Sustainable breeding programmes
for tropical low- and medium input farming systems

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This module discusses important factors to consider when designing sustainable genetic improvement programmes, especially under tropical conditions. Previous attempts to launch breeding programmes in developing countries have too often failed for several reasons, although there are success stories to learn from as well. Long-term and simple strategies are necessary as is the need to efficiently exploit the potential of indigenous breeds. Increased productivity per animal or area of land used also need to be considered. However, that must be achieved while also considering the variable socio-economic and cultural values of livestock in different societies or regions. Within the module there are links [blue] to web resources and [burgundy] to case studies and other related components of this resource that help illustrate the issues presented.

Contents

Citation

Module 3: *Philipsson J., Rege, J.E.O., Zonabend E. and Okeyo A.M. 2011.* Sustainable breeding programmes for tropical farming systems *In*: Animal Genetics Training Resource, version 3, 2011. Ojango, J.M., Malmfors, B. and Okeyo, A.M. (Eds). International Livestock Research Institute, Nairobi, Kenya, and Swedish University of Agricultural Sciences, Uppsala, Sweden

1 Animal improvement for increased productivity and food availability

The challenge to increase food production in developing countries lies in efficient exploitation of genetic diversity among and within breeds of different species. The most productive and adapted animals for each environment must be identified for breeding purposes. Only then will it be viable to increase food production without further increasing the number of animals with the subsequent effects of land degradation. A production system must therefore consider all aspects of the resources needed along with the outputs, both positive and negative.

Many breeding programmes for different species in temperate climates have shown the opportunities to increase the output per animal after a few decades of selection. Even more remarkable results, especially for meat production with different species, have been obtained in well-designed crossbreeding schemes in the short-term. These programmes have been favoured by resourceful environments and well developed infrastructure and markets. Evidence from the tropics also indicates acceptable results in well targeted within breed selection and crossbreeding programmes [CS 1.2 by Mpofu]; [CS 1.5 by Kahi]; [CS 1.40 by Chacko]; [CS 1.19 by Yapi-Gnaore]; [CS 1.26 by Ramsay et al.]. The issue, however, is how to design sustainable breeding schemes for indigenous breeds under inherent tropical conditions (see section 6.2 Module 1 and Rege et al., 2011) where resources are limited, feed availability and quality varies greatly depending on the type, geographical location and season, and the demand on animals that are better able to adapt to the ever changing environment due climate change is increasing. The critical question is how to maximize productivity in these schemes, including fitness and adaptive traits, without adversely affecting the environment and diversity needed for the unknown future. Furthermore, such programmes must be developed in the context of prevailing cultural and socio-economic conditions, i.e., as parts of the livestock use in the total development of a region or community. Consequently, aspects of developing genetic improvement programmes for tropical conditions are far more complex than for breeds in temperate climates of the developed world.

As stated in Module 2, Section 3, the value of indigenous breeds in the tropics and the requirement of long-term strategies that any development of a breeding programme must comply with to be sustainable have largely been neglected. However, the same genetic principles apply to the same species wherever they are. Only methods for application will vary and must be adapted to different circumstances. Designing a breeding programme is much more than genetic theories and increased productivity. It is a matter of infrastructure, community development and an opportunity for improved livelihood of livestock owners through better animals and markets for their products [CS 1.15 by Dzama]; [CS 1.19 by Yapi-Gnaore]. This module will, therefore, indicate some general principles to consider when designing breeding programmes and highlight both genetic and external factors and issues that might be of importance specifically for tropical farming systems.

2 Previous genetic improvement programmes—Lessons

Many attempts to improve livestock in the tropics have been made, mainly by 'upgrading' with temperate breeds in crossbreeding. Improved livestock have been successfully produced or introduced in favourable areas of the tropics, e.g. in some highland areas. However, in maritime climates and in relatively intense peri-urban production systems, many attempts have failed due to introduction of breeds not adapted to tropical conditions, or due to lack of long-term strategies for the breeding programme to be sustainable.

Payne and Hodges (1997) thoroughly reviewed the situation as regards cattle breeding; Kosgey et al. (2006); Kosgey and Okeyo (2007); Mueller (2006) and Peacock et al. (2011) have reported on success and failures for small ruminants, while Rege et al. (2011) have discussed what science can achieve with regard to pro-poor animal improvement and breeding. In fact, many case studies exist from which lessons can be learnt from failures [CS 1.3 by Mpofu]; [CS 1.35 by Shreeram & Prakash], and from successful programmes [CS 1.2 by Mpofu]; [CS 1.5 by Kahi]; [CS 1.40 by Chacko]. Analysing the reasons for failures in different reports reveals some common problems (see Kosgey and Okeyo, 2007), whereas success stories may give possible ways forward.

The major problems are:

- Breeding programmes have been too complex in terms of logistics, technology and other resources without considering the infrastructure required [CS 1.3 by Mpofu].

- Indiscriminate crossbreeding of indigenous breeds with exotic breeds without enough consideration of environmental conditions for production. Lack of plans on how to maintain a suitable level of 'upgrading' or on how to maintain the pure breeds for future use in crossbreeding contribute to non-sustainability. High levels of upgrading have generally led to animals with lower resistance to diseases and impaired ability to withstand environmental stress [CS 1.31 by Philipsson].

- Lack of analysis of the different socio-economic and cultural roles that livestock play in each situation, usually leading to wrong breeding objectives and neglect of the potentials of various indigenous breeds of livestock. Examples of these problems are illustrated in several case studies linked to this module [CS 1.12 by Chagunda].

- Lack of comprehensive approaches to design simple, yet effective breeding strategies in low-input environments.

- Lack of awareness of what genetic improvement schemes may achieve in both the short and long terms with different methods and species.

- Lack of maintenance and promotion of breed standards (uniformity, colour and body conformation), and small population sizes limiting the selection, multiplication and stabilization of crossbreds to form synthetic breeds. Nondescript breeds are being developed because more importance is given to their economic, rather than phenotypic, characteristics [CS 1.40 by Chacko].

Success stories include some important features, such as:

- Introduction of productive breeds from other tropical regions. The most striking examples are found in Brazil, where *Bos indicus* cattle have become dominant beef producers for both domestic use and for the export market.

- Developing a synthetic breed initially based on crossbreeding several breeds to find a suitable mix of indigenous and exotic genes. A well-known example is the development of the Sunandini cattle in Kerala, south-west India, from crossing local zebu cattle with Brown Swiss, Jersey and Holstein and consistent selection within the crossbred population [CS 1.40 by Chacko]. In this way the most valuable genes for the environment in question are conserved in a continuously developing 'breed'.

- Farmer participation and support of investors. No breeding programme will be sustainable unless there is adequate farmer involvement. Similarly, it is difficult to develop breeding programmes without policy support and financial resources. However, it is equally important that the development programmes have exit strategies that they can sustain on their own by being profitable to the farmers and the society [CS by Ojango et al].

3 Some considerations when designing a breeding programme

Approaches better adapted to consider the potential of indigenous livestock breeds must be developed. Realistic ways of improving these breeds must be chosen and applied in the context of environmental constraints and socio-economic demands and within the resources available. Aspects of sustainability and provision of future genetic diversity are critical. A basic principle to follow should be based on the assumption that there is no better way to conserve a breed for future generations than to consistently keep the breed or population viable by using an efficient, demand-driven long-term breeding programme suitable to commercial or cultural needs of livestock owners. In certain cases, it may be important to conserve the desired genes and not the genotype. Well designed crossbreeding and synthetic breed formation programmes can achieve this. Where applicable, especially with regard to genes responsible for adaptation such as disease and parasite resistance, marker-assisted introgression (MAI) would also contribute to sustainable conservation of desirable genes. However, MAI would have to be preceded by identification of such genes and a thorough characterization and understanding of their functions in well-designed functional genomic studies. Such an introgression may also be an effect of long-term crossing between breeds within an area and where traits of both breeds are favoured in the crossbred population.

An important feature of a genetic improvement programme, contrasting to an external input effect, is that the effects of selection accumulate over time (Figure 1). The economic benefits of selection also accumulate. Breeding programmes should, therefore, be seen as investments for sustainable improvements of the animal stock and the potential to produce food or other goods. To realize the benefits of a breeding programme, the breeding objectives must be appropriately defined for the species or breeds, communities and environments concerned, and the strategies laid out can be followed in practice.

