls from France. The purpose was to combine the Modicana good attitude as “maternal breed” and Charolais beef morphology. Modicana cows have a good capacity for feeding calves even in harsh environments. The danger of cross-breeding most of the breed with beef cattle soon became real. For this reason the regional technical offices divided Sicily into two zones: in some areas (free zone) it was permitted to cross-breed Modicana cows with bulls of any other breed and in the other areas (pure-bred zone) it was permitted to breed Modicana cows only with pure-bred Modicana sires. Due to the lack of organization of herd books it was impossible to check if the law was respected in the pure-bred zone. The aftermath was that a portion of the Modicana pure-bred population was lost and the rule was cancelled after some years.

The outcome of the third attempt to improve efficiency of Modicana breed was similar to the first two, completely negative. The common peculiarity for all three failings strives to improve productivity and efficiency of the Modicana breed by cross-breeding with animals selected in different environments, having characteristics that do not fit in the severe Sicilian environments. At present, the plan actually followed is influenced by the failings of the previous strategies.

Present selection scheme actually followed

A selection scheme was recently planned by the Sicilian Association of Animal Breeders (ARA-Sicilia), the Regional Agriculture Offices and the Italian Association of Animal Breeders (AIA). The goal of the selection scheme is to improve milk yield and milk quality for cheese production.

About 20 percent of the estimated pure-bred cows, about 6 000 cows, are milk recorded with the A4 ICAR system that is recording daily yield every month. Milk samples are taken monthly from each cow to estimate fat and protein percentages. Lactation yield is estimated by the Fleischmann method. All lactations are projected to 305 day length. An animal model is then performed to estimate breeding values for milk, fat and protein yield and for fat and protein percentages. Another trait is also modelled to estimate breeding values: kilograms of cheese produced: a combination of milk yield in kilogram and fat and protein percentages produced for each cow. This last trait is assumed as a selection index.

Breeding values for all recorded population are estimated each year. Pedigree indexes are also predicted to choose, together with good morphological characteristics, five young bulls for progeny testing. Five hundred heifers are chosen according to pedigree indexes and good morphological characteristics. Semen of the selected young bulls is used to breed the heifers to obtain about 225 female calves, that have about 180 parities and about 125 complete lactations. Analysing lactation data through an animal model, the best bulls are selected for artificial insemination. Best cows are also selected to become mothers of sires and heifers, and pedigree indexes are estimated for the new generation of young bulls to be progeny tested.

The reason for the small number of young bulls and heifers tested is due to the fact that only part of the farmers join in the plan.

Traits included in the breeding goal

In the new selection scheme applied to the Modicana cattle breed the characteristic to be improved are: milk yield in relation to cheese production and meat production. To increase the commercial value of the milk it was decided to link milk from Modicana cows to a particular type of cheese named, in the Ragusa province, “Ragusano”, elsewhere with different names, but always a “Caciocavallo” cheese type. It was important to establish a connection between a well recognised cheese with Modicana milk, richer in fat and protein than Holstein Friesian milk. The plan is to improve milk yield using only pure-bred animals.

In the future the production of meat will be improved by cross-breeding Modicana cows with beef cattle bulls. This practice already exists in Sicily and at present produces about 35 percent of the meat consumed on the island. Modicana has good maternal traits even in a difficult environment. In the Sicilian hills and mountains, summer is always dry and grass production is close to nothing between May and October. Those areas are also difficult to reach for lack of roads and insufficiency of infrastructure. Improving maternal traits of Modicana cows can be done by planning a selection scheme and by keeping genealogy information and measuring calves daily gain at fixed intervals. Animals with good conformation for meat production and having legs resistant to pasture in harsh environments must be selected. This selection goal can be reached by adding to genealogy data and morphological evaluations performed on each animal by breed experts.

A good industry importing semen of Charolais and Limousine sires is present. When genetic indexes will be performed it will also be possible to select beef cattle sires giving calves, when mated with Modicana cows, having high production in the Sicilian environment.

The result will be to obtain two lines each specialised in a particular production with more possibility to survive in their respective environments. Nevertheless, offering both lines the possibility to register animals in the same herd book, genetic variability will be maintained.

Dissemination of improved genotypes

Improved genotypes are actually disseminated through all animals of the herd book. The Italian law stipulates that all cows, both belonging to any herd book or not, must be bred with improved sires belonging to the herd books. A Modicana cow can be bred, by artificial or natural insemination, only by semen of Modicana sires registered in the herd book or by sires, of any other breed, registered in the respective herd book. To help dissemination of improved genotypes, semen of improved Modicana sires is offered for free to all pure-bred Modicana breeders.

Modicana pure-breds are mainly bred by natural insemination with sires in the herd. Male and female calves from the most productive cows are kept for replacement. Cows’ productivity can have good estimation if milk is recorded, if completely voluntary. If cows are not milk recorded the choice is based on morphology and on rough estimation of milk yield. Cows are usually kept for a long time, it is common to keep cows for more than 13-14 years.

Mating is often influenced by meadow seasonal production, that in Sicily is more abundant at the end of winter and the beginning of spring, and cows naturally regulate months of highest grass production with the period of lactation peak. Modicanas bred in the low-input low-output system have seasonal breeding, most of the calvings occur between December and March with the lowest percentage in July. Use of artificial insemination is opposed by lack of Modicana bull semen. Only recently, with the development of a selection scheme has Modicana semen become available.

Breeding structure

The genetic improvement will act directly only for animals registered in the herd books. Some farms, with animals registered in the herd book, join the "selection nucleus". Interest of the breeders for the selection scheme and advanced breeding system are essential. The farms belonging to the "selection nucleus" participate actively in the scheme by programmed matings to produce young male calves to a progeny test. These farms will be able to increase their income by selling improved genotypes, both offering semen and live animals. The rest of the farms participate in the selection scheme by recording milk yield for each cow thus, with a larger population size, improving accuracy of genetic indexes and enlarging genetic variability. Full participation in the selection scheme is voluntary. Farmers can join the "selection nucleus" anytime, but they must follow the requirement to permit a good operation level of the selection scheme. The farmers having animals not registered in the herd book can not participate in the selection scheme, but they can ask for the admission to the herd book and then fully participate. The requirement for joining the herd book is that all animals must have a morphological evaluation attesting Modicana breed morphology.

Farmer and Government involvement

Most of the expenses, about 80 percent, for planning, implementing and maintaining the selection scheme, for each cattle breed having an Italian herd book, are paid by the Italian Ministry for Agricultural Policy. The cost pays for herd book keeping, milk recording, planning and activity of the selection scheme, morphological evaluation, plus some cost to organize meetings, exhibits, etc. Modicana farmers, joining the herd book, pay for the remaining part whilst the Sicilian regional Government helps Modicana farmers pay a part of the remaining 20 percent.

The Sicilian regional Government recently requested that Modicana cows be exempted by the quota system of production, as in most other regions of the European Union. Sicilian farmers had very few quota allowed to produce milk. The possibility to be released by a quota system will help the dissemination of the Modicana breed in those areas where it was substituted by Holstein Friesian and Brown Swiss cattle.

Several attempts were made to modify legislation to better implement the selection scheme, to help productivity and increase the value of products and overall to develop breeding of Modicana cattle. Funds were destined to farmers for buying and maintaining pure-bred Modicana animals. Funds were also destined to facilitate marketing of Modicana products.

The Italian Ministry for Agricultural Policy also helps research for developing genetic improvement and to improve environmental conditions where Modicana is reared, especially to improve the meadows where those animals are present.

Technical support

The economic support to farmers for joining the herd book was not completely positive for selection scheme success. Many farmers joined the herd book although not really interested. The number of animals participating in the selection scheme is higher, but milk yield records and genealogy registration were less accurate having a negative effect on the genetic indexing and selection scheme. More successful was the support for marketing products of Modicana breed.

Strategy for developing the Modicana breed is coordinated by the Modicana Breeders' Association (A.N.A.MOD.). The technical body of A.N.A.MOD. is composed of animal production experts from universities, research centres and breeder associations. Representatives of regional governmental bodies are also present. About half of the components are Modicana breeders. All decisions regarding planning and implementing the selection scheme are made by this technical body.

Reason for introducing the scheme

The purpose of the scheme to be initiated and maintained is related to increase in milk yield by breeding animals in the less developed areas of the island. This aim can be reached only by rearing Modicana pure-bred or cross-bred. The goal is also social, as having farms in such areas provides work for people in those zones of the island from where people traditionally emigrated from to look for jobs in the main cities in or outside of Sicily. Rearing Modicana breeds in those less developed parts of Sicily is sometimes the only way to give economic value to those territories. Cultural reasons must not to be forgotten. The long history of interaction between Modicana, men and environment helps to understand the adaptation and therefore furnishes hints to better manage animals in the actual production schemes.

The presence of cattle of native origin interacting as part of the environment has high ecological importance. Farms with pasturing animals, keep meadows and grasslands in good condition, as a result of landscape and farm management.

Future activities and results

The support given by the national and regional governments is already encouraging farmers to breed Modicana animals. Support for marketing Modicana products will increase farm efficiency in the future especially for the creation of a brand name defining products only from Modicana farms. Consumers will be attracted by products having the Modicana label because it represents, especially for Sicilians, a synonymous of traditional breeding and production. A typical label for local breeds was successful for Parmesan cheese of the Reggiana cattle. For Modicana it was decided to follow the same procedure. In the near future, governmental support and strategy for marketing Modicana products will stop the decreasing trend of breeding populations. For the following years the positive genetic trend of the selection scheme will be effective and the improved production of the breed contributing to increased economic efficiency of breeding Modicana animals.

Development of a milking machine together with the improvement of udder conformation are needed to increase milk yield and milk with low somatic cell count. Helping farmers to buy and use even simple milking machines is one of the key actions that can improve efficiency of farms. Also farmers should have a refrigeration system to enable them to keep milk without having problems of the loss of quality.

Another key action is to organize regular collection of milk for all farms. Modicana milk must be transformed in the cheese factory or in the farms without being mixed with milk from cows of other breeds. Only in this way can milk have a higher price due to certified cheese to be produced only with Modicana milk.

A good extension service should help farmers to make culling decisions, choose semen from improved sires, increase health and fertility of the herd and choose a feeding system. A specific extension service is needed for improved participation in the selection scheme.

Genetic changes of the Modicana breed of milk yield traits were not significant during the last ten years with the exception of a small positive trend for all productive traits for the last generations. Positive trends were probably due to farm selection and reduction of worst genotypes by the diminishing number of small and less developed farms. The expected genetic trend when the selection scheme will be fully operative is about 35 kg of milk yield per lactation. It is more difficult to predict genetic change for the planned selection to improve meat production by cross-breeding Modicana cows with beef cattle sires.

Iberian pig breeding programme

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Breed

The Iberian pig population is the most important population of the Mediterranean type, one of the three ancient types of domestic pigs. For centuries, this population was maintained with a large effective size submitted to the hard environmental conditions of the semiarid continental climate of the Southwest of the Iberian Peninsula. The characteristic habitat of the Iberian pig is the Dehesa or Montado in Portugal. These are sparse Mediterranean woodlands in which evergreen and cork oaks predominate and in which shrub growth has been reduced by man. The Dehesa constitutes an interesting ecological model of interaction among woodland, grassland and livestock and an important reserve for wild fauna and flora.

Without selective preponderance of any group of breeders, the breed conformation was developed through a process of adaptation to this environment and to the high demand for animal fats. The morphology of the Iberian pig makes it resistant to sunstroke and the high summer temperatures and enables it to travel far in search of food: it has dark skin and hair colour, a pointed snout and legs that are both long and strong. It can endure long periods of hunger because of its low basal metabolism and the early formation of fatty tissues. The thick layer of subcutaneous fat and the high level of intramuscular fat make its meat adequate for dry-cured meat processing, which allows storage and consumption of meat products for the whole year.

Although in the traditional population there were different local varieties (black hairless strains and red, golden or pied varieties), the aforementioned features and others such as short and jowled neck, medium length trunk and pigmented hooves of uniform colour are shared by all Iberian pigs.

Production systems

The main objective of the production of Iberian pigs is to obtain heavy pigs (160-180 kg of slaughter weight) destined to be processed as high quality dry cured meat products. Three different systems of fattening of castrate animals, with increasing input level and decreasing quality and price of the final products, are used today to produce Iberian pigs for slaughter:

a) The extensive system depends on the seasonal availability of mature acorns (Montanera), usually from early November to late February. The whole productive cycle of the animals is planned to achieve 90-110 kg weight at the beginning of the Montanera, with a minimum age of ten months. In this preliminary period, a common objective is the maximum use of field feeding resources: grazing on the spring pastures, stubble fields and any available crop, but supplementation with concentrate feeds is not unusual with restricted feeding. The feeding in Montanera consists, for the most part, of acorns (6-10 kg / day) and variable intake of grass as well as roots and bulbs. A reference value for the total fattening capacity in Montanera has been 5-6 at (57.5-69 kg, 1 at = 11.5 kg), corresponding to an average carrying capacity of 0.5 pig / ha. The present tendency is to increase this in order to be able to increase the number of pigs produced by the Dehesa, whose total surface cannot be extended in the short term.

b) Unfavourable weather conditions or excessive carrying capacity make it necessary to resort to another extensive system of production called Recebo. In this system, with medium input level, low quantities of acorns are supplemented with concentrate feeds during the fattening period or, alternatively, if the acorns run out and the pigs have not yet attained the required slaughter weight, the fattening is prolonged as necessary with commercial feed stuff.

c) Only 35 percent of the pigs are fattened in the two previous extensive systems. The fattening of the remaining 65 percent is based exclusively on the *ad libitum* intake of concentrate feeds (Pienso). In this system, with the higher input level, pigs are kept indoors or closed in open-air fenced areas. This intensive system is particularly appropriate for Duroc x Iberian cross-bred animals, that are commonly slaughtered at only 10-11 months of age.

The fat of the acorn has a very high concentration of oleic acid (>60 percent of fatty acids) and limited concentration of linoleic and saturated fatty acids. Since the pig is a monogastric animal, the fat of pigs fattened in Montanera has a high concentration of oleic acid and low concentration of linoleic, estearic and palmitic acids. This fact is used to verify the system of fattening and to establish the corresponding prices of fattened pigs according to the analysis of fatty acid composition of samples of subcutaneous fat. A minimum concentration of oleic acid (54 percent) and maximum concentrations of linoleic (9.5 percent), estearic (9.5 percent) and palmitic (21 percent) acids are required to obtain the qualification of Montanera pig, the respective values for Recebo pigs being 52, 10.5, 10.5 and 23 percent and the remaining animals are qualified as Pienso. The price per kg of liveweight in the period 1987-1999 ranged from 2 500 to

4 400 Pts / at (217-383 Pts / kg) for Montanera pigs and from 1 600 to 3 500 Pts / at (139-304 Pts / kg) for pigs fattened with concentrate feed, the prices of pigs fattened by the Recebo system was immediate.

