

Sustainable breeding programmes for tropical 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 a number of reasons. Long-term and simple strategies are necessary, as well as the need to better exploit the potential of indigenous breeds. Increased productivity per animal or area of land used 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. There are links [\[burgundy\]](#) to the internet and [\[blue\]](#) within the module to case studies and other related components of this resource that help illustrate the issues presented.

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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 indigenous 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 expansion of animal numbers with subsequent effects of land degradation. Production system must thus consider, all aspects of the resources needed along with the outputs, positive as well as 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, although on a short-term, have been obtained in well-designed crossbreeding schemes. These programmes have been favoured by resourceful environments and well developed infrastructure and markets. The issue now is how to design efficient breeding schemes for indigenous breeds in the tropics, where resources are limited and feed availability varies in harsh climates. How could productivity, including fitness and adaptive traits, be maximised 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. be parts of the livestock use in the total development of a region or community. Thus, 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 1, Section 3.2, 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 community development and an opportunity for improved livelihood of livestock owners [CS 1.15 by Dzama]; [CS 1.19 by Yapi-Gnaore]. This module will therefore point out some general principles to consider when designing breeding programmes, and especially point at both genetic and external factors and issues that might be of importance specifically for tropical farming systems.

2 Previous genetic improvement programmes—lessons to learn

Many attempts to improve livestock in the tropics have been made, mainly by ‘up-grading’ with temperate breeds in crossbreeding. Although it should be recognised that improved livestock have been produced or introduced in favourable areas of the tropics, e.g. in some highland areas, in maritime climates and in relatively intense peri-urban production systems, many attempts have failed. Payne and Hodges (1997) have thoroughly reviewed the situation as regards cattle breeding. In fact, there are many case studies from which lessons can be learnt from failures [CS 1.3 by Mpofu], but few from successful programmes [CS 1.2 by Mpofu]; [CS 1.5 by Kahi]. Analysing the reasons for failures in different reports reveals some common problems [Module 1, Section 6].

- The breeding programmes have been too complicated as regards logistics, technology and requirements of resources without considering the infrastructure available [CS 1.3 by Mpofu].
- A major reason for failure has been 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 less resistance to diseases and impaired ability to withstand environmental stress [CS 1.31 by Philipsson].
- Another reason is the 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 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].

3 Some considerations when designing a breeding programme

Obviously, approaches better adapted to consider the potential of indigenous livestock breeds must be developed. Realistic ways of improving this livestock must be chosen and applied in the context of environmental constraints and socio-economic demands as well as 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 of conserving a breed for future generations than consistently keeping the breed or population viable by applying an efficient, demand-driven, long-term breeding programme suitable to commercial or cultural needs.

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

There are many important circumstances that determine the scope of opportunities as well as constraints of the breeding programme. Agricultural policy and market, environmental conditions, characteristics of animal populations and infrastructure available are examples of such factors. Basic questions concerning the choice of overall breeding strategy include the emphasis on improving indigenous breeds vs. the use of ‘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, as well as to improved resource utilisation and livelihood of the livestock owners. Thus, livestock breeding programmes would make up an important part of the national agricultural policies, aiming at improving the food and income of a country, region or locality and of livestock

keepers. In fact, 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 the environmental conditions, the production system and the culture for which the animals are bred. Village breeding programmes for smallholder farmers [CS 1.19 by Yapi-Gnaore] will be different from large scale farming systems [CS 1.16 by Mpofo]; [CS 1.26 by Ramsay et al.]. Intensive crop–livestock systems, with available good feed and health-care facilities enable other opportunities for rapid improvement programmes than harsh rangeland systems. 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. Developing a programme that considers both the present circumstances and possible future situations, including market conditions, is a challenge. This is because there is a considerable time lag between implementation of the programme and when the benefits of genetic gains are realised. Therefore, breeding programmes should be somehow flexible to be responsive to variable scenarios for future needs of the programmes.