Many important circumstances determine the scope of opportunities for and constraints to the breeding programme. Agricultural and land use policies, market information and access, environmental conditions, characteristics of animal populations and

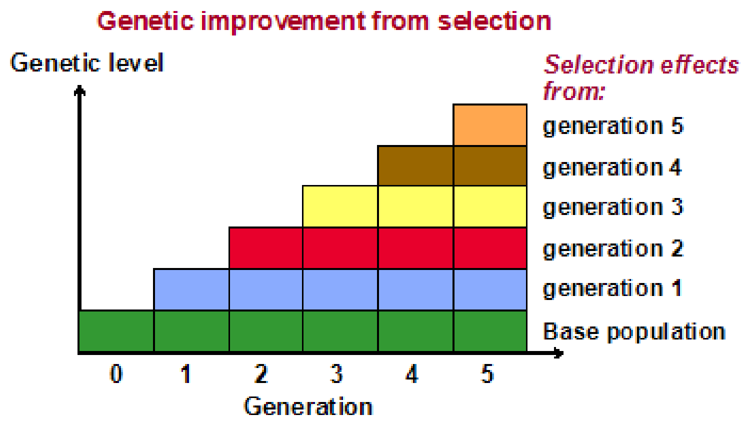

Figure 1. *Genetic improvement from selection.*

infrastructure available are examples of such factors. Basic questions concerning the choice of an overall breeding strategy include the emphasis on improving indigenous breeds vs. the use of tropical breeds from other areas or 'exotic' breeds. This section highlights some of these key elements which need to be considered before the final design of a breeding programme at breed level.

3.1 The agricultural development policy

Animal breeding programmes should be seen in the context of long-term development programmes contributing to both more food and other livestock commodities produced and to improved resource utilization and livelihood of the livestock owners (FAO, 2010; Mueller, 2006; Mueller et.al., 2002). Thus, livestock breeding programmes may be seen as important parts of national agricultural policies, aiming at improving the food and income of a country, region or locality and of livestock keepers. Indeed, in most cases the agricultural development policy sets the scene. The long-term vision of the national interests and the breeding objectives must coincide, although there might be some discrepancies between short-term political goals and the more long-term breeding goals. Some compromises might be necessary and interim solutions applied, while maintaining the long-term goals [CS 1.12 by Chagunda]. Food imports may, for example, be necessary while awaiting the domestic production to increase through whatever means.

3.2 Environment, production system and the market

Any breeding programme is totally dependent on environmental conditions, the production system, the culture of the people for whom the animals are bred, and the market to which the animals and animal products are sold. Village breeding programmes for smallholder farmers, (Mueller, 2006; Wurzinger et al., 2010) [CS 1.19 by Yapi-Gnaore] will be different from those of large-scale farming systems [CS 1.16 by Mpofu]; [CS 1.26 by Ramsay et al]. Intensive crop–livestock systems, with good feed and health care facilities available, enable more opportunities for rapid improvement programmes than harsh rangeland systems do. Whatever the environment, to be sustainable the breeding programme must be market-oriented, i.e., demand-driven, yet considering the multi-purpose use of the animals and the long-term benefits to the farmer. To develop a programme that considers both the present circumstances and possible future situations, including market conditions, is a challenging task. This is because there is a considerable time lag between implementation of the programme and when the benefits of genetic gains are realized. Therefore, breeding programmes should be somewhat flexible and responsive to variable scenarios for the future needs of the programmes.

3.3 Infrastructure and role of farmers

Breeding programmes usually assume some kind of cooperation between the participants, e.g., by common ownership of some valuable breeding stock for wide use, conducting testing schemes involving many herds or employing trained people for artificial insemination (AI) services and other activities [CS 1.2 by Mpofu]; [CS 1.6 by Mpofu & Rege]; [CS 1.14 by Olivier]. The initial developments of breeding programmes are generally made by the government in collaboration with bilateral organizations in most developing countries because of the national benefits of improving livestock for food production and other purposes. In that way, basic investments and structures can be put in place. However, experience shows that it is extremely important that farmers get involved early in the process to ensure that their needs are taken into account and that they provide the support needed for the programme to work (Ahuya et al., 2004; Ahuya et al., 2005; van der Westhuizen and Scholtz, 2005; Kosgey et al., 2006; Peacock, 2008; Peacock et al., 2011); [CS 1.14 by Olivier]; [CS 1.26 by Ramsay et al.]. Throughout the world breeding programmes in the hands of farmers' cooperatives, often with government support, have been successful for several livestock species (Ahuya et al., 2004; Mueller et al., 2006). Specialized breeding companies, however, have evolved under certain commercial conditions, especially for poultry and pig breeding and to a lesser extent for cattle breeding. However, private pioneers have in some cases played important roles in developing breeds and breeding programmes, e.g., in Brazil. Private companies have often been able to produce high quality breeding stock for industrialized production systems. In these cases, it is important, from a farmer's and government's perspective, to ensure that the most suitable animals are developed in relation to the real needs, environmental, socio-economic and other resources given [CS 1.26 by Ramsay et al.].

Infrastructure includes a broad range of essential inputs, which must be available for the breeding programme to succeed. These include trained staff, facilities for breeding animals and logistics for dissemination of germplasm, methods and means for recording, handling of data and evaluation of animals, decision-making bodies, finances, etc. [CS 1.30 by Jensen]; [CS 1.6 by Mpofu & Rege]. One often over-looked assumption is the required integration of all activities constituting a breeding programme. This applies both at the government level and at the practical organizational level. Another potential problem in developing countries is lack of or an inadequate number of people with appropriate training or incentives to successfully run a breeding programme (see Ojango et al., 2010). Lack of required infrastructure is one of the most serious constraints to developing indigenous breeds in tropical countries.

3.4 Matching genotypes with the environment—Or the other way around?

Clearly, to improve any breed or population, one must understand both the inherent genetic constitution of the population and how this interacts with the environment, which itself should also be well understood. It is only then that meaningful genetic improvement programmes can be developed. Given that not all components of the environment can be changed, particularly in low-input tropical production systems, one needs to know which genotypes can be used under such environmental conditions, i.e., different types of production environments need different types of animals [Gibson and Cundiff in ICAR Tech. Series No. 3]. Specifically, specialized exotic breeds are unlikely to survive, let alone produce, in the typically harsh tropical environments [CS 1.26 by Ramsay et al.]; [CS 1.28 by Madalena]. However, continuous improvements and changes of some environmental factors, such as feed availability, veterinary services and development of new production systems, will also be necessary to meet future demands on animal agriculture. In doing so, the environmental stress will decrease and some exotic breeds or crosses may become relevant and valuable for parts of the tropics.

When establishing or planning a livestock improvement programme for a difficult environment, there are two main approaches: one is to alter the environment, making it less rigorous and the other is to select stock which is likely to be the most adaptable to local conditions, including climatic stresses, that also has potential for increased productivity. To what extent should efforts be made to modify production environments to accommodate animals of the highest genetic potential for production, as opposed to concentrating on the productivity of genotypes which withstand the rigours of the harsh environment, while neglecting the scope for its amelioration? There is need to balance efforts in the two areas by examining cost–benefit relationships; either option taken alone will not be optimal, both ways should be explored [CS 1.36 by Sartika and Noor]. In many traditional tropical livestock production systems, levels of animal management and nutrition cannot support the potential of the so-called improved breeds. At the same time, despite the absence of scientifically based knowledge, the levels of traditional knowledge have been thoroughly underestimated or forcibly eroded, leading to inadequate husbandry and, consequently, the observed current poor performance by indigenous livestock populations. The extent to which these environments can be freed of the limitations imposed by climate, disease, parasites and nutrition is often limited. However, where efficient infrastructure is in place, control of diseases and feed resources can improve the situation considerably. Thus, there is a strong case for utilization of the best locally available, adapted genotypes in combination with improvements in the environment, wherever feasible and economical, while also considering development of appropriate breeding programmes for further development of these breeds [CS 1.31 by Philipsson]; [CS 1.39 by Okeyo and Baker].

Successful matching of genotypes with environments assumes availability of a wide range of genotypes. The tropical world is endowed with numerous genotypes. What is required is knowledge of their relative merits and appropriate exploitation of these merits [Breed information]; [DAGRIS]; [DAD–IS]. Developing countries should look at what is available locally or in other tropical areas before importing exotic breeds. Even when some sort of crossbreeding is opted for, the countries must maintain parallel programmes of evaluation, improvement and conservation of the indigenous parental breeds.

Unfortunately, many national governments in the tropical world lack appropriate livestock policies and have not given due consideration to development of indigenous livestock breeds [CS 1.12 by Chagunda]. Indeed, there is a tendency to focus on the imported breeds and often neglect desirable characteristics of indigenous breeds [CS 1.2 by Mpofu]. However, in some tropical situations, e.g., in highlands and in peri-urban production systems with improved environments, there are successful examples of introducing exotic breeds and their crosses with indigenous breeds [CS 1.31 by Philipsson]. The previously FAO-driven State of the World participatory reporting process and the various country reports on farm animal genetic resources (AnGR) [DAD-IS] contain a comprehensive inventory of AnGR at individual country level, with each country identifying its respective priorities and immediate actions that should be taken. The Global Strategy for the Management of farm AnGR provides a technical and operational framework for assisting countries, comprising:

1. An intergovernmental mechanism for direct government involvement and policy development.

2. A country-based global infrastructure to help countries cost-effectively plan, implement and maintain national strategies for the management of AnGR.