Although it is an aspect which demands deeper research, the characteristic marbling of the meat of Iberian pigs and the high concentration of oleic acid provided by the acorns are considered essential for appropriate ripening and flavour development of the products.

Census

The Iberian breed was the most important breed of pigs in Spain until 1960, with 567 000 sows recorded in the official census of 1955. Since then, the number has been drastically reduced due to three simultaneous factors, namely the:

- depreciation of animal fats;
- outbreak in Portugal and Spain of African Swine Fever;
- massive introduction in Spain of foreign pig breeds.

Cross-breeding of Iberian with several colour-coated breeds was started: Tamworth, Wessex, Berkshire, Large Black, Duroc-Jersey and even Large White. Crosses with Duroc became predominant over other options, most of the commercial pigs containing 25 or 50 percent of Duroc genes. The old structure, with differentiated varieties locally diffused and rare genetic interchange among herds, was substituted by a new pyramidal structure characterised by:

- a strong dependence on a small number of elite herds in order to supply pure-bred Iberian breeding animals;
- absence of a specific tier of cross-bred multipliers: Iberian x Duroc cross-bred sows are obtained both in nucleus or commercial herds.

Obviously, the elite herds, located both in private and public farms, were the target of the breeding programme, when it was initiated in 1993.

According to the official census of 1986, the number of pure-bred Iberian sows was 72 000 with other 38 000 cross-bred. The corresponding figures were estimated in 1990 as 31 000 and 71 000 sows, respectively, but the tendency has been reversed during the last years. The estimates obtained for 1998 indicate 107 000 pure-bred and 93 000 cross-bred sows, with an increase of the total number of sows and the proportion of pure-bred Iberian sows, although most of them are dedicated to crossing with Duroc boars.

An increased demand for Iberian pig products occurred in recent years and has attributed to a higher standard of living and a revaluation of traditional foods of top quality. The total number of slaughtered pigs registered a twofold increase from 1986 (841 000) to 1998 (1 690 000). The distribution of the latter according to the system of fattening was 354 000 (Montanera), 236 000 (Recebo) and 1 100 000 (Pienso).

The breeding programme approach

A breeding programme for Iberian pigs based on farm records was designed by the Spanish Association of Iberian Pig Breeders (AECERIBER). For this purpose, a Commission on Genetic Improvement was constituted with animal geneticists from research centres and member representatives of farmers, the processing industry and regional and national public institutions related to pig production. The following objectives were adopted to initiate the breeding programme:

- development of the breed herd book, avoiding the introgression of foreign genes from cross-bred animals used as reproducers;
- characterisation of the productive performance in extensive conditions of the diverse surviving varieties of the breed;
- genetic improvement for the most disadvantageous traits of Iberian pigs (growth and conformation of the most valuable cuts: hams, forelegs and loins).

According to the previously described characteristics of the population and the extensive production system, a breeding programme of the Iberian breed must overcome several important difficulties that can be summarised as follows:

- identification of animals and data recording of field and slaughter performances;
- genealogical control;
- limited connection among herds, due to the unusual artificial insemination.

Several risks must also be avoided:

- possible loss of rusticity;
- reduction of meat quality;
- extinction of local varieties of lower performances.

According to the productive cycle of their farms, the Iberian pig breeders can be grouped into two types that require different approaches: farmers producing piglets, that are sold at three months of age and farmers that extend the productive cycle until the obtention of heavy pigs for slaughter (Complete Cycle). Consequently, the scheme of genetic evaluation developed by AECERIBER combines:

- intra-herd genetic evaluation for weight at 90 days, focused on breeders producing piglets in farms controlled by AECERIBER;
- genetic evaluation for growth in the fattening period and carcass composition based on data annually recorded in family groups of animals sampled from some of the previous herds and tested under uniform extensive management, including fattening in Montanera.

Reproductive traits like litter size are not included in any of the two types of evaluation, mainly because of the scarce genealogical information available in each one of the farms is not sufficient to accurately estimate the breeding values of low heritable traits such as prolificacy. On the other hand, the production costs of piglets represent a very small proportion of the production costs of heavy pigs.

Genetic evaluation for liveweight at 90 d

This evaluation utilises records obtained in the farms from piglets when both parents are known. A modification of the traditional system of mating, in which two groups of boars and sows are confined in a pen for four weeks, is required to control the paternity using only one boar. Individual electronic microchips are used to identify the piglets born in litters with known pedigree. These litters constitute the main input of genealogical information for the recently established herd book of the Iberian breed. A panel of seven microsatellites (CGA, IGF1, Sw2419, Sw911, S0106, S0068, Sw936) mapped in different chromosomes and simultaneously genotyped in multiplex, can be used to check pedigrees in Iberian pigs, with the joint probability of exclusion of paternity equal to 99.91 percent.

The ensemble of information used in the last evaluation for this trait is summarised in the following table:

Regions	Farms	Breeding animals	Piglets with records
Extremadura	12	756	4 683
Andalucía	13	515	3 525
Total	26	1 271	8 208

This information has been used, separately for each one of the farms, to estimate the breeding values for weight at 90 d (EBV_{WT90d}) of the controlled piglets and their parents. Details of the methodology of genetic evaluation can be found in the Annex. Given the poor connection among herds, the validity of these evaluations is restricted to the corresponding farms. In the absence of other recorded traits, the value of the estimated breeding value for WT_{90d} constitutes the genetic index adopted in this type of evaluation.

Genetic evaluation for growth and carcass composition

The breeding goal for the farms of complete cycle was defined according to the results of an economic study of the production of Iberian pigs during the last decade. The following economically most important traits were combined in the breeding goal:

- average daily growth during the final fattening period, that also measures the rusticity as adaptation to the Montanera;
- weight of the most valuable cuts (hams, forelegs and legs) adjusted for a common carcass weight.

Since 1993 AECERIBER has carried out annual tests of performance for these traits based on family groups of animals sampled from different herds and transferred to a common farm in order to estimate the:

- productive differences among the main varieties and lines;
- breeding values for growth and carcass composition of the breeding animals genetically related with the tested animals.

These tests are executed under uniform extensive handling and allow the comparison of the EBV of reproducers born in different herds despite the weak genetic connection between herds. Due to sanitary and management causes, two separate trials have been performed including herds from the Extremadura and Andalucia regions. Pigs are finally slaughtered and cut in the same slaughterhouse, where the weight of carcass and most valuable cuts are recorded. At present, a total number of 753 castrate pigs from 60 boars and 258 sows have been tested in Extremadura and another 735 castrate pigs from 55 boars and 255 sows were tested in Andalucia.

One of the most remarkable results of these analysis is the evidence of strong differences in performance between some of the varieties or lines used in the different farms. The line of higher productive performance is a composite line (*Torbiscal*) resulting from the blending of four ancient Portuguese and Spanish strains in 1963 and posteriorly selected in an experimental farm. The less productive varieties for these traits are two types of hairless pigs. The differences between these extreme lines are: 201 g/d (ADG) and 2.4, 1.3 and 0.8 kg for the adjusted weight of hams, forelegs and loins, respectively. Expressed as percentages of the mean, these figures correspond to: 33.7, 11.6, 9.5 and 25 percent. These differences reinforce the specialisation of the diverse lines, with an increasing diffusion of the most productive lines specifically to obtain commercial pure-bred Iberian pigs and limit the use of the hairless varieties to cross-breeding with Duroc.

Breeding goal and standardised genetic index

In the present approach, all the traits included in the breeding goal are used as index criteria. The genetic evaluation based on several traits requires the weighting of the corresponding estimated breeding values (EBV). Economic weights for ADG, hams and loins were calculated with conventional methods according to data of prices and costs in the last ten years. A singular calculation was carried out for the forelegs, a trait where a minimum weight (5.5 kg) is required by the industry. In this case, the trait distribution in the population and the price difference between forelegs within and outside the optimum range must be considered to calculate the corresponding economic weight. The resultant genetic-economic index that has been used in the genetic evaluations of the complete cycle was:

$$6.90 * EBV_{ADG} + 2000 * EBV_{HAMS} + 1300 * EBV_{FORELEGS} + 2200 * EBV_{LOINS}$$

A standardised index (mean = 100; SD = 10) was also calculated, transforming the previous values. The estimated breeding values for the diverse traits and the global and standardised indices are facilitated to the farmers for easier interpretation of the genetic merit of the animals. Standardised indices (Std. Index) allow the single classification of breeding animals such as:

- Very Good (Std. Index > 120)
- Good (105< Std. Index < 120)
- Acceptable (95< Std. Index < 105)
- Bad (Std. Index < 95)

These indices are used in the public auctions which constitute an important way to dissemination of improved males and females.

Financial support for this breeding scheme is provided by the central and regional governments: a fund of 4 500 000 Pts is supplied annually by the Ministry of Agriculture, Fish and Food (MAPA) of Spain, related to the management of the herd book of the breed and a total of 8 000 000 Pts are annually supplied by the Agriculture Regional Departments of Extremadura and Andalucia to carry out the performance tests of the complete cycle. Policy aspects of the herd book and the implementation of the breeding scheme are specified in two Resolutions of MAPA of Spain adapted to EU regulations.

Inefficiencies of the breeding programme

The level of acceptance of the scheme increases over time and the performance of 500 heavy pigs will be annually tested in future campaigns. Four main inefficient aspects have been evidenced in the execution of the breeding programme:

- pig identification is not always guaranteed by the electronic microchip due to the thick and soft subcutaneous fat which may require regular replacement; the parallel use of eartags is required despite the high proportion of lost tags which are necessary to replace regularly; this problem will be especially important in the next campaigns due to the increasing number of tested animals;
- genetic evaluation for fattening growth and carcass composition is achieved for a low number of breeding animals with more than two and a half years; increased controlled matings are necessary to build a more dense pedigree with a large number of young animals genetically related to the performance tested pigs;
- a number of boars lower than foreseen is utilised by some farmers in controlled mating, resulting in a biased sampling of the correspondent herds where boar family and herd risk being confused;
- separation of the two trials (Andalucía and Extremadura) restricted the validity of the comparison of genetic merit to the breeding animals from farms of the same region; in the future, both trials must be connected overcoming the present barriers.

Other changes must be introduced to the scheme in order to avoid some of the risks quoted in the previous paragraph, namely:

- meat and fat quality parameters (percent of intramuscular fat and profile of fatty acids) will be individually recorded in future campaigns using cheap and non-invasive techniques (Near Infrared Spectroscopy applied to samples from the masseter muscle); these traits will be included in the breeding goal in the next three years in order to attain genetic progress for growth and carcass traits compatible with the preservation of meat quality;
- the possible substitution and / or extinction of hairless varieties due to their lower performance can be attenuated with their appropriate use in cross-breeding schemes; it requires a differentiated standardisation of the index for the ensemble of pig lines mainly destined to cross-breeding, based on the proper mean and standard deviation.

Future progress

Once these changes have been implemented, the future of this scheme will depend on the ability of the market to relate to the top quality, dry-cured products with the pure-bred Iberian pigs fattened under the extensive system. In this case, the number and size of the pure-bred Iberian herds will be augmented, increasing the probability of achieving the relevant genetic progress for the breeding goal. For this purpose, some other operational changes can be suggested in order to increase the selection differentials applied to both sexes and to reduce the long generation intervals, namely:

- the use of artificial insemination can be recommended as a tool to increase the use of boars with higher genetic merit, dissemination of genetic progress and connection among herds, although it requires important changes in the present extensive management of sows that make the detection of estrus difficult;
- the integration of several connected herds in group schemes can facilitate the selection across herds, development of performance tests based on farm data for fattening growth and carcass composition and the eventual inclusion of litter size in the breeding goal.

Adaptation to the Dehesa ecosystem, top quality of dry cured products and preservation of the genetic diversity of the population are the basis of the Iberian pig production, that cannot be removed by the genetic progress attained from the breeding programme.

Annex: Performance results and statistical models

An Animal Model was used to estimate the breeding values for weight at 90 d (EBV_{WT90d}), including the litter common environmental effect as a second random effect:

$$y = Xb + Z_1u + Z_2c + e$$

where, y = vector of records; b = vector of fixed effects (mean, sex, year, batch of farrowings); u, c, e = vectors of additive genetic effects, litter common environmental effects and residuals and X, Z_1, Z_2 the corresponding matrices of incidence. The genetic parameters used in the evaluation for this trait were estimated from data recorded in the farm with more available information, being the corresponding values: $h^2 = 0.21$ (s.d. 0.11) and $c^2 = 0.16$ (0.04).

A summary of the information recorded in the tests for complete cycle are presented in the following tables:

Growth and carcass data recorded in Extremadura trial (pigs from ten herds).

Trait	Tested pigs	Mean	SD	CV	Minimum	Maximum
ADG†, g / day	753	597	153	26	174	1 345
Slaughter wt., Kg	753	162.5	16.7	10	90	216
Carcass wt., Kg	753	134.0	15.3	11	72.0	181.2
Hams, Kg	753	20.6	1.8	9	12.5	27.7
Forelegs, Kg	753	13.6	1.2	9	8.7	17.3
Loins, Kg	570	3.2	0.4	14	1.9	5.1

†recorded in the final fattening period (Montanera)

Growth and carcass data recorded in Andalucia trial (pigs from nine herds).

Trait	Tested pigs	Mean	SD	CV	Minimum	Maximum
ADG†, g / day	683	597	132	22	157	1 033
Slaughter wt., Kg	735	167.5	18.6	11	104	223
Carcass wt., Kg	735	138.9	15.3	11	85.2	192.6
Hams, Kg	735	20.8	2.2	11	12.4	28.3
Forelegs, Kg	735	14.3	1.6	11	9.7	19.7
Loins, Kg	582	3.1	0.4	14	2.0	4.4

†recorded in the final fattening period (Montanera)

The previous information has been used separately for each one of the trials, to estimate genetic parameters and breeding values for ADG, weight of hams, forelegs and loins adjusted for carcass weight of the tested pigs and their parents, using the following Animal Model:

$$y = Xb + Zu + e$$

where, y = vector of records; b = vector of fixed effects (mean, sex, year, herd and carcass weight as co-variable in the analysis of prized cuts); u, e = vectors of additive genetic effects and residuals and X and Z, the corresponding matrices of incidence.