3.3 Infrastructure and farmers' role

Breeding programmes usually assume some kind of co-operation 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 services and other activities [CS 1.2 by Mpofo]; [CS 1.6 by Mpofo]; [CS 1.14 by Olivier]. The initial developments of breeding programmes are generally made by government organisations in most developing countries because of the national benefits of improving the 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, in order to ensure that their needs are taken into account and that they provide the support needed for the programme to work [CS 1.14 by Olivier]; [CS 1.26 by Ramsay et al.]. Breeding programmes in the hands of farmers' co-operatives, often with government support, have, throughout the world, been successful for several livestock species. Specialised breeding companies, on the other hand, have evolved under certain commercial conditions, especially for poultry and pig breeding, and, to a lesser extent, for cattle breeding. Such companies have often been able to produce high quality breeding stock for industrialised production systems. In these cases, it is therefore 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 Mpofo]. One often over-looked assumption is the required integration of all activities constituting a breeding programme. This applies both at the government level as much as at the

practical organisational level. Another potential problem in developing countries is lack of, or inadequate number of people with appropriate training or incentives to successfully run a breeding programme. Lack of required infrastructure is one of the most serious constraints that prevents development of indigenous breeds in tropical countries.

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

Clearly, in order to improve any breed or population, it is important to 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. To the extent 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, specialised 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.

Thus, in attempting to establish 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, while also having potential for increased productivity. To what extent should efforts be made to modify production environments in order 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 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 optimum. In many traditional tropical livestock production systems, level of animal management and nutrition cannot support the potential of the so-called improved breeds. The extent to which these environments can be freed of the limitations imposed by climate, disease, parasites and nutrition is quite limited. This makes a strong case for the utilisation 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].

It should be pointed out that 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 before going for importations. Even when some sort of crossbreeding is opted for, it is important that a programme of evaluation, improvement and conservation of the indigenous parental breeds be maintained in parallel.

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 of 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].

3.5 *What breeds are or may be available?*

The present 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 Mpofo]; [CS 1.31 by Philipsson]. What kind of strategy is needed to effectively utilise these indigenous livestock genetic resources?

A basic question is which breeds to use or target for 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, there may be a shift towards more commercialised meat (e.g. beef) production systems and/or dairy production. 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. On the other hand, beef production in tsetse-infested parts of eastern Africa may consider the use of the Orma Boran, considered to be less trypano-susceptible than most 'beef-type' cattle breeds in the sub-region. This example illustrates the needs for systematic *characterisation of the breeds* presently used in the actual area [Module 2, Section 2]. Such a characterisation 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 very 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 characterisation 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 [Module 2, Section 3.3]. Among the breeds with a 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 global gene pool to draw from. Breeding programmes have, over time, become more international. This requires more knowledge than previously understood to evaluate the

genetics 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](#)].

Are small breeds less productive than larger breeds

A very 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 requirement 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. In addition, 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 Mpofo](#)]; [[CS 1.8 by Mpofo](#)]. However, with improved nutrition and general management, selection for increased growth rate or body weight may be justified.

Ample documented evidences indicates that, under conditions in which indigenous tropical livestock are predominantly kept, specialised large sized imported breeds would be no match, especially for meat production. Most studies done to date — mainly under station or improved (commercial) production conditions in tropical and subtropical 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 the European dairy cattle. However, when adjusted for animal size, the productivity of some breeds is quite considerable, even without considering the harshness of the production environment and the input requirements for indigenous livestock relative to those for specialised exotic breeds. The variation among the indigenous breeds is quite substantial though [[Breed information](#)].

Unfortunately, there are very few systematic breed evaluation studies 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 requirement, superior calving rate and low calf mortality [[CS 1.8 by Mpofo](#)].

Whereas the relationship between body weight and requirements for maintenance is 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 development of a breeding programme is illustrated in Figure 1. It 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 determined by the scope of *farmer participation*.