3. A technical programme aimed at supporting effective action at the country level in the sustainable intensification, conservation, characterization and access to AnGR.

4. A system to guide the Strategy's implementation, facilitate collaboration, coordination and policy development, and maximize cost-effectiveness of activity.

In tandem with the recently revised FAO Breeding Guidelines [see FAO, 2010], most developed and some developing countries have outlined how each of these would be facilitated and the supportive policy and legal frameworks needed to achieve these. Turning these good intentions into actions and tangible outcomes and impacts must be the main focus of all stakeholders. This means that effective breeding strategies should be applied to better exploit the genetic potentials for increased productivity and other values to ensure future availability of adapted species and breeds.

3.5 What breeds are or may be available?

The current distribution of indigenous breeds in most tropical developing regions is mostly a result of history, tradition and local convenience, sometimes even prejudice. There are only isolated cases where deliberate measures have been taken by national governments to implement programmes to select and breed animals specially suited physiologically for each region [CS 1.26 by Ramsay et al.]; [CS 1.28 by Madalena] or to import suitable indigenous germplasm from other tropical developing countries [CS 1.6 by Mpofu & Rege]; [CS 1.31 by Philipsson]. The kind of strategy which is needed to effectively utilize these indigenous livestock genetic resources is a key question for which answers must be provided.

A basic question is which breeds or genotypes to use or target for use and improvement. As there is a natural stratification of livestock breeds by climatic zones, there should be little difficulty in making choices. A good understanding of the environment in addition to knowledge of available breed resources is required to make appropriate decisions on breed choice and necessary improvement interventions [see van der Werf in ICAR Tech Series No. 3], [Nitter in ICAR Tech Series No. 3] and [Gibson and Cundiff in ICAR Tech Series No. 3].

Where opportunity exists for improving the production environment, a shift towards more commercialized meat (e.g., beef) or dairy production or both, may be desirable. In such cases, there are two options. One is to identify a suitable breed from the wide range of indigenous breeds. For example, in Africa beef operations in tsetse-free regions of the south may consider use of well-selected breeding animals from the Nguni, Afrikaner, Tuli or even Boran populations. Conversely, beef production in tsetse-infested parts of eastern Africa may consider using the Orma Boran or introducing the Ethiopian Sheko breeds, considered to be less trypano-susceptible than most 'beef-type' cattle breeds in the sub-region. Alternatively, crossing Boran and N'Dama or Sheko and selecting the resultant crosses so as to retain and use them for further breeding of individuals which possess the right combination of the quantitative trait loci (QTL) responsible for trypanotolerance from both breeds through introgression and selection is also promising (Hanotte et al., 2003; Orenge, 2010). These examples illustrate the need for systematic *characterization of the breeds* presently used in the actual area (Module 2, Section 2). Such a characterization must include both *population structure* and *phenotypic trait descriptions*, with emphasis on production, reproduction and adaptive traits to ensure that both the potential of the breed and what makes it a unique resource in its cultural and socio-economic environment is considered. The population structure describes the number of breeding animals by age and sex and its changes in the past. The dynamics in numbers of animals of a breed is important for the level of efforts in conserving the breed and in demonstrating its future potential for food production [DAGRIS]; [DAD–IS].

If there is a *choice among indigenous breeds* to be selected for an improvement scheme, the facts revealed through the breed characterization form the basis for decision together with an *analysis of the relationships between the breeds*. Methodologies applying molecular genetics offer new opportunities to measure genetic relationships and diversity. Additionally, the economic analysis of the best options (Simianer et al. 2003) needs to be explored and refined (Module 2, Section 3.3). Among the breeds with good potential for food production and other desired products and use, it may be wise to conserve the least related breeds. It may be equally wise to merge small closely related breeds into a common more efficient selection programme than otherwise would be possible to enable the best opportunities to save important genes for future exploitation. Otherwise such breeds may suffer from serious inbreeding and become extinct.

As germplasm in several species can be moved easily around the world today, it means that there is a huge global livestock gene pool to draw from. Breeding programmes have, over time, become more international. This requires more knowledge than previously understood to evaluate what is marketed or made available on a global scale. Although one must always be open to investigate any advantages of bringing in new genetic material into a breed or area, the process to do so requires a critical review of all aspects of the breeding programme (later in this module) [see Gibson and Cundiff in ICAR Tech Series No. 3].

3.5.1 Are small sized breeds less productive than larger ones?

A specific and crucial question to raise in the context of choice of breeds for extensive production systems in the tropics relates to the desirable size of the animals. Under conditions of sparse feeding or low nutritional levels, small animals obviously have an advantage over large ones (Taylor and Murray, 1988). More energy is left for production when the maintenance requirements have been met. In such situations, selecting for body weight above certain optimum levels might result in animals becoming less adapted. In addition to the lower maintenance requirements and other related adaptive attributes already alluded to, an advantage of small body size, often overlooked, is the resulting convenient carcass size for rapid disposal in environments with inadequate transport network and freezing facilities. That is why poultry and small ruminants are relatively more common in such environments. Furthermore, there is no evidence indicating that the quality of beef from the small sized indigenous cattle is inferior to similarly reared large framed exotic stock [CS 1.2 by Mpofu]; [CS 1.8 by Mpofu]. However, with improved nutrition and general management, selection for increased growth rate or body weight may be justified.

Ample documented evidence indicates that under conditions in which indigenous tropical livestock are currently predominantly kept, specialized large sized imported breeds would be unsuitable, especially for meat production. To date, most studies—mainly under station or improved (commercial) production conditions in tropical and sub-tropical countries (e.g., Bonsma, 1949; Buck et al., 1982; Trail, 1984; Vilakati, 1990; Moyo, 1996) have shown that smaller sized indigenous breeds can be as productive as, if not more productive than, European breeds, especially if account is taken of viability and maintenance requirements.

Additionally, the low risk factor of adapted breeds is an important consideration where market values are unstable, while production costs continue to increase, or where the probability of death from environmental stresses is high (Frisch, 1984).

It is a universally accepted fact that indigenous African cattle produce less milk (on a per animal basis) than European dairy cattle. However, when adjusted for animal size, the productivity of some breeds is quite considerable [CS 1.31 by Philipsson], even without considering the harshness of the production environment and the input requirements for indigenous livestock relative to those for specialized exotic breeds. The variation among the indigenous breeds is, however, substantial [Breed information].

Unfortunately, few systematic breed evaluation studies have been carried out in the tropics in which indigenous and exotic breeds have been comprehensively and fairly compared under typical production conditions. However, there have been some interesting studies where small sized breeds were consistently superior in the productivity indices considered, mainly because of the low maintenance requirements, superior calving rate and low calf mortality (Madalena, 1984; Madalena, 1993; Madalena, 2005) [CS 1.8 by Mpofu; CS 1.39 by Okeyo and Baker].

Whereas the relationship between body weight and requirements for maintenance may be well established, the actual cost implications of this relationship in production systems where animals are entirely dependent on pasture is not clear. Nonetheless, figures indicate that where feed availability is a constraint the smaller sized indigenous breeds are superior. However, this situation also applies to temperate climates. In grazing systems, for example as practised in New Zealand, the smaller sized Jersey cows or their crosses do relatively well as regards production in relation to metabolic weight compared to the large sized Holstein cattle, whereas the opposite may be true in intensive feeding systems.

4 Developing the breeding programme

The general framework for developing a breeding programme is illustrated in Figure 2. The framework includes the previously discussed implications of agricultural policies, infrastructure and farmer involvement, markets and some aspects on the choice of populations available. A breeding programme needs to be integrated and its success is largely determined by the scope of *farmer participation.*

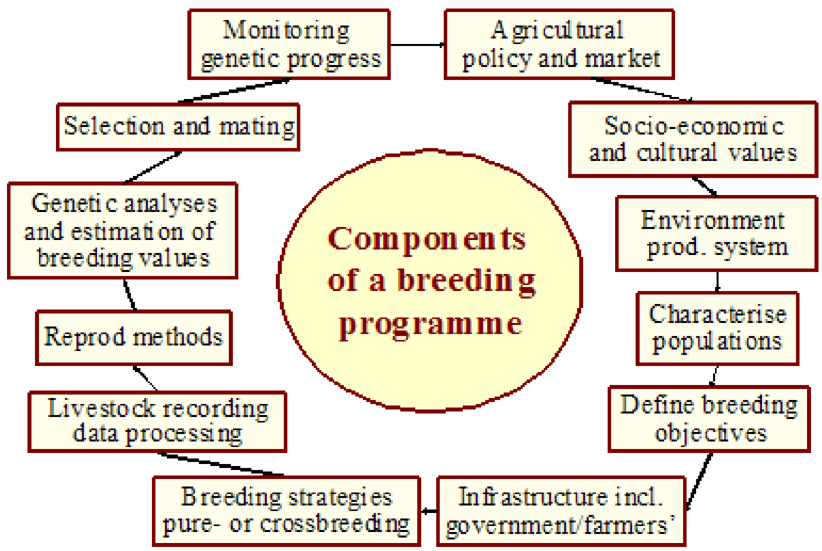

Figure 2. *Components of a breeding programme.*

In the following sections, different breeding strategies are presented and aspects on developing improvement programmes at breed level are dealt with. The scope of any breeding programme must be set in relation to the resources available and the stage of development in the region concerned. It must be kept simple and reliable, at least initially, rather than sophisticated and vulnerable to several prerequisites that cannot be guaranteed [CS 1.3 by Mpofu]; [CS 1.31 by Philipsson]. The design may, therefore, vary considerably depending on the actual breed, production system and other circumstances. Whatever the case, the principle of 'KISS' (keep it simple to be sustainable) should be emphasized in the start up phase of the breeding programme.