The estimates of heritabilities (in the diagonal) and genetic correlations between the diverse traits, with their standard errors are presented in the following table:

Genetic parameters for traits included in the breeding goal.

	ADG	Hams.	Forelegs	Loins
ADG	0.445 (0.043)	0.743 (0.074)	0.693 (0.079)	0.591 (0.090)
Hams		0.484 (0.050)	0.894 (0.038)	0.742 (0.058)
Forelegs			0.544 (0.063)	0.667 (0.070)
Loins				0.522 (0.069)

LAMBPLAN: a sheep breeding strategy

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The mammalian or avian species involved

The species involved are sheep, initially focussing on sheep bred and managed for lamb production, but with a more recent widening of focus to include Merino sheep which are bred and run primarily for apparel wool.

The breed(s) or species involved

The following chart and table show the basic production systems for lamb / sheep production in Australia and the major breeds involved.

Major breeds used in the various categories include:

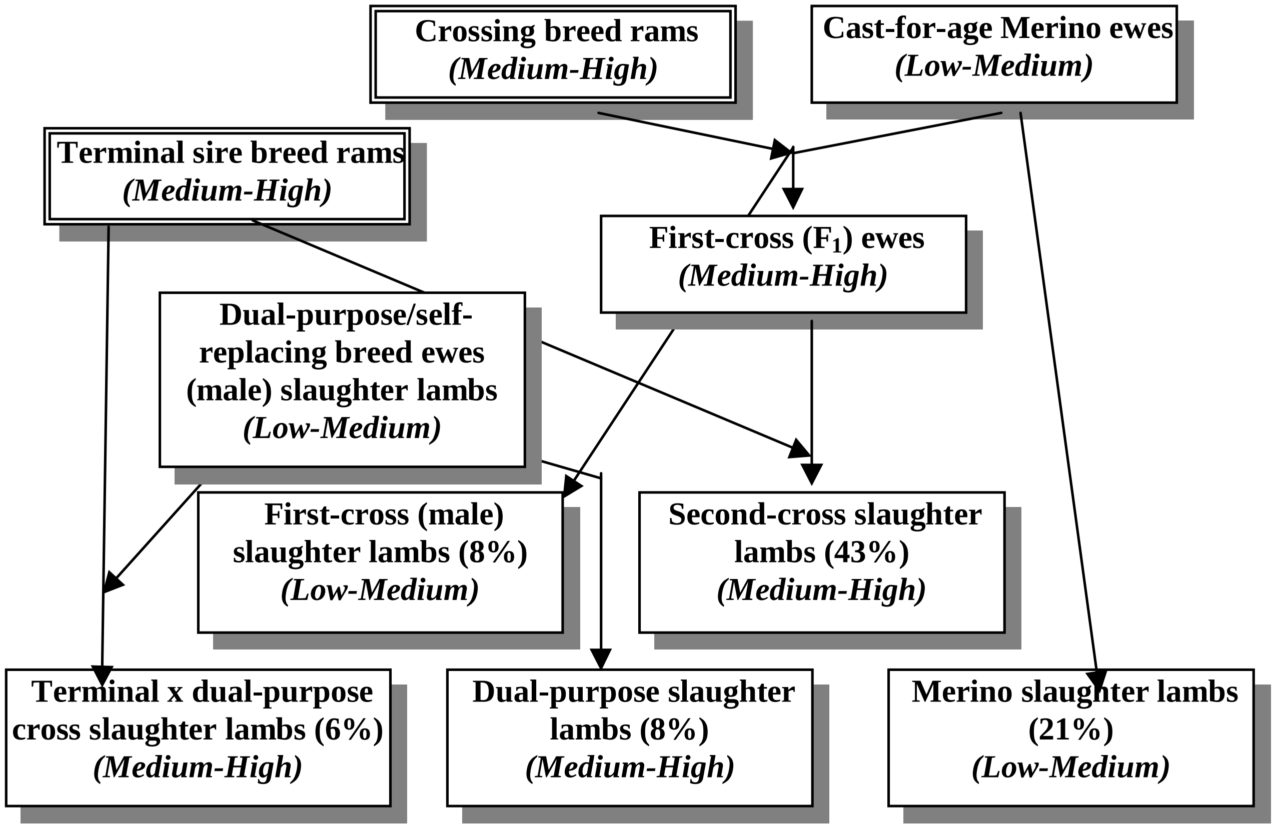
Terminal Sire	Crossing	Dual-purpose / self-replacing
Poll Dorset (0.67)	Border Leicester (1)	Corriedale (0.5)
White Suffolk (0.1)		Coopworth (0.5)
Suffolk (0.1)		
Texel (0.1)		

The core product of the lamb industry is a lamb slaughtered at approximately six months, with carcass weight of approximately 18 kg and carcass fatness of 8-14 mm at the GR site (110 mm out from the backbone at the 12th / 13th rib).

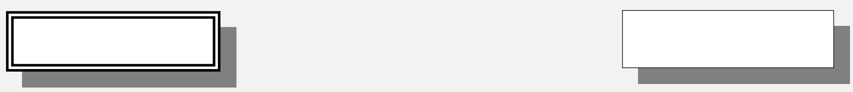
There are in addition approximately 14 percent of slaughter lambs bred as Terminal sire x Merino.

Overall, the Australian lamb production system results in cross-bred lambs being produced primarily from higher rainfall zones within the country, and the dams of these slaughter animals being produced in poorer countries, to a large extent as an "off-shoot" of the Merino ewe population (approximately 60 million).

Figure 1. Crossing systems for lamb production in Australia.



<u>Explanatory note for the diagram</u>



Stud or Nucleus Population(s)　　　Commercial Populations

The phrases in brackets in each text box in the diagram describe the input levels typical of the locations / environments in which each type of animal is run within Australia:

Low: average feed availability and quality is low, and levels fluctuate widely. Parasite burden can be high.

Medium: feed resources may be better managed especially for growing stock, but typically there is a short growing season for pasture.

High: higher rainfall (>650 mm p.a.) supports more intensive pasture production, but may still be quite seasonal. Wetter areas typically impose internal parasite challenges.

This "stratified" system is analogous to that utilised within Britain, with Merinos in harsh dry regions being analogous to the hill breeds run on the high country in Britain. The "first-cross" in both systems "adds" better genetic merit for maternal performance, and the "second-cross" "adds" the genes of fast-growing, higher carcass merit terminal sire breeds.

The approximate input level

In FAO developing country terms, I would assume that the overall input levels are medium / high (but see above).

The approximate number of animals concerned

The total terminal sire breed ewe population (the stud or nucleus population) is approximately 150 000, and the total of crossing and dual-purpose / maternal breeds (again in the stud sector) is 75 000 breeding ewes. The total Merino breeding ewe population (stud ewes) is approximately 750 000 ewes.

Sectors of the breeds involved and dissemination

LAMBPLAN initially targeted the terminal sire sector (1989-1995), then began to increase efforts aimed at adoption within the crossing / dual-purpose / maternal sector.

Dissemination of improved genetic material has been through the sale of breeding animals within the stud sector, with more recently, a rapid growth in the use of AI.

Dissemination to the commercial sector is via sale of commercial rams and commercial ewes (where "commercial" means their progeny are grown for slaughter).

Very little attempt has been made to change the mechanics of movement and sale of genetic material, although as across-flock evaluation has been implemented and breeders' concerns about disease risk have increased, AI has become much more widely used. LAMBPLAN has actively worked with breeders and breeding groups to ensure cost-effective use of AI (and more recently ET).

The approach through which the breeding goal was established

In the initial stages, where the focus was on terminal sires, the broad goal was to enhance capacity to produce larger, leaner lambs. In the absence of either value-based trading for slaughter lambs or clear price signals for fatness / leanness, a simple "desired gains" approach was used with three standard index options (and hence objectives):

- High Growth: designed to maximise genetic improvement in weight at constant age whilst restricting genetic change in fatness to zero;
- High Lean: designed to maximise reduction in fat depth at constant weight, with a small increase in weight at constant age;

- Lean Growth: designed to give equal (in genetic standard deviation units) improvement in weight at constant age and fat depth at constant weight.

The Lean Growth Option was accepted by breeders as the ideal “default” option.

More recently, this approach has evolved considerably:
- In terminal sire breeds, index options are moving more and more towards formal $ Indexes as more traits are incorporated and trading of both seedstock and slaughter lambs become more and more value-based;
- In dual-purpose / maternal breeds, formal $ Indexes were made available almost as soon as the relevant traits were delivered (the trait was defined, genetic parameters estimated, and Estimated Breeding Values or EBVs produced), although simple “desired gains” options have also been provided. The major maternal breeds each have breed-specific $ Indexes, in some cases with more than one option to suit particular production system x target market niches.

In all cases, delivery of Index options has involved discussion with, and feedback from, breeders and some iteration through time as breeders consider more traits, the desirability of particular trait changes and the strengths and weaknesses of their particular breeds / flocks.

Note that Index options tend to be “breed oriented”, although a very small number of individual breeders have used customised indexes they have developed either themselves or with some input from LAMBPLAN.

The plan designed to achieve this breeding goal

No formal plan was ever in place, but the key activities involved were:

- procedures for delivering EBVs and Index values were developed;
- these were promoted to breeders;
- the value of superior breeding stock was outlined and promoted to commercial producers.

At what stage of the development of the programme did the diversion occur?

I think the approach outlined in the former chapter has continued to be the basis of LAMBPLAN. What has changed (and this has been gradual), is the range of traits for which EBVs can be produced, the range of Index options, and more recently, the effort put into improving breeding programme design at the individual and group level.

The stimulus for this evolution has been:

a) feedback from breeders wishing to incorporate more traits into their breeding objectives; and
b) feedback again from breeders recognising the existence of some specific production pathway x target market niches, and seeking indexes appropriate to those niches.

Traits included in the breeding goal

The following tables outline the traits available in LAMBPLAN and the major Selection Index options available (excluding Merino Indexes at this point). The traits measured and / or reported in LAMBPLAN are reported in table 1.

Maternal and direct EBVs for all weight traits will be available by August 1999.

The main Selection Index options available through LAMBPLAN are outlined in the table 2.

The selection criteria followed

The previous tables outline the range of traits for which EBVs can be produced. Clearly, many of these can be used as criteria in a multi-trait evaluation system, for the traits included in the indexes outlined above.

LAMBPLAN has worked with breeders to identify the cost-effectiveness of different combinations of criteria (in terms of accuracy of the resulting Index values and hence potential for genetic gain). The decision as to which criteria will in fact be measured rests with the breeder or breeding group.

LAMBPLAN has recently introduced “Data Quality Grades”, which are recording and measurement protocols differing in their effect on individual trait and index accuracy. Gold is quite intensive recording, silver less so, and bronze lower still. These Grades are an attempt at a more practical approach to accuracy / reliability, and have been enthusiastically adopted by LAMBPLAN clients.

Table 1. Traits measured and/or reported in LAMBPLAN.

Trait code	Trait name
bwt	Birth weight
wwt	Weaning weight
wwtm	Weaning weight maternal
pwwt	Post-weaning weight
cwt	Carcass weight
ywt	Yearling weight
hwt	Hogget weight
awt	Adult weight
Trait code (cont'd)	Trait name (cont'd)
pwcf	Post-weaning fat depth
cfat	Carcass fat depth
ycf	Yearling fat depth
hcf	Hogget fat depth
yfat	Yearling GR fat depth
pemd	Post-weaning eye muscle depth
cemd	Carcass eye muscle depth
yemd	Yearling eye muscle depth
hemd	Hogget eye muscle depth
ygfw	Yearling greasy fleece weight
hgfw	Hogget greasy fleece weight
ycfw	Yearling clean fleece weight
hcfw	Hogget clean fleece weight
acfw	Adult clean fleece weight
yfd	Yearling fibre diameter
hfd	Hogget fibre diameter
afd	Adult fibre diameter
nlb	Number of lambs born
nlw	Number of lambs weaned
ysc	Yearling scrotal circumference
pfec	Post-weaning faecal egg count
yfec	Yearling faecal egg count

NB: in addition, a range of wool style/quality traits, and a range of structural soundness traits, are being introduced to LAMBPLAN during 1999. Research is now being initiated that will lead to the implementation of a range of eating quality traits during 1999/2000.

Table 2. The main Selection Index options available through LAMBPLAN.

Index	Selection Emphasis (as % of Total Genetic Change)						
	wwt	ywt	Yfat	yemd	ygfw	yfd	nlw
Wool & Reproduction	10	20	- 20	- 5	20	-	25
Dual-purpose + Muscle	20	20	- 0	20	20	-	
Corriedale Standard	20	0	20	20	20	0	20
Corriedale + Growth	23	27	0	10	20	0	20
Coopworth	18	25	- 1	5	16	-	35
Border Leicester	15	25	- 3	6	16	-	35
Terminal Sire ~ 60:20:20		60	- 20	20			
Terminal Sire ~ 80:10:10		80	- 10	10			

N.B.: absolute values across a row sum to 100; where a – sign is included this indicates direction of selection.

Dissemination of improved material

See material on chapter "Sectors of the breeds involved and dissemination".

The population breeding structure

The lamb industry has a clear division between breeding flocks (studs, or the nucleus) and commercial production flocks.

There is little formal structure within the breeding sector, although LAMBPLAN has worked with a number of groups that are now becoming the elite nuclei (dispersed) within their respective breeds (or composites).

A small number of nucleus or group breeding schemes have existed from time to time, with initial screening usually relatively unplanned and inaccurate genetically.

Since the move to across-flock evaluations, newer moves are being made to establish genetically elite nucleus operations, both within pure-bred and new composite populations. Technically these are very advanced, but it remains to be seen whether these operations will have the business skills to develop and win significant market share.

Farmer and government involvement

Financial support

The following tables outline investment levels by source into LAMBPLAN over the period 1998-1997, and 1998-2002. Note that all values are in Aus$ million.

Table 3. Return on Investment in LAMBPLAN (Aus$ million) 1988–1997.