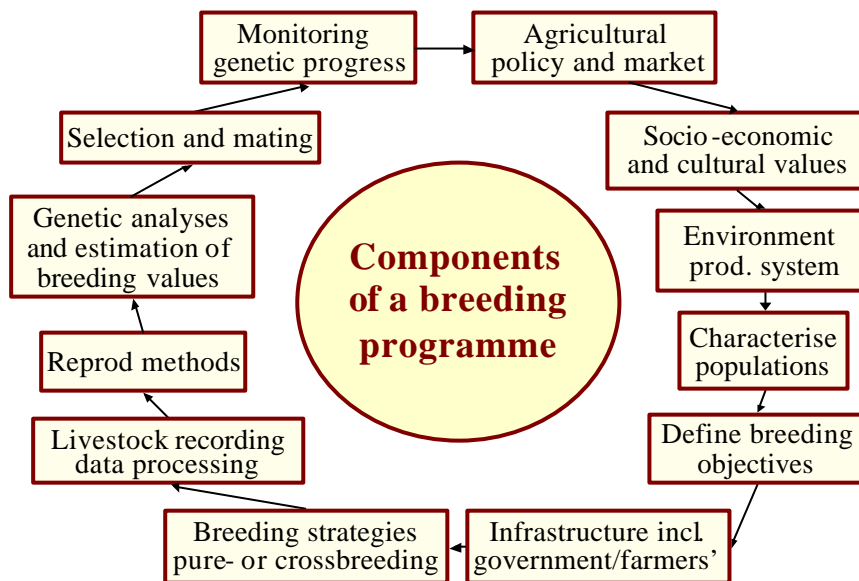


Figure 1. *Components of a breeding programme.*

In the following chapter, different breeding strategies will be presented and aspects on developing improvement programmes at breed level will be dealt with. It should be pointed out that 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 a number of pre-requisites 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 emphasised.

4.1 What strategy to choose

Payne and Hodges (1997) have reviewed in rather detail the past developments of genetic improvement programmes for cattle in the tropics, as well as 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:

- 1 crossbreeding indigenous breeds with temperate breeds without artificial insemination
- 2 improving indigenous breeds
- 3 progressively substituting the breed with another indigenous breed
- 4 crossbreeding indigenous breeds with temperate breeds using artificial insemination
- 5 forming a composite (synthetic) breed.

The choice of strategy is dependent on many different factors specific to each situation and can be analysed according to the issues indicated by each one of the components illustrated. In general, these options should aim at being simple enough to allow programmes to be launched without much resources. However, in most cases, the schemes are based on open nucleus herds where the indigenous breeds are kept under selection. From these herds, males, either purebred 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 the alternatives no. 2 and 3 above. Through extensive breed characterisation work it will be more likely to find interesting indigenous breeds for use far outside their present habitats—the success of the Sahiwal breed, and the potential of the Kenana, Butana and N'Dama breeds—deserve special attention in this respect [see Breed information]. Also the additive genetic variation within the indigenous breeds seems to be large and has so far not been much exploited. The formation of synthetic breeds has been tried and several breeds of today resulted from such practice [CS 1.26 by Ramsay et al.]. It is also an interesting way out of a situation when systematic crossbreeding does not work, while the incorporation of exotic genes are deemed important [CS 1.5 by Kahi].

4.2 Defining the breeding objectives at breed level

The ultimate goals of a breed at the *macro-level* are 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. 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 10–15 years time horizon, while in pig and poultry breeding, the considerably shorter generation intervals also allow for shorter time horizons in selection.

It is extremely important that the breeding objectives are set at the national, regional or local level, and not by outsiders, in order to truly reflect the real needs of the area, and that the farmers support the direction of change [CS 1.14 by Olivier]; [CS 1.28 by Madalena]. There are many examples where breeding programme failures have occurred in developing countries (Cunningham and Syrstad 1987; Okeyo 1997; Payne and Hodges 1997). Some of these are specifically presented and discussed in case studies [CS 1.3 by Mpofu]. The conflicts that may occur between the long-term goals, expressed at national or organisational level and the interest of farmers in short-term benefits could be solved either by regulations or incentives for participation in a co-operative breeding programme.

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

As an alternative to calculation of relative economic weights, one may put *restrictions* on the change in specific traits, or define what is the *desired gain* 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, also the short-term benefits for farmers must be considered to get good farmers' 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 or not 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 placing major emphasis on selection for performance (Burrow et al. 1991). 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, thus, should avoid complicated selection criteria. Therefore, one should, in most cases, try to focus selection on a few, say 2–3, major traits for improvement [[CS 1.19 by Yapi-Gnaore](#)].

In a dynamic breeding programme, seeking the optimal utilisation of the genetic resources available, the breeding objectives should be reviewed on a regular basis in light of what has been achieved so far, and of 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 Purebreeding or crossbreeding?