4.1 What strategy to choose

Payne and Hodges (1997) reviewed in detail the past developments of genetic improvement programmes for cattle in the tropics and what could be seen as the major options available for the future in seeking sustainable breeding systems. These differ for many reasons from the programmes designed for temperate breeds in Western countries. In summary, five major options are proposed:

- crossbreeding indigenous breeds with temperate breeds without AI
- improving indigenous breeds
- progressively substituting the breed with another indigenous breed
- crossbreeding indigenous breeds with temperate breeds using AI
- forming a composite (synthetic) breed.

The choice of strategy depends on many different factors specific to each situation and can be analysed according to the issues indicated by each one of the components illustrated. Generally, these options should aim at being simple enough to allow programmes to be launched without many resources. In most such cases, the schemes are based on open nucleus herds where the indigenous breeds are kept under selection. From these herds, males, either pure bred or crossbred, are distributed for use in smallholder or village farming systems. In this way, the indigenous breeds chosen for improvement will be conserved for the future. Depending on breed characteristics, the level of management and development one may choose a simpler or more advanced scheme. What have largely been neglected so far are options 2 and 3 in the bullets above. If comprehensive breed characterization is undertaken, it would be more likely to find interesting indigenous breeds for use far outside their present habitats—the success of the Sahiwal breed globally, the potential of the Kenana, Butana and N'Dama in Africa and the Nelore, Gir and Sindi breeds of Indian origin, but further developed in Brazil, deserve special attention in this respect [see Breed information]. Additionally, the additive genetic variation within the indigenous breeds seems to be large and has so far been little exploited [CS 1.36 by Sartika and Noor]. Formation of synthetic breeds has been tried and several breeds of today resulted from such practice [CS 1.26 by Ramsay et al.]; [CS 1.40 by Chako]. It is also an interesting way out of a situation when systematic crossbreeding does not work, while the incorporation of exotic genes is deemed important [CS 1.5 by Kahi]. However, the advantages of forming a synthetic breed from crossbreds must outweigh the loss of heterosis that otherwise could be achieved from systematic crossbreeding.

4.2 Defining the breeding objectives at breed level

The ultimate goals of a breed at the *macro-level* should be expressed by the agricultural development policy, market, production system and the output required from the resources available in the system of a country, region or locality [see FAO, 2010]. At the *micro-level*, the definition of breeding objectives means that the relative importance of improvement of different traits of the breed for a given production environment must be determined [Groen in ICAR Tech Series No. 3]. In doing so, a long-term horizon of breeding should be kept. In cattle breeding, that means at least a time horizon of 10–15 years, while in pig and poultry breeding the considerably shorter generation intervals also allow for shorter time horizons in selection.

Breeding objectives must be set at the national, regional or local level by local stakeholders (and not by outsiders) to truly reflect the real needs of the area; farmers must support the direction of change (Ahuya et al., 2004; Kosgey et al., 2006; FAO, 2010) [CS 1.14 by Olivier]; [CS 1.28 by Madalena]. The conflicts that may occur between the long-term goals, expressed at national or organizational level and the interest of farmers in short-term benefits could be solved either by regulations or incentives for participation in a cooperative breeding programme.

When deciding upon a *breeding strategy*, though, the effects of longer time periods must be considered, consequently, when evaluating different crossbreeding strategies, several generations of selection and mating must be considered [Computer exercises: Breeding plans].

When determining the relative importance of different traits in the breeding objective one may, as an alternative to calculation of relative economic weights, put *restrictions* on the change in specific traits or define what the *desired gain* is in each trait. Whatever the choice of method of weighting traits, the following additional points must be considered:

- Although the long-term goals determine the breeding objectives and the role of each trait, the short-term benefits for farmers must be considered to get good farmer participation.
- In almost all situations, it may be difficult to exactly value the change in all desired traits in economic terms; fundamental traits must anyway be considered in the selection programme, e.g., through independent culling or other appropriate methods if the indexing procedure does not work or is not the appropriate approach.
- Special care must be taken in dealing with fitness and adaptive traits, especially if antagonistic genetic relationships exist between these and primary production traits.

The issue of whether to directly select in harsh environments for adaptive traits in addition to such important traits as production, reproductive performance and growth, is debatable. As physiological adaptability is expressed in performance, does selection of animals on the basis of performance alone give sufficient consideration to adaptive mechanisms involved in maintaining, say heat balance? Generally, favourable correlations suggest that adaptability traits would not be compromised by emphasizing selection for performance (Burrow et al., 1991; Mueller, 2006). There are, indeed, indications that selection for performance (e.g., reproduction, survival, growth etc.) in stressful environments will lead to selection for the most suitable animals (McDowell, 1972; Turner, 1984). Besides, as the number of traits in a selection programme increases, genetic progress that can be made in improving any one trait slows down unless the traits are highly genetically correlated [Computer exercises: Breeding plans]. Additionally, there are no satisfactory estimates of heritability of measures of adaptability in these populations. Moreover, cooperative breeding schemes, considered ideal for genetic improvement of indigenous livestock in developing countries, need to be as simple as possible initially and should, therefore, avoid complicated selection criteria (Kosgey et al., 2006). Nevertheless, one should, in most cases, try to focus selection on only the most important traits improving productivity and fitness for the environment in question [CS 1.19 by Yapi-Gnaore].

In a dynamic breeding programme seeking the optimal utilization of the genetic resources available, the breeding objectives should be reviewed regularly based on what has been achieved so far and on likely long-lasting changes of the market or agricultural policies [Groen in ICAR Tech Series No. 3]; [Weller in ICAR Tech Series No. 3].

4.3 Pure breeding or crossbreeding?

An early consideration, related to the choice of breeds, is whether the characterization of the indigenous breeds available shows that they have the potential for required improvement through pure breeding or if some kind of crossing with exotics or other tropically adapted breeds might be a better strategy.

The choice of breeding method, pure breeding alone, also using crossbreeding or breeding for a synthetic breed, is perhaps the most important decision to be made when designing a breeding programme. It relates partly to the previous discussion on characterization of genetic resources, including exotic germplasm being available on the international market. Key issues include:

- What are the level of performance and the potential of genetic improvement through selection within the indigenous breed?
- What alternative breeds are available for crossbreeding and what levels of performance and adaptability to the environment could be expected from 1st and 2nd generation crosses?
- How important are effects of heterosis for the traits of major interest?
- What are the opportunities for keeping pure bred stock of two or more breeds being available for maintaining a long-term crossbreeding programme?
- In the long run, what are the costs and benefits of crossbreeding compared to within-breed selection aimed at improving the same set of traits?
- Is the formation of a synthetic breed a viable alternative to both pure breeding and crossbreeding with other breeds?

Crossbreeding has principally been applied in the tropics to exploit breed complementarity. Specifically, specialized exotic (mainly temperate) breeds have been crossed with indigenous breeds to combine the high productivity of the former with adaptive attributes of the latter. Success stories are clearly available from countries that have good infrastructure (Madalena, 2005), [CS 1.5 by Kahi]; [CS 1.25 by Filho]; [CS 1.26 by Ramsay et al.]; [CS 1.28 by Madalena]; [CS 1.40 by Chacko]. However, many crossbreeding programmes have either lacked long-term strategies on how to maintain a suitable level of upgrading or have been too complicated to conduct in practice [CS 1.5 by Kahi]. As a result, uncontrolled crossbreeding has been identified as a major cause of loss of genetic diversity in indigenous breeds, primarily through replacement of pure indigenous breeds with crossbreds. However, these crossbreds may have provided the base for new synthetic breed developments, which thereby could carry on valuable genes from the original indigenous breeds to future generations.