Expenditure (-) and benefits (+) in Aus$ million over 1988-1997	Breeders	Levy payers	Gov't. Direct	Processors and retailers	Totals
Genetics R&D		-1.1	-1.1		-2.2
LAMBPLAN delivery	-1.6	-0.9	-0.9		-3.4
Breeder cost / return	+11.6	-11.6			
Producer cost / return		+13.3		-13.3	
Cost / return to others				+48.0	+48.0
Net Benefits	+10.0	-0.3	-2.00	+34.7	+42.4
% of the Aus$48 m benefit - by sector	+23.6%	-0.1%		+81.8%	=100%
Benefit to cost ratio	6.25 to 1	0.98 to 1		3.6 to 1	7.6 to 1

Table 4. Return on Investment in LAMBPLAN (Aus$ million) 1998-2002.

Expenditure (-) and benefits (+) in Aus$ (million) over 1988-1997	Breeders	Levy payers	Gov't. Direct	Processors and retailers	Totals
Genetics R&D		-1.0	-1.0		-1.9
LAMBPLAN delivery	-0.6	-0.3	-0.3		-1.1
Breeder cost / return	+37.3	-37.3			
Producer cost / return		+73.0		-73.0	
Cost / return to others				+263.4	+263.4
Net Benefits	+36.7	+34.4	-1.3	+190.4	+260.4
% of the Aus$260 m benefit - by sector	+14.1%	+13.2%		+73.1%	=100%
Benefit to cost ratio	61 to 1	1.9 to 1		3.6 to 1	8.8 to 1

R&D Levies: under industry development legislation in Australia, sheep and beef producers pay a small (up to 2 percent of gross value) ad-valorem levy to a farmer-owned corporation (Meat and Livestock Australia (MLA). This corporation invests these funds in R&D, marketing and promotion, training and so on. The R&D funds invested are matched up to specified limits by Commonwealth Government funding. The levy-payers are therefore commercial sheep and beef producers.

Note that it is expected that breeders and the combination of commercial producers and taxpayers will approximately equally share the direct LAMBPLAN costs (management, database, data processing and reporting and direct research) over the next five years. Commercial producers and taxpayers will share the costs of expected general genetics research (new traits, genotype x production system interaction and gene markers) over this period.

Clearly, overall “system performance” over the next five years should be much better than during the first ten. This is due to the joint impact of:

a) the lag time for improvement to flow into the commercial population;
b) considerable increase in rate of genetic gain after the move to across-flock evaluations.

Finally, this analysis highlights two features that are typical of the development of livestock improvement systems:

a) there is a lag period before benefits accrue, which depends on the generation length of the species, the rate of adoption of genetic selection as well as on the rate of gain; and
b) there is an uneven distribution of benefits within livestock supply chains, the majority share accrues to processors, retailers and consumers. The benefit accruing to consumers is in the form of lower real price of food and improved quality and may be considered as the “benefit” that the industry has to deliver to consumers simply to sell anything.

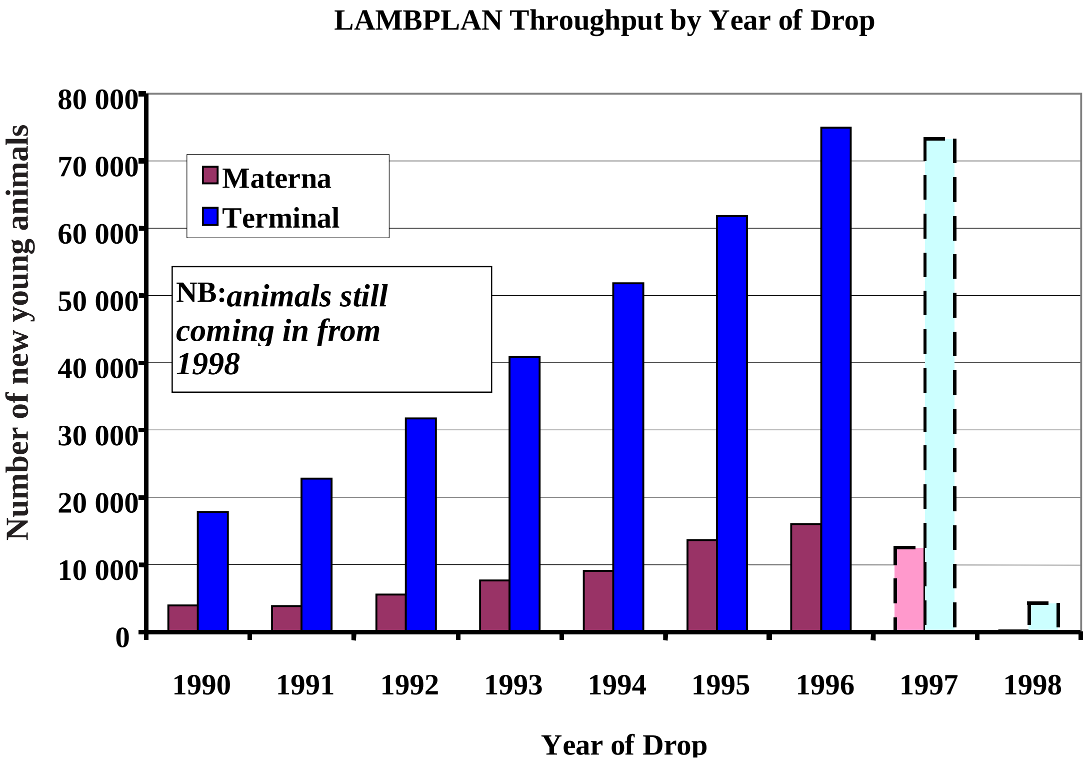
Also, the relative distribution of benefits will vary as the system develops. The fact that the majority share of the benefits of investment in genetic improvement accrues off-farm, means that genetic improvement effectively “buys” market share in the medium- to long-term. Lack of genetic improvement virtually guarantees loss of market share through failure to maintain or increase real price competitiveness and often also through suffering an increasing quality gap with alternative consumer products.

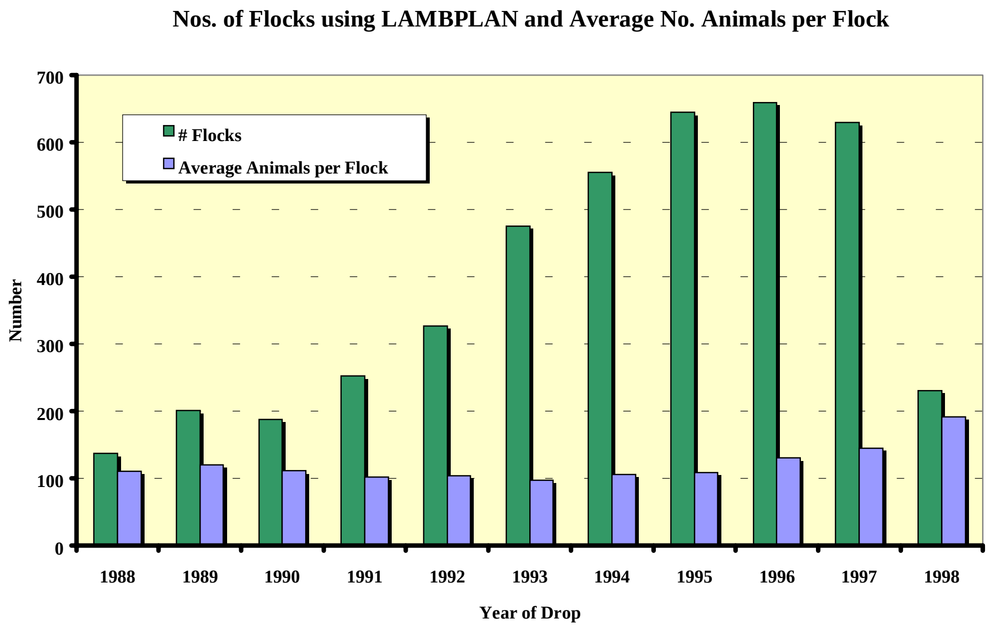
Levels of acceptance of the scheme over time

The following three charts outline growth in numbers of animals being evaluated through LAMBPLAN differentiating terminal sire and dual-purpose / maternal animals, in numbers of flocks using LAMBPLAN and average numbers per flock and total numbers by drop.

Numbers of studs using LAMBPLAN and numbers of animals being tested have grown steadily, and continue to grow, as has average number evaluated per flock.

Note that the total "market" for terminal sire breed animals is approximately 150 000 p.a. and for dual-purpose/maternal is 100 000 animals p.a. Current throughput is approaching 70 percent of all terminal sire breed animals per drop, some 11 percent of crossing breed animals and 85 percent of dual-purpose/maternal.

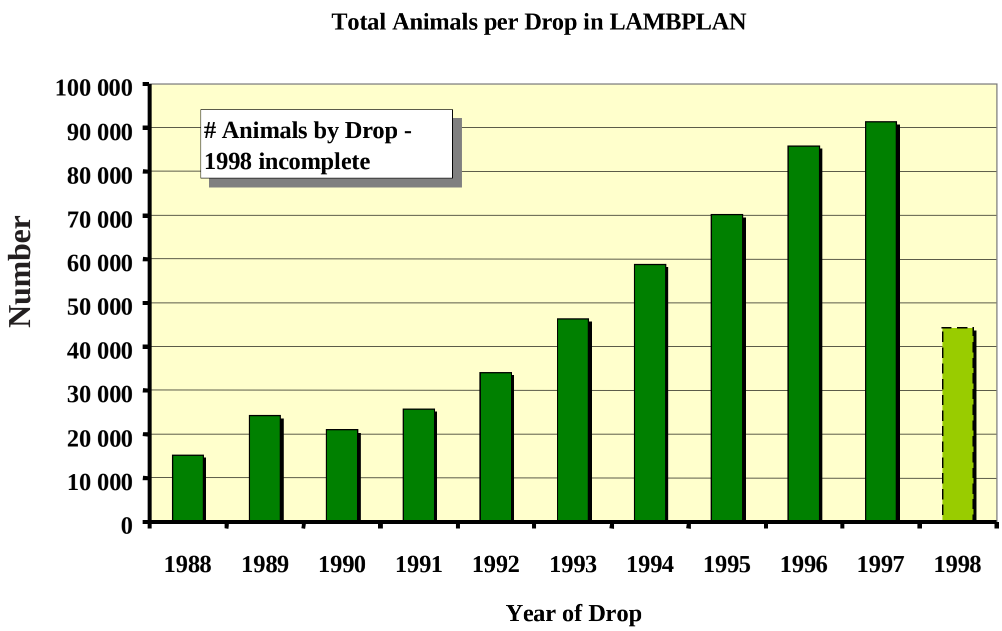




NB: data from the 1998 drop will continue to come into the database for the next ten to twelve months and we expect another small amount of data from the 1997 drop.

These totals do not include Merino data.

Note that the average number of animals per flock is rising steadily, as breeders enter more female animals and a proportion of breeders are increasing their flock sizes.



NB: Data from the 1998 drop will continue to come into the database for the next ten to twelve months

Policy development

No specific policy or legislative issues have been involved in the development of LAMBPLAN, apart from the decision of the Meat Research Corporation to invest R&D levies in the programme and some supporting R&D projects during the period 1986-1999.

Type and nature of technical support

Farmer support

Most farmer support has been very simple extension aimed at highlighting the on-farm value of differences in EBV or Index via terminal sires. Typically these "trials" have involved generating between 100 and 500 lambs sired by High v Low or High v Average sires. Farmers are then involved in collecting data on the lambs, following the lambs through to slaughter and even retail, and evaluating the differences in progeny performance.

Further support has focussed on involving EBV information in sire buying, usually at auction.

More recently, a considerable effort has been made to encourage and assist the development of farmer production and marketing alliances, with some emphasis on ensuring that seedstock sources are appropriate to the production system x target market niche. This extension has involved not only awareness of genetics, but also improved feeding and management, value-based trading and coordinated marketing.

Research and development

Industry has invested in a number of R&D projects designed to enhance and support LAMBPLAN. These are briefly outlined below:

1. Meat Elite: establishment of an elite terminal sire nucleus flock incorporating CT-scanning in measurement protocols. This project achieved a number of outcomes: successfully producing crops of very high merit animals that have had enormous impact on industry, development of genetic parameters for some body composition traits, assisting industry in practical evaluation of nucleus schemes and leading to the establishment of highly successful dispersed nucleus programmes in all major meat breeds in Australia.
2. Maternal Trait Genetic Parameters: a straightforward variance component estimation project focussed on traits relevant to dual-purpose and maternal breeds.
3. Commercial Progeny Expression of Sire EBVs under varying nutrition: progeny testing sires ranging in genetic merit in a number of sex x nutritional regime treatments.
4. Terminal Sire Central Progeny Testing: wide-scale progeny testing of industry terminal sires in a small number of central locations (usually government research stations) with designed linkage between sites and years. Over 400 sires have been tested over nine sire intakes. The programme is now evolving to concentrate on young genetically elite sires with most testing efforts focussed on carcass composition and eating quality traits.
5. Maternal Central Progeny Testing: a smaller scale and more recent version of the Terminal CPT, evaluating sires from a number of breeds largely on the basis of their cross-bred daughter lifetime performance.

6. Structural Trait Genetic Evaluation: now close to completion, this project has been stimulated by the increasing use of AI (and ET), and greater concern about disease risks.

Recently, LAMBPLAN has been involved in developing a number of R&D projects which will focus on detection and utilisation of genetic markers / QTLs / major genes for carcass and meat quality traits. Not all of these will be funded, but there will be major effort in this area during the next five years.

Throughout all these projects, there has been a very strong focus on strengthening links between research and practice and on encouraging wider adoption of measurement, objective selection and cost-effective breeding programme design.

Training

Most training efforts have been limited to maintaining animal assessment and basic advisory skills in the LAMBPLAN Field Operators (accredited fat and muscle scanners), and in general extension to breeders and commercial producers.

What actions were successful?

I think it is fair to say that no activities have been unsuccessful: all have involved evaluation and demonstration of the value of genetic differences in production traits in some way, and all have aimed at promoting wider adoption of recording and use of genetic information.

To date, LAMBPLAN has had the least success in achieving adoption in the Border Leicester breed, which is used as a crossing sire and for which ram prices are essentially unrelated to daughters' lifetime performance. This breed has a very traditional "attitude", but is now facing serious competition from new dam breeds and composites and from genetically improved dual-purpose Merinos. Within the next five years, the breed seems likely to undergo serious decline in ewe numbers. A small dispersed nucleus programme has been established throughout the breed, and there is evidence of satisfactory genetic improvement within the Border Leicester flocks using LAMBPLAN.