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

The choice of breeding method, purebreeding alone or also using crossbreeding, is, perhaps, the most important issue to decide upon when designing a breeding programme. It relates partly to the previous discussion on characterisation of genetic resources, including exotic germplasm being available on the international market. Key issues include:

- 1 What is the level of performance and the potential of genetic improvement through selection within the indigenous breed?

- 2 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?
- 3 How important are effects of heterosis for the traits of major interest?
- 4 What are the opportunities of keeping purebred stock of two or more breeds being available for maintaining a long-term crossbreeding programme and infrastructure?
- 5 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?
- 6 Is the formation of a synthetic breed a viable alternative to both purebreeding and crossbreeding with exotic breeds?

Crossbreeding has principally been applied in the tropics to exploit breed complementarity. Specifically, specialised exotic (mainly temperate) breeds have been crossed with indigenous breeds to combine the high productivity of the former with adaptive attributes of the latter [CS 1.5 by Kahi]; [CS 1.25 by Euclides Filho]; [CS 1.26 by Ramsay et al.]; [CS 1.28 by Madalena]. Despite potential benefits from crossbreeding, there are not too many success stories in the tropics. Most 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 by crossbreds, but also through loss of certain traits, hence genes, not included in the breeding objectives at that time.

On behalf of FAO, Cunningham and Syrstad (1987) made an extensive analysis of 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 and 1990b) support these findings in general, but found the 62.5% level optimal. Results may, however, vary according to environmental conditions and traits studied [CS 1.28 by Madalena]. A general conclusion is, though, that crossbreeding to produce animals with up to 50% of the genes from temperate breeds can be recommended where crossbreeding, at all, is an option.

In practice 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, they have then been able to raise their income through selling milk from improved cattle [Module 1, Section 2]. However, as females are not replaced at the farm but mainly provided from government farms, this system is not sustainable and should only be utilised to introduce improved animals. These should instead be produced through systematic crossbreeding at the village farm level. However, the never-ending question has been what breed to use when mating the F_1 -animals. Usually too complicated schemes have been proposed in order to maximise the genetic gain, considering both additive and non-additive genetic effects, and then the programme has failed due to practical difficulties to run the scheme.

Thus, it is important to find a simple crossbreeding strategy, which can easily be followed under practical conditions. For simplicity and cost reasons it should be based on a continuous use of the females produced in the herd, just allowing new males to enter the herd live or by artificial insemination. Figure 2 exemplifies such a plan (Malmfors 2001). It is based on continuous use of F_1 -males on the indigenous and by time crossbred females in village herds allows a maximum of 50% exotic genes to be incorporated in the female stock. The strategy is based on the following two corner-stones:

- 1 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.
- 2 *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.

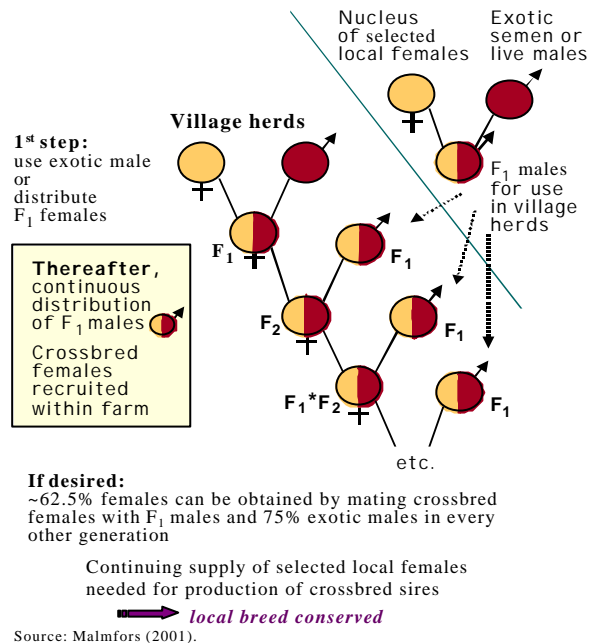


Figure 2. Example of crossbreeding scheme for livestock.

The application of 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 -heifers 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 under way. It is, however; important to note that the degree of success will depend on to what extent the villagers are involved in the design, implementation and review stages of the performance and pedigree recording system.

The advantages of this crossbreeding scheme are: crossbred females are recruited within the village farms

- only crossbred males need to be distributed
- no risk for too high ‘up-grading’
- 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 fails any reason, 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 maximised (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.