On behalf of FAO, Cunningham and Syrstad (1987) extensively analysed results from crossbreeding in the tropics. Their clear conclusion was that consistent improvements in most performance traits were achieved in 'upgrading' dairy cattle to as much as 50% with temperate breeds. Beyond that, results were variable. Brazilian studies by Madalena et al. (1990a, 1990b) support these findings. Results vary according to environmental conditions and traits studied [CS 1.28 by Madalena]. A general conclusion is that crossbreeding to produce animals with up to 50% of the genes from temperate breeds can be recommended where crossbreeding is an option.

In practice, for cattle many schemes have been adopted where F_1 heifers have been produced at government farms and been distributed before first calving to smallholder farmers. In this way, the farmers have then been able to raise their income through selling milk from improved cattle (Module 1, Section 2.3). However, as females are not replaced at the farm but mainly provided from government farms, this system is not sustainable and should only be utilized to introduce improved animals. The females should instead be produced through systematic crossbreeding at the village farm level. Brazilian experiences also show the opportunities for specialized production of pregnant F_1 heifers for sale to specialized dairy farms. Results for dairy goats from FARM-Africa's initiative in East Africa have demonstrated that this can successfully work (Ahuya et al., 2004) [CS Ojango et al]. However, the never-ending question has been what breed to use when mating the F_1 animals. Usually schemes that are too complicated have been proposed to maximize the genetic gain, considering both additive and non-additive genetic effects. Too often the programme has failed due to the practical difficulties of running the scheme if sufficient infrastructure is not in place.

It is important, therefore, to find a simple crossbreeding strategy which can easily be followed under practical conditions. For simplicity and cost reasons (Peacock et al., 2011), it should be based on continuous use of the females produced in the herd, allowing new males to enter the herd live or by AI. Figure 3 exemplifies such a plan. It is based on continuous use of F_1 males on indigenous females and by time on crossbred females, in village herds and allows a maximum of 50% exotic genes to be incorporated in the female stock. The strategy is based on two cornerstones:

- A *nucleus herd* of selected animals of the pure indigenous breed is kept for continuous selection within the breed and for mating with an exotic breed to produce F_1 males for distribution to village herds.
- *Crossbred females* in the village herds are bred to new *F_1 males* from the nucleus herd to produce the next generation of females at farm level.

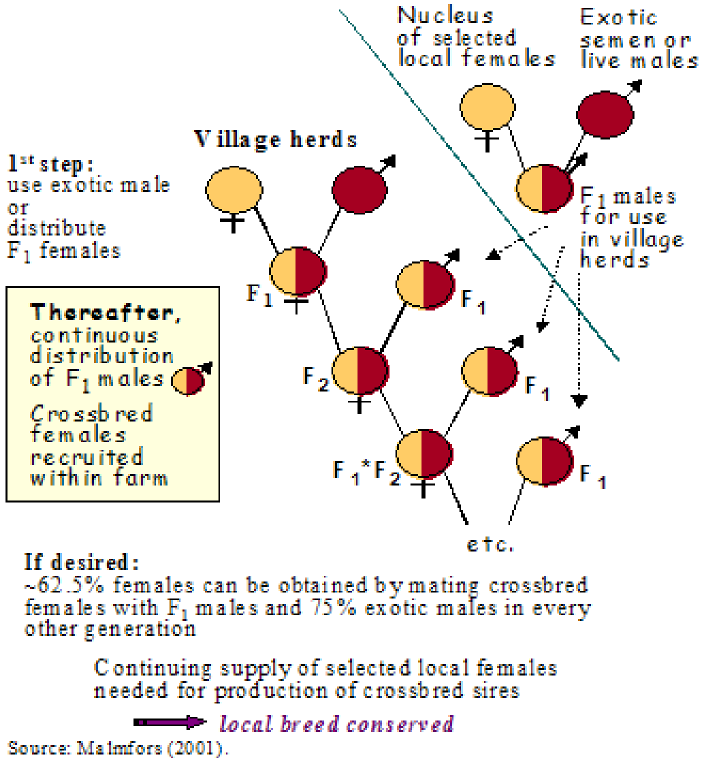

Figure 3. *Example of crossbreeding scheme for livestock.*

This strategy leads to animals that on average contain 50% of the genes from the indigenous breed and 50% from the exotic breed. To speed up the programme, F_1 females can be produced directly by using exotic males, or semen from these, for mating the females in the village herds. If a higher degree of upgrading is desired, e.g., 60–65%, then the nucleus herd should produce males that initially have 75% exotic genes, but later also F_1 males for rotational use. The 50% plan is quite simple, while the other one starts to become a little complicated. If the nucleus herd for some reason fails to produce the F_1 males, there is an opportunity to continue to select both females and males within the herd populations established at village level. A synthetic breed or population is then underway. However, the degree of success will depend on the extent to which villagers are involved in the design, implementation and review of stages of the performance and pedigree recording system (Okeyo, 1997; Ahuya et al., 2004, 2005; Kosgey et al., 2006; Peacock et al., 2011)

The advantages of this crossbreeding scheme are:

- crossbred females are recruited within the village farms
- only crossbred males need to be distributed
- no risk of too high 'upgrading'
- simple method, requiring minimum infrastructure

- local breed will be conserved (in nucleus herd), genetically superior individual indigenous animals resulting from each generation of selection can be used to improve a wider population of the indigenous breed in production systems and environments where they are best suited. If the programme for any reason fails it will not lead to erosion of the initial genetic resources, but as an alternative, maintain these in a new synthetic population.

The disadvantages are:

- Heterosis is not maximized (but the complementarity of additively inherited traits is exploited, i.e., desired traits are selected for and combined).
- Some segregation in crossbred females may occur but this could be counteracted through selection within the village herds.

Overall, it is believed that the advantages of this simple scheme by far outweigh the disadvantages mentioned. However, *inter se* mating of F_1 animals to produce F_2 animals are less predictable in performance than F_1 animals, partly dependent on breed combination and its interaction with the environmental conditions. It is therefore advisable to research, or at least carefully monitor, the results of each generation before wide-scale implementation of the proposed scheme.

To improve *dairy cattle*, it seems often obvious to apply crossbreeding with temperate breeds in tropical farming systems. However, some indigenous breeds such as the Kenana in Sudan and the Sahiwal in both Asia and Kenya have potentials to be used in pure breeding and for crossbreeding with other indigenous *Bos indicus* breeds [CS 1.31 by Philipsson]. The Jamnapari goats of India would play similar roles in improving milk and meat production in goats under tropical conditions. For *beef production*, several high potential indigenous breeds are available for tropical environments, e.g., the Boran cattle in Ethiopia and Kenya, Brahman in India, Tuli, and Nguni breeds in Zimbabwe and South Africa respectively and Nelore in Brazil.

The choice of breeding strategy, i.e., pure vs. crossbreeding has vast implications at both farm and organizational levels and should be based on facts that are as extensive as possible [FAO, 2010]. Any change in the direction towards crossbreeding from an ongoing pure breeding strategy should be preceded by research that provides information on performance, reproduction and health, including adaptive traits [CS 1.23 by Fall]. Such information is needed at least for the F_1 animals and their backcrosses to the exotic breed compared with pure breds in representative environments. Serious attention must also be paid to the logistic aspects of organizing the crossbreeding programme to be sustainable.

4.4 What type of livestock recording schemes and data processing may be available?

The goal of livestock recording schemes is usually to provide farmers with information about individual animals for management and for breeding purposes. The objective could also be phrased as to provide an *information system* about the livestock, their use, performance and development, by both farmers and national authorities. The available infrastructure, including physical and human resources, will determine the type of recording scheme that can be effectively implemented. The sort of scheme offered will differ considerably depending on the farming structure and production system. Early stages of development require simple solutions to be sustainable. With time and experience, the schemes may be made more sophisticated (Kosgey et al., 2011). It is better to start recording in a few cooperating herds that can be handled well, rather than running a scheme on a wide scale that cannot be supervised efficiently. In any new recording scheme efforts should be made to incorporate, where possible, the existing indigenous systems and institutions to ensure quick adoption and success.

Nucleus herd breeding schemes where the selection of breeding stock is concentrated in a few herds from which the selected animals are spread to other herds, are attractive in many developing countries as suggested by Smith (1988). They are designed to allow a good recording on a limited number of animals and data management at reasonable cost, and may be combined with the use of efficient reproduction technologies [CS 1.7 by Khombe]. Open nucleus breeding schemes, which also allow inflow of high potential breeding animals from other herds, have been proposed as ideal for genetic improvement in situations with moderate levels of management (Smith, 1988; Barker, 1992). A nucleus herd programme is used to both conserve an indigenous breed and to upgrade the local population (see Figure 4).