In hindsight, I believe greater effort should have been made to introduce across-flock evaluation earlier. This would have required better R&D coordination within Australia and greater expenditure on extension, but there is clear evidence of accelerated genetic gain after the transition from within-flock to across-flock. It is important to stress, however, that the extension challenges arising would have been very much greater, because of the pressure placed on breeders by the existence of across-flock evaluations.

Reasons for introducing the scheme

LAMBPLAN was introduced as part of a relatively well-coordinated approach to turning around the fortunes of the Australian lamb industry.

By the mid- to late-1980s the industry was in serious relative decline, due to rejection of its basic product by consumers (for being too fatty and with insufficient lean meat), and to non-competitive cost-of-production.

The initial focus of LAMBPLAN was on terminal sire breeds, which (in hindsight) provided an opportunity to rapidly address the product appeal problem. As this has been tackled and gradually improved (average carcass weight is now rising by approximately 0.4 kg per year, with a steady decline in carcass fatness at constant weight), attention is shifting to include reducing costs-of-production through improved maternal efficiency.

What are the most significant activities of the scheme?

A prototype of the scheme was developed by the NSW State Department of Agriculture, with very simple, one-on-one, extension and servicing.

This was extended nationally under the aegis of the Meat Research Corporation, beginning in 1988. A small number of key breeders were involved from the start.

During this phase, the involvement and dedication of a very small number of experienced extension personnel was critical to steady adoption and to give a sense of ownership amongst breeders who used the scheme.

Since LAMBPLAN was launched as a national programme in 1989, there has been continuous involvement of a very small number of individuals, scientists, advisers and field technicians. There has been one national coordinator throughout that time. The dedication and patience of these individuals has undoubtedly been critical.

Equally important has been the steady programme of supporting R&D, always focussed on practical, commercial outcomes and wherever possible aiming at very simple messages for breeders and producers.

Increasingly, breeders have taken more and more ownership of the programme, reflected in the fact that as of 1998, LAMBPLAN has been adopted as part of the farmer-owned Meat and Livestock Australia, and breeders have accepted the challenge of meeting full cost-recovery for LAMBPLAN services.

Finally, it is important that LAMBPLAN has been part of a wider industry programme aimed at improving all factors affecting product quality and cost-of-production throughout the value chain: breeders have been continually made aware that all sectors of the industry face the challenge of continuous improvement.

Two areas of technical development are obvious:

- enhancing electronic data capture at all points and increasing web-based reporting;
- providing for some "product differentiation" between clients simply interested in basic genetic information and those pursuing extremely high rates of genetic gain, and / or closer commercial integration with customers / partners through the value chain.

What changes should be made now to the design and operation of the scheme to make it more successful and why?

In addition, LAMBPLAN faces some decisions concerning the optimal skills base of the field technicians and accredited consultants, and the exact nature of their contractual relationship(s) with LAMBPLAN and its clients.

Expanding on this point, it seems almost certain that there will be increasing emphasis on providing more and more advanced training in the skills of animal breeding.

This implies that the future success of the LAMBPLAN business depends on maintaining steady growth in, and effective integration of:

- technical "power", the capacity to understand and utilise genetic variation;
- practical and commercial competence ensuring that breeders, producers and others in the supply chain know how to exploit genetic variation and to manage the businesses that depend on this.

What are the future directions for development in design, operation and policy to expand the success of the scheme over time?

LAMBPLAN is currently considering developments in a number of areas. These will only be implemented if careful assessment and market research suggests that they will add to technical and / or commercial effectiveness and to client satisfaction.

These potential developments include:

- moving to fortnightly (or weekly) complete updates of all evaluations (currently carried out monthly);
- moving to across-breed evaluations initially for terminal sires and then for all breed groups;
- incorporation of procedures for evaluating, reporting and utilising markers, QTLs and major genes;
- delivery of tools for integration of genetic and management decision-making through the value chain;
- direct contracts for genetic information delivery and management through to retail;
- closer involvement in the adoption of advanced reproductive and genetic analysis technologies;
- evolution of the relationship between LAMBPLAN and its clients towards relationships more closely resembling business partnerships;

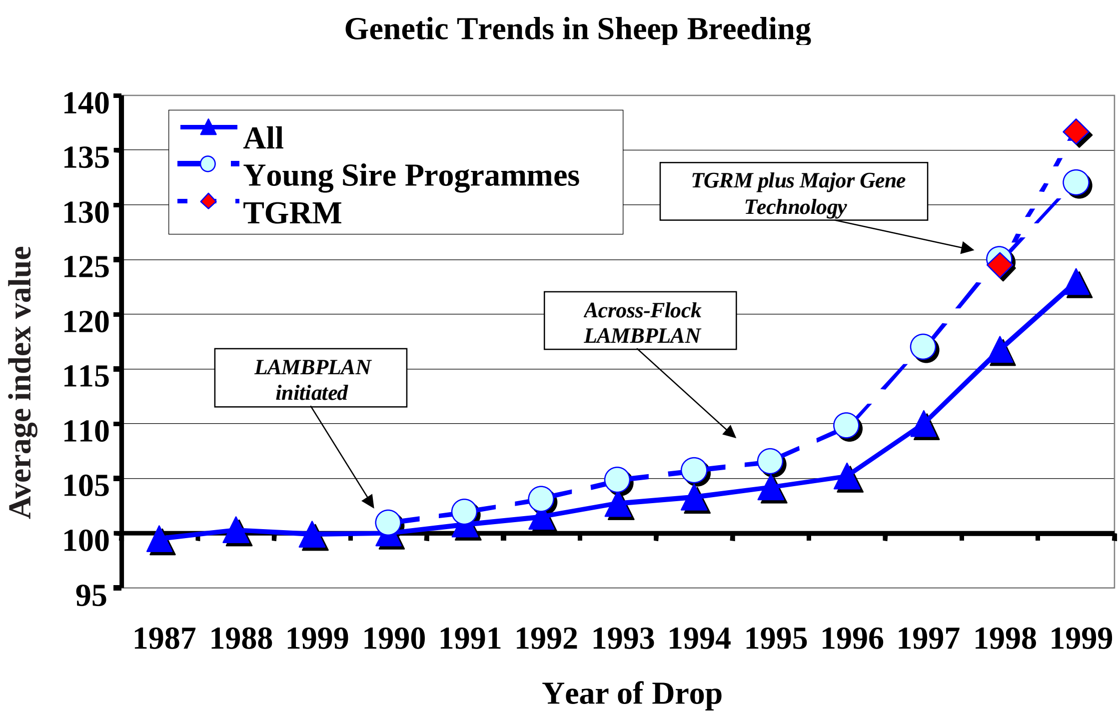
- direct investment in technologies utilising more intensive genetic information.

LAMBPLAN has progressed through a steady development process to this point: this process is summarised in the following table and chart (over page).

Table 4. Phases in the development of the LAMBPLAN system.

Phase	Time Period	Value-adding Processes	Average Rate of Gain (Index Standard Deviations per Year)
Pre-LAMBPLAN	Pre 1988	Very limited data, limited adjustment for fixed effects	0
Sire Model, Within-Year and Flock	1988 -1995	Steady growth in data, better adjustment for fixed effects, use of half-sib information, within-flock and within-year evaluation only	0.13
Animal Model, Across-Flock and Year	1994 -1999	a) Continuing growth in data, improved models, across-flock and across-year evaluation. b) Organized programmes using AI	a) 0.31 b) 0.70
"TGRM plus"	1998	Continuing growth in data and better models, across-breed evaluations, TGRM plus major gene technology plus reproductive technologies	Average approximately 0.50, but full application of breeding programme design tools will achieve >1.5

"TGRM plus": an informal phrase indicating that LAMBPLAN is moving to focus service around the TGRM product, and linking a range of analysis and value-adding components into the overall package of genetic information delivered to clients.



LAMBPLAN is now entering an era where the service provided to clients is in fact management of the entire genetic resource, so that optimal breeding programme design is the core output, but which comprises a series of "information components", such as EBVs, Indexes, and so on.

Available estimates of genetic change in the population due to the scheme

These estimates are presented as genetic trends for the major indexes used in the major breeds using LAMBPLAN. Selection emphasis in these Indexes is summarised in the Table 1.

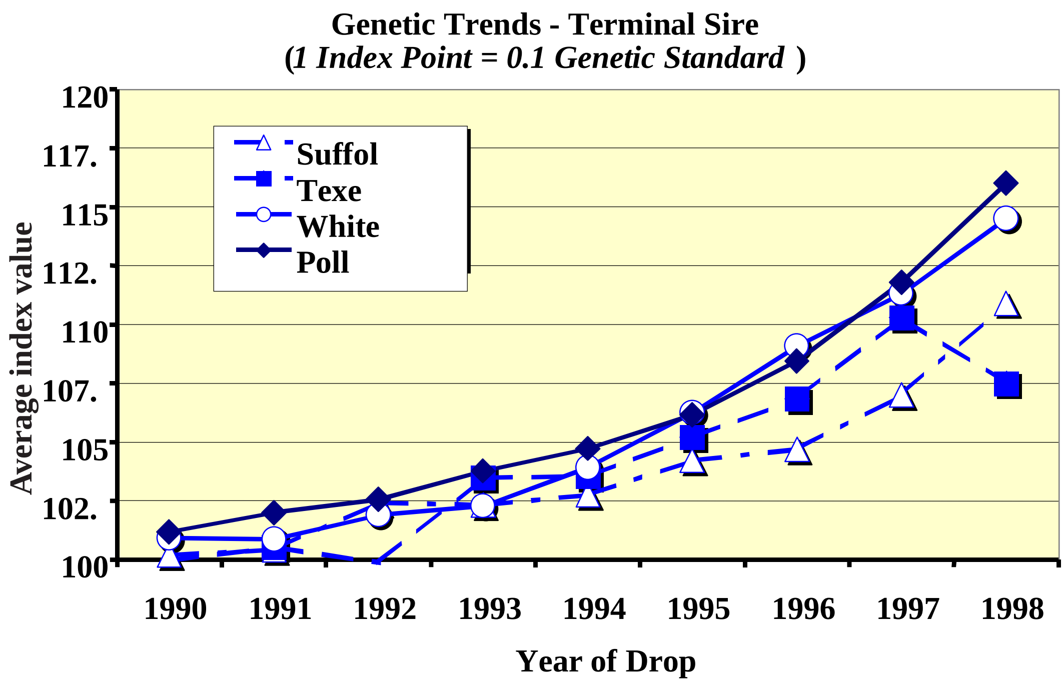
Genetic trends in component traits are available from the author: they are generally in line with predictions from index theory both in amount and relative change, or balance of response. The "balance of response" has become closer to prediction as breeders are made aware of the importance of ensuring that the appropriate data is available to support reliable genetic prediction.

The number of traits included in the indexes seems almost certain to increase as:

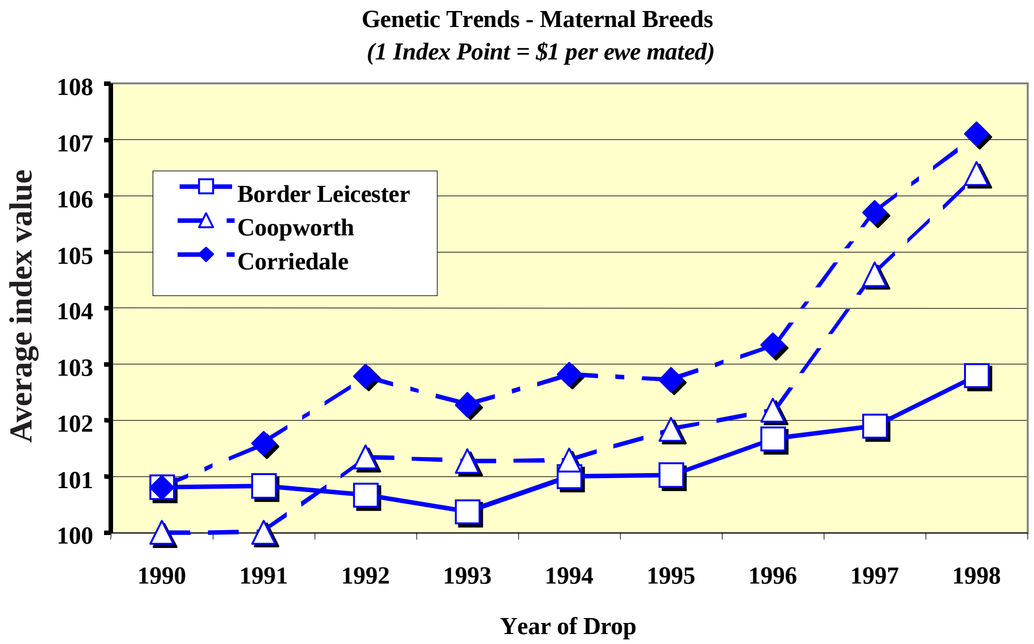
a) producers, processors and retailers become more aware of the impact of genetic differences on profit functions at each stage in the supply chain;

b) breeders (and others) become increasingly aware of the benefits of genetic change (and of the costs of unwanted or unanticipated correlated responses).