For *dairy cattle* improvement, it seems often obvious to apply crossbreeding in tropical farming systems. However, some indigenous breeds such as Kenana in Sudan and Sahiwal in both Asia and Kenya, have potentials to be used in purebreeding and for crossbreeding with other indigenous *Bos indicus* breeds [CS 1.31 by Philipsson], while, Jamnapari goats of India would play similar roles in improving milk production in goats, under tropical conditions. For *beef production*, there are a number of high potential indigenous breeds available for tropical environments, e.g. the Boran cattle in Ethiopia and Kenya. With improved management, crossbreeding with appropriate specialised beef breeds may also be considered for beef production.

The choice of breeding strategy, i.e. pure vs. crossbreeding, has vast implications at both farm and organisational levels and must be based on solid facts. Any change in the direction towards crossbreeding, from present purebreeding, 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 F₁-animals and their back-crosses to the exotic breed, compared with purebreds, in representative environments. Serious attention must also be paid to the logistic aspects of organising the crossbreeding programme to be sustainable.

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

Livestock recording schemes usually have the goal to provide farmers with information about individual animals for management as well as for breeding purposes. The objective could also be phrased as to provide an *information system* about the livestock, their use, performance and development, by farmers as well as by 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. It is better to start recording in a few co-operating herds that can be handled well, rather than running a scheme on a wide scale without the possibility to supervise the scheme efficiently.

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, allowing also in-flow 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). As illustrated in Figure 3, a nucleus herd programme is used for both conserving an indigenous breed and for upgrading the local population.



Figure 3. *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, it is important that the activities are well integrated to be cost-effective, and provide the farmer 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 of recording different aspects of the livestock, partly lose their value as the information is not integrated and fully utilised [CS 1.19 by Yapi-Gnaore]; [ICAR Tech. Series No. 1. 1998].

4.5 What reproduction technologies are feasible?

Artificial insemination (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 amount of pregnancies that are 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 Kenya as a result of increased production of milk from crossbreeds and exotic breeds. 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 Mpfu]; [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 is lacking 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 and for establishment of gene banks. Provided the technique and infrastructure are available, it may also be useful in developing countries [CS 1.16 by Mpofu].

4.6 What methodologies for genetic evaluations should be applied?

Tropical regions are endowed with a wide diversity of breeds and strains of livestock. In addition, 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. Given the fact that most populations of indigenous tropical livestock have been subjected to only very mild selection pressures for productivity, the general trend of high heritability estimates is expected [CS 1.6 by Mpofu]; [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 amount of data. Additionally, most of these studies have suffered from poor experimental design. These, together with the generally poor animal management in these situations, have obviously resulted in large environmental variations. Thus, heritability estimates on the lower end of the scale have often resulted from large environmental variation rather than from small genetic variation. Thus, 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.

A critical component of genetic improvement, only second in importance to ‘variation’, is selection intensity. In traditional systems, reproductive rates are often so low and mortalities so high that there is hardly any opportunity for selection. Farmers invariably have to keep all animals that survive. Absence of recording is another important constraint, which makes it impossible to undertake selection on objective criteria. Selection pressure is further compromised in most cases by small herd sizes and/or uncontrolled breeding in communal grazing systems.

The basic principles for genetic evaluations based on pedigrees, individual performance and sib and progeny information are though always valid. The more information included from the individual and close relatives, the more accurate will the estimated breeding values 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-emphasised, 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 areas, it seems quite important to use rather advanced genetic statistical methods of analysis of the

performance data, i.e. BLUP Animal Model, in order to correctly separate genetic and environmental effects. [Group discussion exercises: Breeding programmes].

- 3 Present progress in molecular genetics indicate, that information on genetic markers associated with specific traits, e.g. disease resistance and quality of products, may become quite useful in the future for genetic evaluations, as is indicated in the next section [CS 1.19 by Yapi-Gnaore].

The use of mass selection, 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.