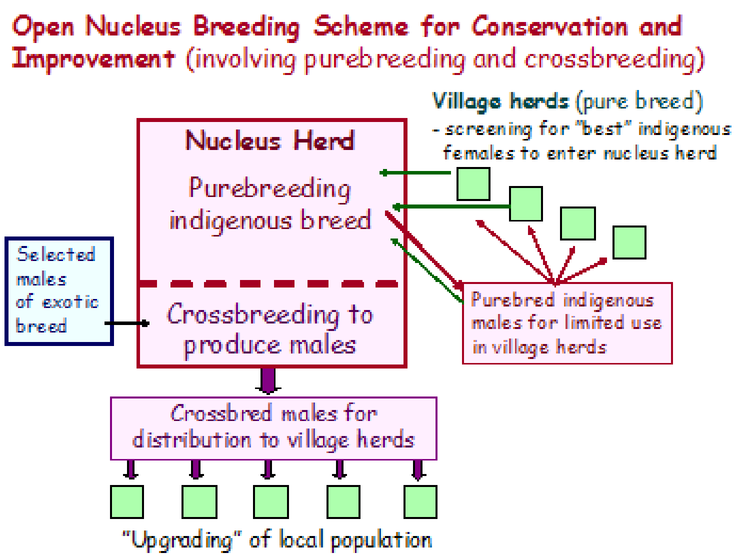

Figure 4. *Open nucleus herd breeding scheme—basis for conserving an indigenous breed and upgrading local population.*

As recording schemes include different activities and serve various purposes but involve the same farmers and animals, the activities must be well integrated to be cost-effective and provide the farmer with added information [CS 1.13 by Banga]; [CS 1.14 by Olivier]; [CS1.19 by Yapi-Gnaore]; [CS 1.26 by Ramsay et al.]. There are many examples around the world where good attempts at recording different aspects of the livestock partly lose their value as the information is not integrated and fully utilized (Wasike et al., 2011); [CS 1.19 by Yapi-Gnaore]; [ICAR Tech. Series No. 1. 1998]. Alternative forms of dispersed nucleus breeding schemes and modified sire reference schemes have been successfully implemented in Latin America and parts of Asia (Mueller, 2006).

4.5 What reproduction technologies are feasible?

AI has undoubtedly proven its value for genetic improvement programmes of several species, but most notably in cattle. The success in cattle breeding depends on the number of pregnancies it is possible to achieve per bull and per year through AI compared to males of other species. The utility of frozen semen in cattle is also exceptionally good. These advantages have also proven beneficial in many developing countries, not the least in crossbreeding when genes of exotic breeds have been introduced through semen imports. The widespread use of AI in the Kenya highlands of East Africa, for example, provided the opportunity of introducing milk for school lunches in the country as a result of increased production of milk from crossbreeds and exotic breeds. This technology has also lead to one of the most successful smallholder dairy systems in the developing world apart from the Indian example (Stall et al., 2008a). However, with the sudden change of policy and removal of public support, the system simply collapsed. The development of Sunandini cattle as a synthetic breed through consistent use of AI provided almost a tenfold increase in the per capita consumption of milk among the people of Kerala Province in southern India [CS 1.40 by Chacko]. Therefore AI has great advantages from a genetic improvement point of view through its effective dissemination of germplasm and the opportunities for strong selection of breeding stock [CS 1.31 by Philipsson]. Equally important, this methodology has great advantages in controlling or eradicating diseases that might be transmitted in natural mating systems.

However, the use of AI has also failed in many situations in developing countries because of the lack of infrastructure and the costs involved, such as for transportation and liquid nitrogen for storage of semen or because the breeding programme has not been designed to be sustainable [CS 1.3 by Mpofu]; [CS 1.31 by Philipsson]. Improper use of AI for crossbreeding indigenous cattle with exotics may be disastrous when, for example, a long-term strategy lacks information on how to maintain the appropriate level of exotic genes in an environment that cannot support pure exotic breeds. The pros and cons of using AI should therefore be critically reviewed for each case before designing breeding programmes.

Another reproduction technology proven to enhance genetic progress in many situations is embryo transfer (ET). Superior females may be super-ovulated and mated with highly selected males to produce embryos of high expected genetic merit. Such systems suit nucleus-breeding schemes well and provide specific opportunities for conservation and development of minor breeds, for establishment of gene banks and for synthetic breed formation. Provided the technique and infrastructure are available, it may also be useful in developing countries [CS 1.16 by Mpofu]. However, the costs versus benefits must be critically evaluated, considering actually obtained and not ideal technical results. Use of sexed semen, either alone or via *in vitro* production have also been tried, but no commercial success has been achieved to date. Scenarios where use of sexed semen in combination with genomic selection has been simulated by Pedersen et al. (2010), however, the results showed non-significant potential genetic gains, and even fewer gains are possible when such strategies are used in combination with multiple ovulation and embryo transfer (MOET) technology.

4.6 What methodologies for genetic evaluations should be applied?

Tropical regions are endowed with a wide diversity of breeds and strains of livestock. Besides, the available body of evidence indicates that there is substantial within-breed variation in most of the economically important traits. Indeed, estimates of heritability of these traits in tropical breeds in well-managed populations are often either within the range of or higher than corresponding estimates from temperate regions. Since most populations of indigenous tropical livestock have been subjected to only very mild artificial selection pressures for productivity, the general trend of high heritability estimates is expected [CS 1.6 by Mpofu and Rege]; [CS 1.9 by Aboagye]. However, the few available estimates of heritability for production traits in indigenous tropical breeds have invariably been based on insufficient data. Furthermore, most of these studies have suffered from poor experimental design. These factors, and the generally poor animal management in these situations, have obviously resulted in large environmental variations and biases. Therefore, heritability estimates on the lower end of the scale have often resulted from large environmental variation rather than from small genetic variation. The low reproductive performance of tropical cattle may largely be due to environmental, mainly nutritional, stresses. Nonetheless, estimates of heritability of female fertility traits in the tropics, while low to moderate, are usually higher than estimates in temperate cattle breeds.

Another critical component of genetic improvement, apart from ‘variation’ is selection intensity. In low-input (traditional) systems, reproductive rates are often so low, especially in cattle, and mortalities so high that there is hardly any opportunity for selection. Farmers invariably have to keep all female animals that survive, not because they are they most productive, but because they are hardy. Absence of recording is another serious constraint, which makes it impossible to undertake selection on objective criteria. Selection pressure is further compromised in most cases by small herd sizes and uncontrolled breeding in communal grazing systems (Rege et al., 2011).

The basic principles for genetic evaluations based on pedigrees, individual performance and sib and progeny information are, however, always valid. Generally, the more information included from the individual and its close relatives, the more accurate the estimated breeding values will be. However, three points need to be made:

1. The concept of progeny testing as a method for genetic evaluation and selection is widely over-emphasized, especially if the breeding programme does not allow a rather high level of infrastructure and sophistication and if the populations are small.

2. Because of the large environmental influences on production in many tropical production systems, it is tempting to use rather advanced genetic statistical methods of analysis of the performance data, i.e., BLUP (Best Linear Unbiased Prediction) Animal Model, to correctly separate genetic and environmental effects and to consider all genetic relationships [Group discussion: Breeding programmes]. However, using BLUP does not comply with the KISS principle! It may therefore be advisable, at least at the beginning of a selection scheme, to select just on phenotypic values within similarly raised or kept animals of the same age. With time, more advanced methods for genetic evaluation may be applied. Current progress in molecular genetics indicates that information on genetic markers associated with specific traits, e.g., disease resistance and quality of products, may become useful in the future (and would be cheaper) as a complement in genetic evaluations, as is indicated in the next section [CS 1.19 by Yapi-Gnaore].

The use of *mass selection* (animals selected on phenotype), including pedigree information, seems to provide the best base in many situations for correct ranking of potential breeding stock in developing countries, especially for animals held in nucleus herds with good record keeping. Mass selection is also a valuable method for screening animals to form the initial nucleus population. Animal identification systems that use already existing indigenous traditional knowledge and simpler methods such as scoring and ranking of only the top 5–10% of animals in the herd, where herds are large as in pastoral communities, would provide a good avenue for using more accurate genetic evaluation methods. Within traditional livestock production systems livestock keepers (e.g., pastoralists) can identify and rank their stock accurately. Ranking methods used within these systems can be documented and practically applied if the livestock keepers are involved in the design of evaluation programmes from the outset (Kosgey and Okeyo, 2007).

4.7 DNA-analyses and genetic marker information useful for selection and introgression

The hitherto most successful proven use of molecular genetics in practical breeding programmes relates to identification of single genes which in their recessive homozygous forms are lethal or bring defects to the animal. Successful DNA-tests have been developed for a number of such genetic defects, e.g., Bovine Leukocyte Adhesion Deficiency (BLAD) and Complex Vertebral Malformation (CVM) in cattle, which enable their elimination from the populations in question. BLAD, an immune deficiency, and CVM, a vertebra malformation, are defects widespread in the Holstein cattle breed caused by recessive genes. In both cases, carrier bulls had been used widely around the world before the defects were discovered [See OMIA] or the website (http://omia.angis.org.au/).