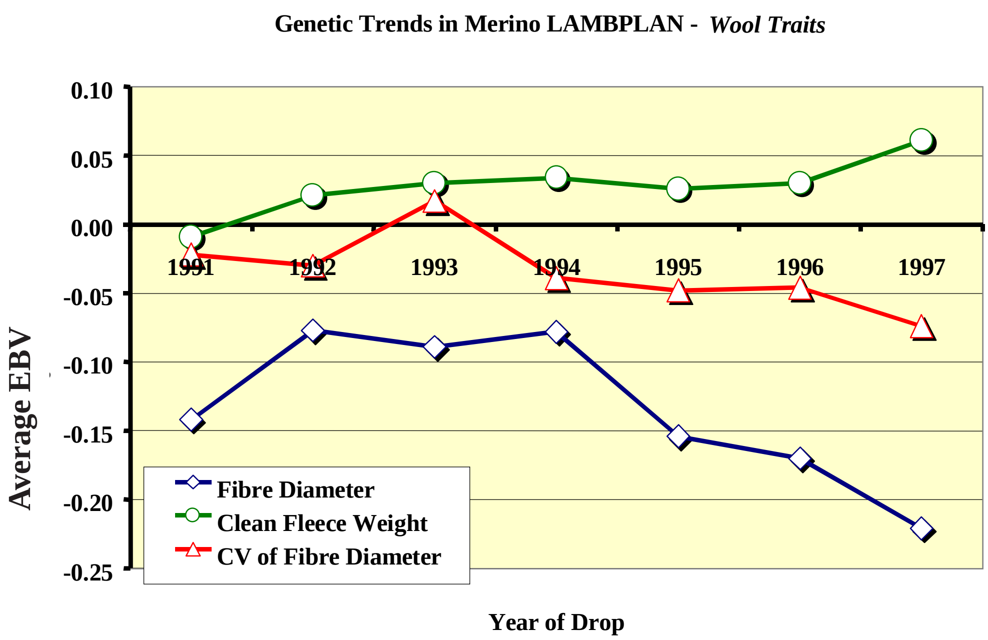
Genetic Trends in Index - Major Terminal Sire Breeds



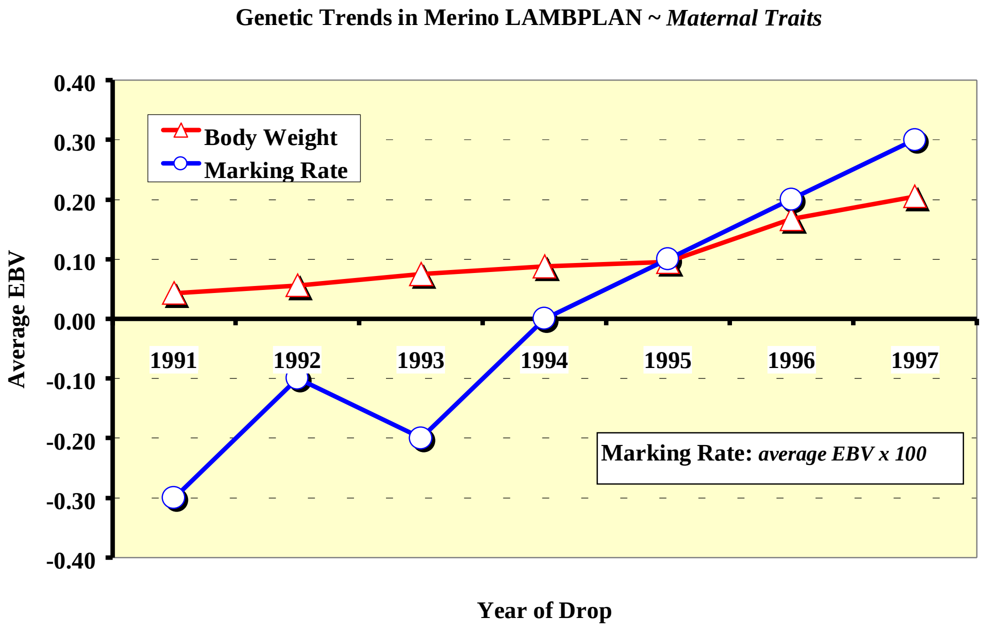
Genetic Trends in Index - Major Dual-Purpose/Maternal Breeds



Genetic Trends in Merinos using LAMBPLAN - major wool traits



Genetic trends in Merinos using LAMBPLAN - maternal traits



The breeding programme for the Angora goat in Australia

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The principal product of the Angora goat is mohair which is a long, lustrous speciality fibre. The fibre is white with a mean diameter of about 25μm for kids and 30-36μm for commercial adult grades. The fibres grow continuously and the coat from superior Angoras is mostly free of medullation and kemp (Wildman, 1954).

The goat resource in Australia

Angora goats originated in Turkey and were introduced to South Africa in 1838, USA in 1849 and Australia in 1853. The first European settlers brought dairy goats to Australia in 1778 and importations continued thereafter. In 1853 acclimatisation societies and pastoralists (farmers) imported Angora and Cashmere goats so that by the late 1880s there were a few Angora flocks of several thousand animals. However, severe drought over many years led to these animals being released (or escaped) into public lands where they joined many other escaped dairy goats to form what is now known as the Australian feral goat.

Today the feral goat is essentially a low-milking dairy goat type with an undercoat of down (Holst, 1981). In 1950 only one recognised Angora flock existed in Southern Australia. By 1975 the genetic resource was about 2 500 Angoras and perhaps 1 million non-domesticated feral goats.

Lessons

Early attempts to develop a mohair industry failed because:
- there was no source of quality genetic material;
- breeding aims were not defined;
- there was no industry organization;
- poor nutrition (especially droughts);
- shepherding/fencing was inadequate.

Breeding programm. Stage 1. (1970-1984)

In the 1970s sheep farming in Australia was a large industry suffering a wool price collapse and it was natural that several farmers sought to diversify by including mohair production. Their small ruminant management skills were good, they understood animal fibre and they had shearing (fibre clipping) facilities. Fencing was adequate. Individual identification of goats was by eartags with, in bucks, ear tattoos (Holst, 1998).

There was a comprehensive Government infrastructure (research, advisory services and veterinary) servicing the sheep industry (mostly at no cost to farmers) and specialised laboratories for wool fibre measurement (fee charged). In 1971, an Angora / mohair industry association was established together with a research committee; the latter due to the efforts of a single enthusiastic luxury-fibre entrepreneur. Funding was limited.

At this time there was an assumption, that range (or pastoral country) and browse was good for Angora goats and mohair production. This was based on the Edward's Plateau in the USA and range in South Africa. Unfortunately, the rainfall variability and quality of range in Australia is not comparable to either of these countries.

With this background the first planned mohair industry in Australia was initiated. It consisted of a small number of studs established to produce sires for a larger number of commercial mohair producers who would use cross-breeding to generate larger flocks (Table 1).

Table 1. Description of the breeding aims for Stage 1 of the Angora/mohair industry.

Section	Breeding aim	Breeding objective	Selection criteria	Breeding plan
Commercial mohair producers*	Profit through diversificati on	Fleece weight Fibre diameter	Visual / greasy fleece weight Visual	Cross-breeding (Angora x feral)
Breeders of Angora goats **	Profit through breeding sires	Fleece weight Fibre diameter Style Kemp	Visual / greasy fleece weight Visual / limited lab Visual Visual	Straight-breeding from existing Angoras

* Located in range and agricultural areas.
** Located in agricultural areas only.

Breeding aims

Overseas estimates of heritability for economically important traits were moderate (Table 2). However, estimates of phenotypic and genetic correlations were scarce and there were no genetic parameter estimates for Australian Angora goats.

The setting of breeding objectives was influenced by overseas experience which was based on the relative economic value of each trait affecting their mohair quality and quantity. In most cases commercial mohair producers simply want to produce large quantities of the most profitable fibre and it is assumed that the price signals they receive are reliable. In Australia, at that time, mohair was sold in bales on description and not on measured data and Clark (1990) described differences in the relative values for quality attributes between buyers and processors. Since cross-breeding was the major activity, the breeding objectives were fleece weight and fibre diameter.

The cross-breeding programme (Table 3) for the commercial producers of mohair was a slow process. While fifth generation animals could be considered pure-bred they retained an unacceptable level of medullated fibre and kemp (Patel, 1982; Shelton, 1986). Indeed the reduction of percent kemp fibre in the flock was a practical problem at that time. Kemp was expensive to measure in the laboratory, the sampling site was poorly defined and it was thought to have a low heritability. Yet Texan and African breeders had successfully reduced it to negligible amounts.

Table 2. Estimates of the heritabilities of some selection traits for Australian and overseas Angora goats before and after 1972 (from RA Clark, 1990).

Trait	Country	Heritability	Reference
Greasy fleece weight	Turkey	0.26 - 0.15	1
	USA	0.40	2
	USA	0.13 - 0.83	5
	Australia	0.42 - 0.45	6
Fibre diameter	USA	0.12	2
	Turkey	0.19	4
	USA	0.11 - 0.24	5
	Australia	0.08 - 0.14	6
Kemp score	USA	0.43	2
	USA	0.05 - 0.19	5
	Australia	0.36 - 0.42	6
Medullation	Australia	0.0 - 0.39	6

References 1.Sincer (1963); 2. Shelton and Bassett (1970); 3. Yalcin (1972); 4. Yalcin *et al.* (1979); 5. Shelton and Snowder (1983); 6. Gifford *et al.* (1991).

Conduct

The industry association provided a focus for farmers in the Angora industry and to those who may be interested in joining. It conducted rural livestock competitions, provided a register for breeding stock and generally provided education material, either written or through group meetings. It had a national responsibility and was the spokesperson on issues concerning the mohair industry.

Initially the mohair was sold to independent buyers for domestic and export (mostly UK) markets. Members of the association quickly realised that prices could be improved if the individual farm lots were classed and pooled. This also provided another educational opportunity.

Table 3. The cross-breeding programme as used by commercial mohair producers.

Generation	Breed of doe	Breed of buck	Breed of progeny
1	unregistered feral B	angora A	½ A ½ B
2	½ A ½ B	A	¾ A ¼ B
3	¾ A ¼ B	A	$^{7}/_{8}$ A $^{1}/_{8}$ B
4	$^{7}/_{8}$ A $^{1}/_{8}$ B	A	$^{15}/_{16}$ A $^{1}/_{16}$ B
5*	$^{15}/_{16}$ A $^{1}/_{16}$ B	A	$^{31}/_{32}$ A $^{1}/_{32}$ B

* does mated < 12 months of age – nine years from 100 feral does to 100 angora does.

Role of the Government and related agencies

The services provided by the Government and related agencies to the new mohair industry were invaluable and essential to its development. They included research on genetics, products, management, fibre measurement and diagnostic techniques for disease; changes to legislation and facilitating the registration of chemicals for goats. Education of farmers and the service industry was a major activity.

Outcome of the first breeding Programme

In describing the results, Stapleton (1985) and Gifford et al. (1985) indicated that Australian mohair had a yield of about 91 percent, mean fibre diameter ranging from 24µm at the first shearing, 26µm at the second, 30µm at the third and fourth shearing and 33µm in later fleeces. This differs little from the limited data published between 1975-1977 (Evans, 1980). Kemp was two percent down from three to five percent in 1978, but still unacceptably high. Indicative clean fleece weight at the third shearing was 1.12 kg (six months fleece).

In 1985 mohair fibre production would not have been profitable for farmers.

Lessons

Several problems were identified and lessons learned:

- the range environment was not suitable because of variable nutrition, kid predation, vegetable matter fibre contamination;
- animal production was inferior to that reported overseas, with the assumption that genetic material was inferior;
- marketing - demand for fibre and returns were variable between years - kemp and gare were a significant deterrent to buyers.

Breeding programme. Stage 2. (1984-...)

A depressed mohair market and the realisation by breeders (angora goat numbers dropped from 275 000 to 150 000) that Australian mohair had unacceptable levels of kemp and gave low fleece weights, relative to that available from the main producing countries of South Africa and USA, led to a demand to import genetic material.

In 1984 local breeders purchased several Texan goats, rather than South African, believing that the disease risk would be lower. Australia's strict protocol (National Government) to ensure that such importations were free of scrapie disease meant that the imported goats were bred in quarantine for over seven years. This resulted in over 1 000 animals being available to the industry in 1992 and available to research prior to that event (Table 4).

A performance recording Programme for Texan goats in quarantine (Lollback, 1995) demonstrated that Texan goats had:

- greasy fleece weights almost double that of selected Australian Angoras and clean fleece weights at least 50 percent higher;
- very low (< 1 percent) incidence of kemp;
- considerable variation in performance between the imported animals.

Table 4. Description of the breeding aims for Stage 2 of the Angora/mohair industry.

Section	Breeding aim	Breeding objective	Selection criteria	Breeding plan
Commercial	Profit through diversification	Fleece weight Fibre diameter Kemp	Visual/greasy weight Visual Visual	Purchase superior bucks, heavy culling of progeny
Breeders	Profit through breeding sires	Fleece weight Fibre diameter Kemp, gare Style	Greasy wt./clean on selected Visual/some laboratory Visual/some laboratory Visual	Use selected imports on large proportion of does. Use MOPLAN

Such was the acceptance and demand for imported genetics that it was estimated that 50 percent of the local Angora does were bred to Texan bucks in 1992, the first year of their release.

Two years after the Texan purchase, Angora embryos from South Africa were imported into New Zealand quarantine. In 1999 a further importation of South African Angoras was made available to local breeders.

Nongenetic gains

After 25 years of Angora breeding there were demonstrable improvements in the goat fibre industry. These included an improved level of technical knowledge by farmers, improved metrological services, an increased variety of marketing options, the breeding and rearing of Angora goats in more suitable environments and increased acceptance of goat production by the other livestock sectors.

Relative to sheep and wool production, the level of input by commercial mohair producers was medium whereas the Angora breeding sector maintained a high level of input. Breeders were technically well informed and possessed skills and services derived from the traditional sheep industry.

All breeders were members of an industry association and received regular information by newsletter and by attending shows and conferences. Government livestock advisers and researchers were active and made an important contribution to knowledge and confidence.

Not surprisingly, when the mohair market signalled low prices for the Australian product, it was the breeders who initiated and invested in the importation of genetic material and set the breeding objectives for Stage 2.

Genetic gains

Stapleton (1985) outlined the requirements and need for a performance recording service and central register for Australian Angora goats. However, this was largely ignored in the industry until the importation of Texan goats. MOPLAN, the performance recording and genetic evaluation service, was developed to collect production data on the imported goats and their progeny, whilst they were in quarantine. It involved a standard system of data collection and the genetic evaluation of economically important traits. It was a collaboration between owners, the Departments of Agriculture, the Animal Business Research Institute, Armidale (data register and genetic evaluation) with funding from the Government and the mohair industry. MOPLAN uses BLUP technology to enable it to use information from relatives in calculating Estimated Breeding Values and index values for performance based on the first two shearings (Table 5). However, the index values may be limited in that an animals' lifetime performance is difficult to predict and the base population is not homogenous (Stapleton 1997).

Table 5. Example of index values and returns for Texan cross goats (Stapleton 1995,96).

% Texan	MOPLAN index	Fleece weight (mean 5 fleeces)	Fleece relative value
0 Aust	97.9	1.63	100
37	96.8	1.99	119
50	99.3	2.32	135
75	105.0	2.44	155
87	106.3	2.62	165
100 Texan	108.5	2.84	174

Lessons

With practical breeding objectives and quality genetic material it is possible to breed a robust animal producing quality fibre. However, difficulties remain:

- Poor domestic markets (tradition) for meat and skins results in low values;
- Predation (usually fox *Vulpes vulpes* and bird) affects kid survival figures;
- Mohair values fluctuate regardless of fibre quality but in periods of low world demand, kempy mohair is overlooked;
- MOPLAN has not been widely adopted because there is no clear incentive at this time to change from subjective assessment and limited objective measurement. Breeders are experiencing a low demand for high merit bucks and incur additional costs associated with fibre metrology and central register services;
- In Australia, goats are still socially not acceptable to the average sheep and cattle farmer. An estimate of the current number of Angora goats is 60 000. Nevertheless, there is an anticipated medium term demand for non-fibre meat goats for the maintenance of range and pasture (weed control).