Current progress in molecular genetics has also shown that information on the genetic background of quantitative traits will be available to an increasing extent in livestock. Recent developments, following the sequencing of whole genomes of several species, have opened up completely new opportunities. By correlating the DNA information, single-nuclear-peptides (SNP), in the chromosomes with phenotypic information of the same animals it is possible to develop regression formulas for prediction of breeding values of future animals. Thus, breeding values can be predicted for the newborn animal with an accuracy almost twice as high as that obtained with just pedigree information. The gain is larger for traits with low heritability than for those with high heritability. Practical use of the methods began in 2009 in dairy cattle breeding, but it is still difficult to evaluate the efficiency of the methods practised (Reents, 2010; Wiggans et al., 2010; Weigel., et al., 2010). Four important pre-requisites must be mentioned:

1. In order to develop the regression formulas to predict breeding values of future animals it is necessary to base these calculations on large sets of population data on phenotypic information of all traits for which breeding values are going to be predicted. So far, when using panels of 50K SNPs in dairy cattle several thousands of bulls with accurately estimated breeding values have been needed in the so-called reference or training populations which contain both SNP information and breeding values based on phenotypic records.

2. Due to selection based on SNP information the prediction formulas need to be regularly revised. Thus, continued phenotypic recording of important traits is still needed.

3. Results for one breed are not directly applicable in another breed, i.e., data and prediction formulas need to be developed for each breed where the methodology is going to be practised.

4. Although costs for genotyping individual animals are rather high they will most likely reduce, but will still be high for large-scale use.

A specific area of use of genomic evaluation is for parentage testing. Also, in cases where no pedigree information is available it may be possible to determine the genetic relationships among animals in a population, provided enough SNPs are available for the analysis.

The area of genomic evaluation and selection is under very rapid development, not least the technical tools to use. The use of SNP panels of variable size will be available, e.g., panels with 3K for screening purposes as well as 800 SNPs for more accurate predictions in dairy cattle. Also whole genome evaluations are in the pipeline (Interbull Bulletin 41, 2010). Whatever happens, no progress in the use of genomic selection is possible without accurate phenotypic records of large populations. That is why it is still urgent to develop livestock recording in the developing world.

Previous research and use of molecular genetic information has focused on identification of quantitative trait loci (QTL) for economically important traits in many different species and breeds. Thus in some cases, information on QTL (Module 4, Section 6) added valuable information to breeding programmes by so-called marker-assisted selection (MAS). Its greatest impact in practical situations was expected to be where phenotypic information is limited, e.g., when the heritability of the traits in the breeding goal is low, when the trait is expensive to record, when the traits cannot be recorded on all individuals (sex-limited traits, carcass traits and disease traits).

When QTL has been located accurately, marker information can be used in the genetic evaluation of individuals even if the gene itself is not pinpointed. Potentially, MAS can increase genetic progress by increasing accuracy of evaluations, by increasing selection intensities and by decreasing generation intervals (Dekkers, 2004; Cole et al., 2010). For dairy cattle, for example, several different breeding schemes using MAS have been proposed (reviewed by Weller, 2001; Meuwissen, 2005). A recent review by Marshall et al. (2011) and results of a study by Bennett et al. (2010), show that unlike gene assisted selection (GAS), MAS could be of limited application in some traits, especially in dairy and beef cattle. However, MAS has potential application in poultry, pigs and beef cattle breeding. In progeny testing schemes marker information can be used in addition to phenotypic information from the daughters of sires and for pre-selection of young bulls before entering progeny test.

These advantages are even more obvious with genomic selection as this method makes use of not only QTLs but also all small genetic effects of the other loci in the genome.

Introgression is a breeding strategy for transferring specific favourable alleles from a donor population to a recipient population. This would, for example, be of great interest for genes responsible for disease resistance, which could be introgressed into a susceptible but otherwise economically superior breed. The strategy has two components:

- fixation of the favourable alleles in the recipient population
- reduction or elimination of the rest of the donor genome from the recipient population.

Crossing the donor and recipient population produces an F_1 generation. Thereafter, a series of backcrosses to the recipient population is performed, but in each generation only individuals that carry the favourable donor allele are selected to produce the next BC generation. After a number of back crossings, the progeny are inter-crossed and a population that is homozygous for the donor allele is obtained. The higher number of BC generations before the inter-cross and the larger proportion of the genome will then be from the recipient population. When the gene to introgress is a QTL, genetic markers must be used to identify the favourable donor allele. Markers can also be used to identify the origin of the remaining genome and therefore decrease the number of BC generations needed. The DNA-based marker identification technology is becoming cheaper with time thus enabling MAI to become affordable, even under low-input production systems, so long as the breeding programme is effectively organized. Such a MAI scheme is shown in Figure 5.

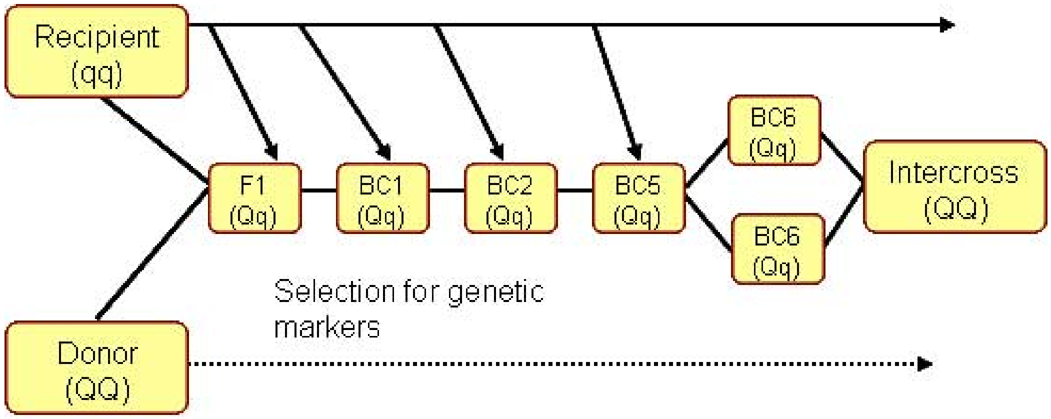

Figure 5. *An introgression breeding scheme with MAI.*

Under tropical conditions, there are presently two obvious candidate traits for MAS and MAI-trypanotolerance in African cattle and helminth resistance QTL in sheep. Several QTL related to trypanotolerance have been detected in an experimental cross between the trypanotolerant breed N'Dama (*B. taurus*) and the East African Boran (*B. indicus*) as reviewed by van der Waaij (2001), while helminth tolerance QTL in sheep is currently being studied at ILRI in experimental crosses between the helminth tolerant Red Maasai breed and the susceptible Dorper sheep breed. These QTL, if found to be of substantial influence, could be used for MAI, MAS or GAS if the associated genomic area/SNPS were to be identified; they could also be used in a combined introgression and selection programme. A drawback with a pure MAI programme is the large number of individuals required, and ensuing high costs, when several QTL are to be introgressed. There is also a possibility that other advantageous genes besides the mapped QTL or positive gene combinations are lost when the donor genome is eliminated. This loss of genes/gene combinations is also a risk when only marker information is used for selection within a breed or in a hybrid population; use of MAI and MAS in addition to conventional methods is therefore recommended. However, an important advantage with QTL information for resistance to diseases is that animals can be selected without exposing them to infection. That is, individuals or embryos that carry the required genes can be selected as early as immediately after conception. The individuals or embryos can be further tested for the other desirable genes for high growth, carcass quality etc. soon after birth.

5 Balancing rate of genetic gain, diversity and environmental impact

A number of conflicts, e.g., between the desires to achieve both accurate breeding values and high selection intensity, will occur when designing a breeding programme. Consequently, various issues must be considered to optimize the programme. The scheme giving the theoretically highest genetic gain may also not always be the best. For example, applying the highest selection intensity might be biologically possible and will in the short run lead to large genetic improvements. In the longer run, however, problems with inbreeding maybe encountered due to the faster narrowing genetic base. It is also well accepted that progeny testing provides excellent opportunities to achieve high accuracy in estimation of breeding values, but the test resources required leave little room in smaller populations for use of the reliably tested selected animals. Selection based on progeny testing also prolongs the generation intervals, contributing to reduced genetic progress. In intensive production systems large inputs, e.g., of feed resources and health care, may for a time provide the largest genetic improvements and favour certain genotypes. Later, shortages of resources may not allow the expected gains to be realized. Therefore, the design of a breeding programme must accommodate a whole range of complex considerations to provide an optimum solution for the genetic resource utilization. Designing a sustainable breeding programme means finding the best compromise among all factors that determine the success of the programme. This could be short and long term. In many situations, use of young bull schemes would be a better option than engaging in poorly organized dairy cattle progeny testing scheme (See computer exercise on breeding plan).