The future

Producers agree that the Texan and South African genetic material has contributed significantly to the Australian Angora / mohair industry. Qualitative evaluation of the impact will take some years but the outcome appears to be a more robust Angora producing a quality fibre. The unstable profitability and social non-acceptance of goats (diminishing) continues to hinder the size of the Australian industry.

Summary

1. The principle product of an Angora goat is mohair fibre. It must aim to produce high quality fibre to obtain premium prices and to avoid zero demand for inferior products in many years.

2. Central to fibre quality is the genetic resource and the environment.

3. It is possible to upgrade a large resident goat population by cross-breeding with high merit Angora bucks, though it is slow.

4. Regional breeding success depends on education (animal management, fibre), services (education, metrology, marketing, breeding, performance recording) and prices (reflects world supply).

5. Access to superior Angora bucks, at an acceptable cost, is essential. Role for stud breeder, Government agencies, etc.

6. Production and marketing of quality mohair fibre is not possible under a ‘laissez faire’ system. Some degree of centralisation is warranted for education, breeding progress and marketing.

7. Breeding plans, such as MOPLAN, need a significant economic incentive before they are adopted yet the outcome (superior animals) is accepted.

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Sustainability of dairy cattle breeding systems utilising artificial insemination in less developed countries - examples of problems and prospects

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Introduction

In the last two decades total milk production has almost doubled while the heads of cattle have increased by 28 percent in developing countries (FAO, 1999). There is a large variation among regions. The Far East region shows the sharpest production increase, also per capita, while Africa and the Near East show the largest increase in heads of cattle but a continuous decrease in per capita supply of milk. Thus, improved milk production is very important in many of the lesser-developed countries.

The substantially improved yields are due to increased cattle numbers but also improved management and genetic potential of the cattle. In many tropical and subtropical areas the introduction of exotic breeds such as Friesian, Jersey, Guernsey, Ayrshire and Brown Swiss by the use of artificial insemination (AI), mainly through cross-breeding and in certain areas with less climatic stress and good management also as pure-breeds, has led to increased production. However, it is a well-known fact that the initially very promising results obtained in the F_1-generation through cross-breeding in the tropics are usually not as good in the next few generations if one continues to cross with an exotic breed. Thus, long-term breeding strategies are important for sustainable and continuous improvement of production and cattle populations, be it indigenous, exotic or cross-bred cattle.

Strategies and possibilities of successfully conserving indigenous cattle breeds have been examined by FAO and continuous improvement of the indigenous breeds has been stressed as a necessity for future survival as commercial breeds (FAO, 1992).

The purpose of the present paper is to review some cases as examples of breeding programmes utilising AI in developing countries and summarise principally important problems and prospects for sustainable breeding systems.

Cases

Four different cases are reviewed. Two represent indigenous breeds considered to be of relatively high genetic potential and two exemplify the utilisation of exotic dairy breeds in tropical or subtropical conditions.

The Sahiwal breed in Pakistan and Kenya

The Sahiwal breed originated in the central and southern parts of Punjab, Pakistan, which is characterised by a subtropical and arid climate. The dominating position as cattle breed in this area throughout the last century started to change with changed production systems in agriculture and was further accelerated by the introduction of AI and cross-breeding with temperate dairy breeds. Crosses with Sahiwal have been extremely successful in the prevailing conditions and have been much more in demand by farmers than the pure-breed. While the average lactation yield is commonly reported to be 1 500-2 000 kg for the pure-bred Sahiwal, crosses with Holsteins produce 2 500-3 000 kg (Khan *et al.*, 1989).

The rapid decline in the pure Sahiwal breed, mainly due to indiscriminate cross-breeding has led to an estimated total number of about 10 000 cows in Pakistan (Hodges, 1987), out of which 2 000 breeding females can be found in recorded Government herds, the majority found in only three herds. Another 2 000 cows are estimated to be kept in India and 2 500 in Kenya. The latter originate from imports starting in 1939 from India and later from Pakistan. Very little exchange of genetic material has taken place between the different countries in the last three to four decades. AI is used to some extent in all three countries to maintain the pure Sahiwals. A thoroughly designed breeding programme has been applied for a long time for the Kenyan population in Naivasha, while progeny testing programmes were launched already 20 years ago in both Pakistan and India.

Besides a relatively high potential for milk production in harsh conditions, the Sahiwals today are characterised by rather few milk let-down problems and good beef characteristics. These traits have led to an international demand for semen and Sahiwal-crosses in tropical and subtropical countries. Several synthetic breeds have also evolved from the use of Sahiwal in crosses with *Bos taurus*, for example, Jamaica Hope, Karan Swiss (India) and AMZ and AFS (both Australia).

Results from retrospective analyses of the Sahiwals in Pakistan were reported by Dahlin (1998) as follows:

- most Sahiwal herds had been kept rather closed and inbreeding co-efficients were, on average 5 percent, in some farms even more than 10 percent. The effective population size was estimated at about 30 animals only in recorded herds;
- average milk yield was 1 400-1 650 kg in lactations one to three with a C.V. of 43-45 percent. A large phenotypic variation over the years was observed;
- estimates of heritability for milk yield were 0.14-0.20 with as large an additive genetic variation (C.V.) as 12-16 percent;
- estimated genetic trend was close to zero and many bulls with large progeny groups had negative breeding values indicating the application of inadequate selection criteria.

Some main results from genetic studies of the well-known Sahiwal herd at Naivasha, Kenya, covering a 20-year period (1964-83), were reported by Wakhungu *et al*. (1991) as follows:

- average lactation milk yield was 1 662 kg with a C.V. of 34 percent;
- differences in average production within the herd amounted to more than 500 kg between years;
- heritability for milk yield was estimated to 0.27 but an annual genetic trend of only +3.65 kg revealed inefficient breeding value estimations and / or selection procedures.

Problems

1. As a result of indiscriminate cross-breeding by inseminating Sahiwal females with exotic breeds in Pakistan, the main problem of the breed is its small and declining population size. The lack of gene flow between countries, as well as between the nucleus herds, contributed to a rather high degree of inbreeding.

2. AI has mainly been used for cross-breeding but not as efficiently to develop the breed itself. Fluctuating environmental conditions call for more efficient methods for genetic evaluations and selection.

3. Despite the fact that AI has also been applied to Sahiwal bulls, the international demand for semen has not been met.

Prospects

Due to its high potential in harsh conditions, the Sahiwal breed was soon pointed out by FAO to be given high priority for conservation by management, in order to develop the breed for further global use. Important pre-conditions are that all countries seem to practice good recording routines as a basis for genetic evaluations and selection. Also the necessary infrastructure and some competence among people to conduct a breeding programme seem to exist. Thus, a conservation scheme could follow the normal procedure of developing a breeding programme. However, in this case the cooperation between countries, both for exchange of germ plasm and for future joint genetic evaluations, needs to be developed.

Successful cooperation between countries, in order to make efficient use of the few Sahiwals available in breeding herds, is essential for the survival of the breed. This includes the effective use of AI and a BLUP-Animal Model for genetic evaluations, in order to account for the large environmental effects, as well as optimum use of all information. Such a development would greatly enhance the possibilities for efficient selection of bulls for pure-breeding, as well as for production of cross-breds to the benefit of much larger tropical areas of the world than is presently the case.

2. The Kenana-case of Sudan

The Kenana breed is a true Zebu of Sudan with the main habitat in the hot, arid zones of the central parts of Sudan, south of Khartoum between the Blue and White Niles. In an FAO study, the total population was estimated at about 3 million (Cunningham, 1987). The production systems range from pure nomadic to more settled systems for milk production in urban areas.

The Kenana breed has the reputation of being one of the most productive indigenous African milk breeds. While field data are hardly to be found, lactation records from experimental stations on average show yields of about 1 500 kg (Wilson *et al.*, 1987; Ageeb & Hillers, 1991). Mature cows weigh around 400 kg.

Since AI was introduced on a larger scale in Sudan in 1976, only imported semen of the Holstein breed was made available to the farmers during a ten year period. Progressive farmers joined the AI-scheme and were happy to note a considerable increase in production from their F_1-animals, which seemed to function well in the prevailing environmental conditions.

Problems

Results from experimental stations have shown, as could be expected, that ¾ and 7/8 Holstein crosses did not keep up with the F_1 animals, but had problems with resistance to diseases and suffered from environmental stress. However, the AI-scheme did not for some time offer any long-term breeding strategy but just crossing with imported semen. Progressive farmers had no alternative and would gradually experience poorer results if staying with the original AI-scheme.

The development of more intensive settled production systems near the urban areas of Sudan, results from a great need to improve the food supply. Such a demand called for the use of exotic breeds in cross-breeding with the Kenana. However, the lack of a long-term strategy for cross-breeding became a threat to the breed. As a result of such a situation, neither the pure-breeding nor the cross-breeding programme would be sustainable.

Prospects

The FAO-study referred to (Cunningham, 1987) considered the high potential of the Kenana breed and its crosses for milk production in rather stressful environmental conditions and in an area with a large human population. Thus, the pure Kenana breed needed to be conserved by management.

In order to establish a sustainable system, an open nucleus breeding programme was suggested to be run at one of the experimental stations with about 200 pure-bred cows. About ten percent of the cows should be recruited annually among good females in village herds. The aim would be to further develop the genetic potential for milk production including good fertility of the pure-breed. Thereby, high quality bulls of the pure-bred, as well as cross-bred bulls, could be guaranteed available for both AI and natural service.

As a result of local semen production, cross-bred bulls were introduced in 1986 and also from 1990 locally bred bulls of the exotic Holstein and Jersey breeds and from the indigenous Kenana and Butana breeds (Mohammed Osman Hamid, 1999).

By establishing a nucleus herd for the Kenana breed as the basis for the conservation plan at an experimental station, and another one for cross-bred animals, a sufficient infrastructure and personal competence to conduct a sustainable breeding programme could be guaranteed. This has resulted in a semen production system supporting both a long-term conservation policy and the needs of the farmers to have commercially viable and well adapted cattle.

3. The West Indies-case of exotic breeds

This case concerns a small Caribbean island which is one of the most heavily populated in the world. Agriculture is dominated by its sugar industry. Dairy and beef products are in shortage and it is a Government policy to diversify the agricultural sector, for example, by more animal production.

The stress to animals of the tropical environment is to some extent alleviated by the maritime climate. However, tick-born diseases are common and require appropriate management controls.

The population of 3 500 head of dairy cows is dominated by exotic breeds, mainly Holstein (70 percent), Jersey and Guernsey. A Governmental AI service is available with domestic semen production from a few bulls of the breeds mentioned. The Government questioned whether it would be possible to continue with the pure exotic breeds due to the disease situation and climatic stress or if an introduction of Zebu crosses would be necessary. A shortage of females for herd replacements had been noted and was assumed to be due to poor reproduction as a result of heat stress and lack of resistance to diseases.

Survey of status and problems

The need to improve production, totally and per cow, led to a survey on production and reproduction results with analyses of records made available from individual farms (Philipsson, 1981). Some important findings were:

- exotic breeds were producing rather well (Holsteins: 3 500 kg; Jersey and Guernsey: 3 000 kg per lactation);
- calving intervals were 15 months and reproduction problems occurred due to tick-born diseases and an unreliable AI-service without appropriate supervision;
- officially reported non-return statistics indicated high fertility, but this was explained by the use of village bulls when AI failed;
- low turn-over rate of AI-bulls causing inbreeding in the commercial herds;
- the farmers had no influence on the quality and kind of AI service offered to them.

Prospects

This case clearly demonstrated fairly good production of exotic breeds, but also the need to apply reasonable management tools for tick control, rather than bringing in Zebu-genes for increased resistance to diseases and climatic stress.

Also the shape-up of a mismanaged AI-scheme, both technically and genetically, could improve reproduction results, without the use of a sophisticated ET-programme, which was offered by a donor country envisaged to alleviate some shortage of replacement heifers.

If farmers were given more responsibility for the services requested, these activities would be more efficiently carried out provided Government policies changed and training was offered to farmers and those working with the AI-service. Importation of semen would be less costly than the domestic semen production as exotic breeds seem to be suitable for this environment.

The Kenya-case of a modern AI breeding programme

The climate of the central parts of Kenya allows a rather advanced milk production system, even with pure exotic breeds such as Friesian, Ayrshire, Guernsey and Jersey, when a reasonable management standard is kept. Milk-recording and AI-schemes were applied early in Kenya as a means of continuously improving production. For example the average production of recorded Friesian herds amounts to 3 500 kg milk (Rege, 1991a), while some reach an annual production per cow of 5 000-6 000 kg.

After the country's independence in the mid sixties, the number of small-scale producers increased tremendously and so did the demand for semen. The cow population largely became a product of up-grading the indigenous Zebu cattle, using semen of exotic dairy breeds. The demand for semen was initially covered by bulls being imported from various countries. The AI service expanded to as much as about 0.5 million inseminations per year in the early seventies. Due to high costs of bull and semen importation and the possibilities of a genotype x environment interaction, the domestic recruitment of bulls was started. A specially designed progeny testing programme (PTP) was launched in 1969 followed by a contract mating scheme (CMS), in order to use imported semen of top bulls with superior local dams and bring the sons produced into the AI-stud. The whole AI-scheme was initially set up by experts from a number of donor countries, which further supported it while it was run by the Kenyans as a Government service to the farmers.

The overall effect has been tremendous as regards increased milk production from large as well as small-scale producers. The increased production by up-graded cows was, for example, a key to the school lunches with milk offered in Nairobi. The *planned* breeding programme was indeed as advanced as in any developed country. Thus, the same infrastructure, equipment, competence of staff and other resources was assumed to be available. However, in reality that was not the situation.

Problems

An analysis of 20 years of experience and results of the AI and breeding scheme in Kenya was performed by Philipsson *et al*. (1989) and has been further analysed in some detail by Rege (1991a and b). Some main findings were:

1. The different parts of the breeding programme (AI and milk-recording) were managed by different ministry departments and were totally disintegrated. They lacked the organization with farmer influence and leadership needed, in order to comply with the objectives outlined for the breeding programme.

2. The participation rate of milk-recording gradually declined due to lack of feedback information to the farmers. The PTP- and the CMS-schemes were severely affected, thus resulting in continuously fewer bulls being recruited for AI. The age structure of the AI bulls became unfavourable and semen production decreased, so that the demands could not be met.