Although it is a delicate issue to optimize a breeding programme for a given population considering genetic factors and the population structure, several external factors are necessary for the programme to be sustainable. Farmers' acceptance and involvement and appropriate infrastructure have been pointed out earlier, and the KISS principle. A sustainable breeding program should incorporate robustness of the system so that it may withstand externalities such as climatic problems, disease outbreaks, political instability and lack of continuity in organization of the activities. Thus, it is important to align with strong organizations with a common interest of improved livestock use and production.

6 Monitor the breeding programme to show impact

A final, but significant, part of a breeding programme is the initial evaluation of the options and regular analyses of the outcome of the programme (FAO, 2010); [CS 1.6 by Mpofu and Rege]. Such analyses should demonstrate the genetic improvements obtained in all important traits and also the effects on total output of products and per unit of measurement, e.g., per animal, per hectare etc. and the economic impacts at both farm and national levels. Outputs should be related to inputs and the status of natural resources utilized. These change with time and must be revised accordingly. By regularly monitoring the breeding programme, corrective measures can be taken to improve it [Computer exercises: Breeding plans]; [Manual exercises: Selection and Genetic gain]. Showing the impact of the breeding programme may also be essential for its future support. If regular monitoring cannot be conducted, similar studies could be done as research projects at certain intervals, whereby data from the recording scheme are used to analyse the genetic changes in different traits and to study population structure [Group discussion: Breeding programmes].

7 Research is needed to support the breeding programme

The design of any efficient breeding programme relies on research results and practical experiences. The research should include analysis of breed characterization data, estimation of genetic parameters specific to the actual breed and environment [CS 1.8 by Mpofu]; [CS 1.9 by Aboagye]; [CS 1.16 by Mpofu], development of appropriate methods for estimation of breeding values and for selection, analysis of results from different reproduction technologies etc. Evaluation of exotic germplasm and its utilization is another important area [CS 1.4 by Mpofu]; [CS 1.5 by Kahi]; [CS 1.8 by Mpofu]. The advent of molecular genetics and MAS provide new opportunities and bring research and practical breeding programmes closer. Experiences from many countries show the value of data from livestock recording schemes for research (Figure 6). Using such data is advantageous as they are relatively cheap and offer opportunities to estimate relevant genetic parameters for the breeding programme and to monitor its progress. Furthermore, they familiarize more people at scientific and extension level with livestock data and results that reflect real life situations. Livestock recording schemes, therefore, provide effective mechanisms for implementation of research results in practice (Philipsson et al., 2005).

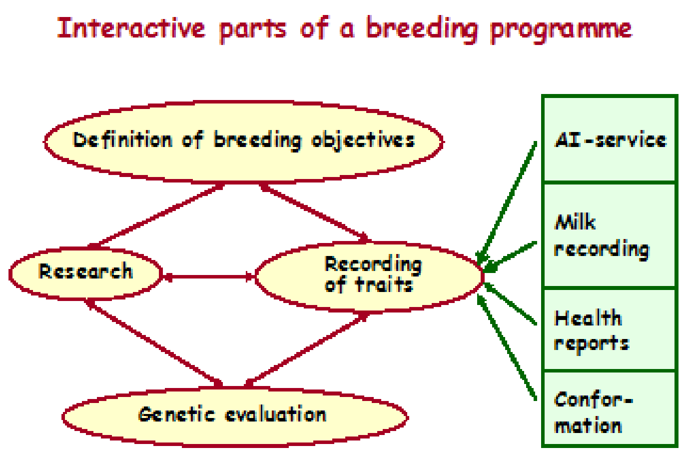

Figure 6. *The interactive parts of a dairy breeding programme.*

Technical (research and academic) institutions design and sometimes perform/conduct genetic evaluations. However, these institutions do not provide adequate and timely feedback on the evaluations to farmers; this is one reason for the failure of breeding programmes in developing countries. Lack of feedback should no longer occur given the great advances and reduction of costs in telecommunication and communication through the Internet. Moreover, access to cell phones and Internet connectivity are expanding rapidly in many areas. Innovative use of these systems in relaying raw data to data centres and results back to the farmers should be explored.

8 Globalization of breeding programmes—Opportunities and threats

The dramatically increased trade in frozen semen and embryos, mainly of cattle, and eggs and live animals of other species has led to globalization of breeding programmes of a number of species and breeds. In dairy cattle breeding, for example, bulls of six major breeds, namely Brown Swiss, Guernsey, Holstein, Jersey, Red Dairy Cattle (Ayrshire) and Simmental (dual purpose), are nowadays genetically evaluated on an international basis through the INTERBULL system. Data from about 30 countries from 4 continents are included. South

Africa and Australia represent the tropical parts of the world, while New Zealand represents specialized grazing conditions. By utilizing data on daughters of the same bulls spread in many countries and environments, it has been possible to estimate the genetic correlations between results obtained in different countries. Therefore, genotype by environment interactions that exist between different regions and production systems are considered when estimating the breeding values of individual bulls. These international genetic evaluations have expanded to include mastitis resistance, calving traits, fertility, workability traits and longevity as complements to production and conformation traits. Selection of bulls across countries based on such breeding values has enhanced the opportunities for more correct selection according to the breeding objectives in each region or country. By applying the genotype by environment correlations, more top bulls are also identified globally. This supports the maintenance of a larger genetic diversity compared to the previous situation when all countries used the same top bulls [See www.interbull.org].

The intense global use of a few individual sires introduces a high risk that some of these sires may transmit undesirable genes that are not easily detected when used on a limited scale, e.g., BLAD and CVM. In both cases carrier bulls had been widely used around the world before the defects were discovered. Luckily DNA-tests had been developed for both defects to detect any carrier and are providing a means to omit such bulls from breeding (see Module 4 Section 6). These are just examples of what can happen and probably is happening with yet unknown defects. However, these examples point at the opportunities to find and eliminate recessives that otherwise would have stayed in the population and continued to cause sporadic damage. It underlines the necessity for strict reporting mechanisms to detect any animal with congenital defects. For information on inherited diseases and defects, see [OMIA] or the website (http://omia.angis.org.au/).

Although globalized breeding programmes primarily seem to involve the developed world, they also have an effect on breeding in tropical countries. Usually, the same type of germplasm is marketed in tropical regions as in temperate areas without much analyses of what is needed for each specific market. There are all kinds of reasons to be more critical in developing countries when choosing germplasm from temperate breeds than is currently the case. Increased interest and participation in INTERBULL for information on international comparisons has been recommended for Africa, Asia and Latin America, where the import of semen from exotic breeds from more temperate environments is prevailing or desired (Philipsson et al., 2005; Interbull Bulletin 33, 2005). Thorough analyses of the national breeding objectives should provide guidelines and improve the opportunities for choice of breeds and individual animals that fit local conditions. Increased participation also helps to be aware of what is going on globally.

9 Measures to conserve threatened breeds

FAO has defined population sizes at which breeds could be labelled endangered and at risk of extinction. Although, such numbers need not be taken literally, they provide useful guidelines. To prevent breeds from becoming extinct, various measures are recommended. *In* *situ* conservation schemes involve support of live populations of such size that viable breeding programmes should be possible to maintain, while avoiding inbreeding problems. The aim of *ex situ* conservation schemes is twofold: maintaining gene banks by cryopreservation (semen and embryos) and, if possible, maintaining the remaining small populations (see FAO, 2007a; FAO, 2011).

As the effects of breeding programmes are determined on a long-term basis, it is quite important to continuously monitor changes in population sizes and immigration of genes between populations. The Global Strategy for the Management of Farm AnGR provides a technical and operational framework for assisting countries as laid out in chapter 3.4.

Additionally, FAO has developed a communication and information tool, the Domestic Animal Diversity Information System [DAD-IS], to implement the Global Strategy [FAO, 2007b-GPA]. The objective of DAD-IS is to assist countries and country networks by providing extensive searchable databases, tools, guidelines, a library, links and contacts for the better management of all AnGR used in food and agriculture. That way, it would be possible to effectively apply certain measures to conserve threatened breeds. However, for the systems to work, the country-level participation must remain highly proactive and professional and use participatory approaches with livestock keepers, Otherwise, one may consistently get stuck with projects aimed at rescuing the remaining small number of animals of a breed, but at a stage when it is too late to develop the breed.

As stated initially in this module, there is no method more efficient for conservation and sustainable development and use of a breed than keeping it commercially or culturally interesting for present and future generations!

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