3. Progeny test results obtained with a herd-mate-comparison method (HMC), were usually not available until after the death of the bulls.

4. Genetic studies revealed good genetic progress during the first ten years and a decline thereafter. The HMC-results were poorly correlated with later produced BLUP-values of the bulls (Rege, 1991b).

5. Breeding goals and selection practices were too influenced by international standards favouring big cows and of conservative breed societies judging cows at shows, rather than the limitations of the Kenyan markets and environments. Thus, unrealistic requirements of possible bull dams kept the recruitment of young bulls low.

6. The field service was too dependent on the effective transportation of AI technicians. As a Government service it did not function properly.

As a whole the programme was too sophisticated at the available level of infrastructure and competence to run the scheme. The split responsibilities of AI (Veterinary Department of the Ministry), recording (Animal Production Division) and herd books (farmer organizations) was detrimental to the understanding and implementation of a fully integrated breeding programme.

Prospects

Although the very ambitious breeding plan collapsed, no doubt the AI service as such, offering bulls of various breeds to large- as well as small-scale farmers, proved its value in a process of up-grading local cattle for better production and to maintain pure exotic breeds in areas with a good environment.

The future existence of the AI field service relies on the possibilities of privatising it into farmer cooperatives. Such a move started in 1990. Similar privatisation seems also to be a necessity for the AI-stud, which needs to integrate its selection schemes with recording and evaluation of the animals.

As regards the selection scheme, a much simpler approach should be taken with just a young bull programme, based on imported bull sire semen used with superior local cows, but without a complicated and demanding progeny testing scheme. Such a programme could be gradually developed as the level of infrastructure and competence to run the programme increases.

General findings affecting the sustainability of breeding programmes

The problems being mentioned from these four examples are of a very broad nature. However, some experiences are commonly noted and therefore seem to be of strategic importance. The problems found could rather easily be divided into matters regarding:

- Breeding objectives and utilisation of genetic resources;
- Methodological, technical and operational issues;
- Policy and organizational aspects.

These areas are all equally important, if one really aims at developing the genetic resources available. In analysing real life cases, as those above, it could first of all be noted that the breeding programmes applied have seldom emerged from a well thought of theoretical plan, except for the Kenya-case, but were merely the result of implementing new technologies, for example, AI, without much of a long-term strategy.

Breeding objectives and utilisation of genetic resources

Commonly faced problems regarding *utilisation of genetic resources* concern the neglect of the value of many indigenous breeds and the necessity to conserve and develop them. The real threat to such breeds comes when cross-breeding through AI with exotic breeds shows such good results in the short-term that most producers want to benefit from cross-breeding and nobody takes the responsibility for the pure indigenous breed and its future development.

The need to apply long-term strategies in cross-breeding programmes is apparent. Too often what happens in the long run with both the pure-breed and the cross-breds in second and third generations is neglected. The *choice of breeds* and *definition of breeding goals* are matters that need serious consideration in relation to the prevailing environmental conditions. Especially in areas of serious environmental constraints, it may not even be advisable to produce any F_1 cows, but just cross-bred bulls for slower up-grading of the cattle stock.

The questions related to *breeding objectives* concern, for example, desired size of the cow, single-purpose versus double- or triple-purpose animals and the need to combine production, reproduction and health traits in order to consider adaptability in the breeding objectives. Such questions are quite important to clarify, before embarking on a semen importation programme from an exotic breed in relation to national goals and environmental and management constraints.

Methodological, technical and operational issues

Any sustainable breeding programme requires development and improvement of the breed in order to *ensure its future competitiveness*. This will require that aspects of inbreeding and relationships can be kept under control, especially in breeds with a small population and where the genetically superior animals can be identified. In countries with harsh climates, the environmental conditions might fluctuate considerably. This means that rather *efficient statistical methods for genetic evaluation* are needed, so that non-genetic effects can be removed and that optimum use can be made of, for example, the pedigree information. Practical applications of BLUP-animal models have shown their value in such circumstances.

For small breeds, *nucleus breeding schemes* should be preferred where the resources available can be concentrated on a single or a few herds. Good evaluation methods are still needed, but the organization of recording and handling of data is rather uncomplicated.

For larger breeds where AI is readily available, progeny testing may be an alternative, but considering the resources it takes it seems rather questionable in most cases. A much simpler approach would be the application of just a *young bull AI-programme* with a quick turn-over rate of bulls. Such a programme could either be linked to nucleus herds of a domestic breed, or to the use of imported semen of continuously selected top bulls with well-known characteristics, used as bull sires with locally identified superior cows to produce the young bulls. However, progeny testing has too often been considered a compulsory, almost “magic”, component of a breeding programme, even if it has no relevance. This has been an educational problem since simpler and more relevant methods are often prevented from being applied.

Policy and organisational issues

The policy and organisational questions greatly concern the lack of knowledge or understanding of the full concepts of an *integrated breeding programme*. Not only must the long-term genetic strategies be carefully chosen, but also an integrated set of activities with harmonised decision-making procedures in order to achieve the defined breeding goals is needed.

As farmer participation is essential it is equally essential that *farmers influence* the establishment of the breeding objectives and services rendered. The development of *livestock recording schemes* is a necessary pre-requisite for any genetic evaluation of data to be used for selection purposes. It is important that such schemes are developed to fit the most essential purposes and could often be kept quite simple.

The strategic importance of the *educational components* of any development programme must be stressed. The competence level of the staff of the developing country determines the level of advancement of the programme to be implemented. Increased personal competence and its continuity in the programme, adds to the possibilities of achieving the aims of the programme. Even more important, it leads to a better position of the developing country to choose its own strategies and to better evaluate the various kinds of offers that possible donors, experts, semen agents, etc. are presenting.

Finally, a strategic point of any development programme, involving support from some kind of aid agency, is that it must include follow-up activities on a long-term basis. These should involve advisory services as well as some research for analyses and evaluations of results so far obtained, revision of future strategies and a human capacity building component.

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Appendix 1

Workshop Definitions

Lower input production environments – include the broad range of medium and low input production environments throughout the world, i.e. all but those which can be categorized as high input; with high, medium and low input being defined by FAO as:

(a) ***High input production environment.*** A production environment where all rate- limiting inputs to animal production can be managed to ensure high levels of survival, reproduction and output. Output and production risks are constrained primarily by managerial decisions.

(b) ***Medium input production environment.*** A production environment where management of the available resources has the scope to overcome the negative effects of the environment on animal production, although commonly one or more inputs will limit output, survival or reproduction.

(c) ***Low input production environment.*** A production environment where one or more rate-limiting inputs impose continuous or variable severe pressure on the livestock, resulting in low survival, reproductive rate or output. Output and production risks are exposed to major influences which are beyond human management capacity

> Commonly, for developing country production environments, enabling policy, planning and technical capacity, and financial resources are all in short supply.

Biological diversity (Biodiversity) -The variety of life in all its forms, levels and combinations. It encompasses genetic diversity, species diversity and ecosystem diversity.

Agrobiodiversity (Agricultural Biological Diversity) - That component of biodiversity that contributes to food and agriculture production.

Domestic Animal Diversity (DAD) - The spectrum of genetic differences within each breed, and across all breeds within each domestic animal species, together with the species differences; all of which are available for the sustainable intensification of food and agricultural production.

Farm animal genetic resources (AnGR) - Those animal species that are used, or that may be used, for the production of food and agriculture, and the populations within each of them. These populations within each species can be classified as wild and feral populations, landraces and primary populations, standardised breeds, selected lines, and any conserved genetic material.

Breed - Either a subspecific group of domestic livestock with definable and identifiable external characteristics that enable it to be separated by visual appraisal from other similarly defined groups within the same species; or, a group for which geographical and/or cultural separation from phenotypically similar groups has led to acceptance of its separate identity.

Conservation of farm animal genetic resources - Refers to all human activities (for example, strategies, plans, policies, actions and other measures) that are undertaken to ensure that the diversity of farm animal genetic resources is being maintained to contribute to food and agricultural production and productivity, now and in future.

***In-situ* conservation of farm animal genetic diversity -** Refers to all measures to maintain live animal breeding populations, including those involved in active breeding programmes, in the agroecosystem where they developed, or are now normally found, together with husbandry activities, that are undertaken to ensure the continued contribution of these resources to sustainable food and agricultural production, now and in the future.

***Ex-situ* conservation of farm animal genetic diversity -** Refers to all conservation of genetic material in-vivo (but out of the environment in which it developed) and in-vitro, including inter alia, the cryoconservation of semen, oocytes, embryos, cells or tissues.
(*ex-situ* conservation and *ex-situ* preservation are used synonymously).

Genome - The complete set of genes and non-coding sequences present in each cell of an organism, or the genes in a complete haploid set of chromosomes of a particular organism.

Animal genome (gene) bank - A planned and managed repository of Farm Animal Genetic Resources. Repositories include the environment in which the genetic resource has developed, or is now normally found (*in-situ*) or facilities elsewhere (*ex-situ – in-vivo* or *in-vitro*). For *in-vitro, ex-situ* genome bank facilities, germplasm is stored in the form of one or more of the following: semen, ova, embryos, cells and tissue samples.

Clone - A genetic replica of another organism obtained through a non-sexual (no fertilization) reproduction process. Cloning by nucleus transfer involves the transfer of a donor nucleus from (cultured) cells of embryonic, fetal or adult origin into the recipient cytoplasm of an enucleated oocyte or zygote, and the subsequent development of embryos and animals. These clones usually have different mitochondrial genomes**.**

Genetic distance - Measure of the genetic similarity between any pair of populations. Such distance estimates may be based on phenotypic traits, allele frequencies or DNA sequences. For example, genetic distance between two populations having the same allele frequencies at a particular locus, and based solely on that locus, is zero. The distance for one locus is maximum when the two populations are fixed for different alleles. When allele frequencies are estimated for many loci, the genetic distance is obtained by averaging over these loci.

Genetic distancing - Collection of the data on phenotypic traits, allele frequencies or DNA sequences for two or more populations, and estimation of the genetic distances between each pair of populations. From these distances, the best representation of the relationships among all the populations may be obtained.

Production traits - Characteristics of animals, such as the quantity or quality of the milk, meat, fibre, eggs, draught, etc. it (or its progeny) produce, that contribute directly to the value of the animals to the farmer, and that are identifiable or measurable at the individual level. Production traits of farm animals are generally quantitatively inherited; i.e. they are influenced by many genes, whose expression in a particular animal also reflects environmental influences.

Adaptation traits - Complex of traits related to reproduction and survival of the individual in a particular production environment. Adaptation traits contribute to individual fitness and to the evolution of animal genetic resources. By definition, these traits are also important to the ability of the animal genetic resource to be sustained in the production environment.

Fitness - The relative ability of an organism to survive and transmit its genes to the next generation.

Evaluation - Measurement of the characteristics that are important for production and adaptation, either of individual animals or of populations; most commonly in the context of comparative evaluation of the traits of animals or of populations.

Characterisation of Animal Genetic Resources - All activities associated with the description of AnGR aimed at better knowledge of them and their state. Characterisation by a country of its AnGR will incorporate development of necessary descriptors for use, identification of the country's sovereign AnGR, base-line and advanced surveying of these populations including their enumeration and visual description, their comparative genetic description in one or more production environments, their valuation, and ongoing monitoring of those AnGR at risk.

Utilization of Farm Animal Genetic Resources - The use and development of animal genetic resources for the production of food and agriculture. The use in production systems of AnGRs, which already possess high levels of adaptive fitness to the environments concerned, and the deployment of sound genetic principles, will facilitate sustainable development of the AnGRs and the sustainable intensification of the production systems themselves. The wise use of AnGRs is possible without depleting domestic animal diversity. Development of AnGRs includes a broad mix of ongoing activities, which must be well planned and executed for success, and it is compounding over time, hence its high value. It requires careful definition of breeding objectives, and the planning, establishment and maintenance of effective and efficient animal recording and breeding strategies.

Management of Farm Animal Genetic Resources - The sum total of technical, policy, and logistical operations involved to understand (characterisation), use and develop (utilization), and maintain (conservation) animal genetic resources.

Production environment - All input–output relationships, over time, at a particular location. The relationships will include biological, climatic, economic, social, cultural and political factors, which combine to determine the productive potential of a particular livestock enterprise.

Sustainable intensification of animal production systems - The manipulation of inputs to, and outputs from, livestock production systems aimed at increasing productivity and/or production and/or changing product quality, whilst maintaining the long-term integrity of the system and its surrounding environment, so as to meet the needs of both present and future generations of humans. Sustainable agricultural intensification must respect the needs and aspirations of local and indigenous people, take into account the roles and values of their locally adapted genetic resources, and consider the need to achieve long-term environmental sustainability within and beyond the agroecosystem.

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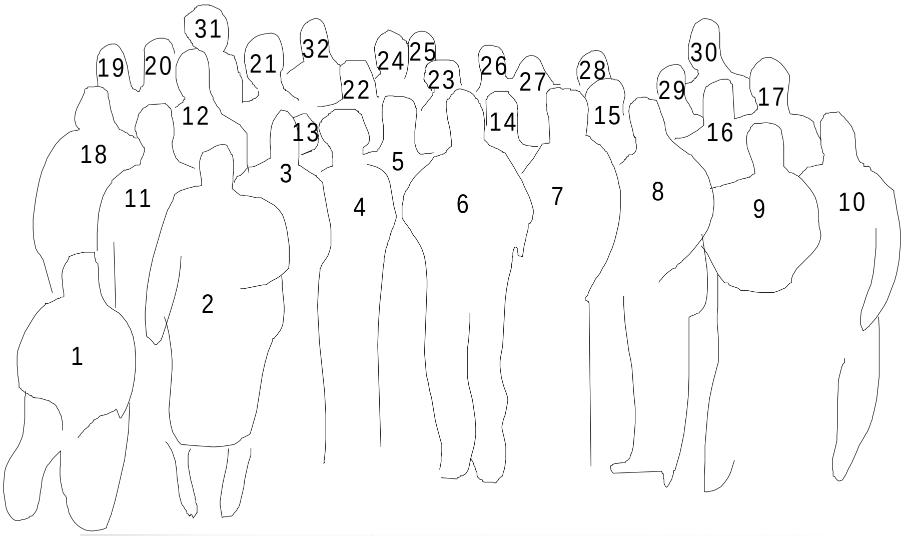
Bella, Italy, 22-25 September 1999



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