4.7 Genetic marker information can be useful for selection and introgression

Present progress in molecular genetics has shown that information on the genetic background of quantitative traits will be available to an increasing extent in livestock. Thus, information on quantitative trait loci (QTL) [Module 4, Section 7] may become quite useful in breeding programmes in the future. Marker-assisted selection (MAS) will have its greatest impact in practical situations, where the efficiency of selection on phenotypic information is limited, e.g. when the heritability of the traits in the breeding goal is low, when the traits cannot be recorded on all individuals (sex-limited traits, carcass traits, disease traits) and when there are negative genetic correlations among traits.

- 1 When a 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. For dairy cattle, for example, several different breeding schemes using MAS have been proposed (reviewed by Weller (2001)).
- 2 Progeny testing schemes:
- 3 marker information used in addition to phenotypic information from daughters in sire breeding values and
- 4 marker information used for pre-selection of young bulls before entering progeny test.
- 5 Multiple Ovulation Embryo Transfer (MOET) nucleus breeding systems, in which marker information and phenotypic records of half-sisters are used for selection of sires, to be used in the nucleus.
- 6 Half-sib selection schemes, in which marker information and phenotypic records of half-sisters are used for selection of bull sires or all bulls, to be used in the commercial population.

Simulation studies reveal that the potential gain from MAS varies a lot between breeding schemes; the efficiency of a progeny testing system only increases a few percent, whereas a substantial genetic gain can be achieved through MAS in the two latter systems. MAS is already being used in some commercial breeding programmes for e.g. dairy cattle, pigs and poultry, but at this stage no realised results from applications of MAS in livestock have been published.

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 genes, which could be introgressed into a susceptible but otherwise economically superior breed. The strategy has two components:

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

Crossing the donor and recipient population produces an F₁ generation. Thereafter, a series of back crosses (BC) to the recipient population is performed, but in each generation only individuals that carry the favourable donor allele is selected to produce the next BC generation. After a number of backcrossings, the progeny are intercrossed, and a population that is homozygous for the donor allele is obtained. The higher number of BC generations before the intercross 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 thus decrease the number of BC generation needed. Such a marker assisted introgression (MAI) scheme is shown in Figure 4.

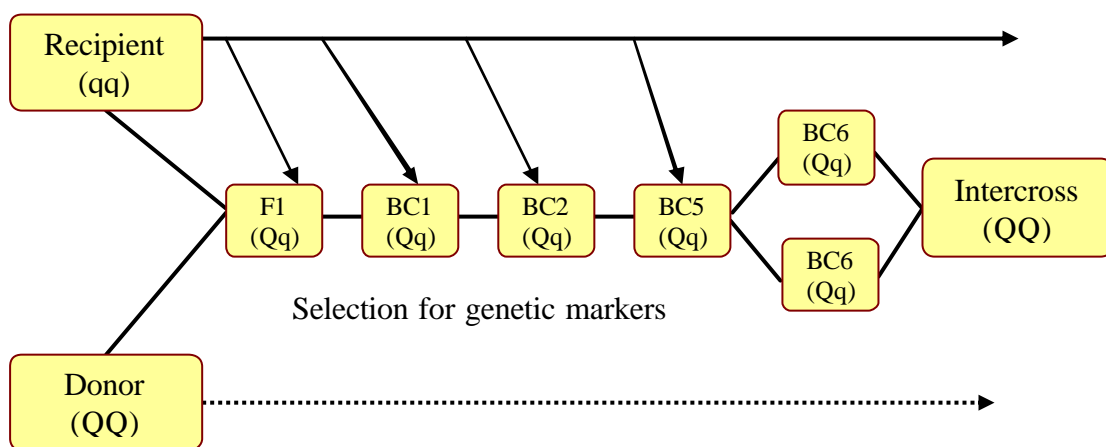


Figure 4. An introgression breeding scheme with MAI.

Under tropical conditions, there is presently one obvious candidate trait for MAS and MAI—trypanotolerance in African cattle. Several QTL related to this trait have been detected in an experimental cross between the trypanotolerant breed N'Dama (*B. taurus*) and East African Boran (*B. indicus*) as reviewed by van der Waaij (2001). These QTL could either be used for MAI, MAS or in a combined introgression and selection programme. A drawback with a pure MAI programme is the large number of individuals required, and thus the 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 breed or in a hybrid population. However, an important advantage with QTL information for resistance to diseases is that animals can be selected without exposing them to infection.

5 Balancing rate of genetic gain, diversity and environmental impact

A number of conflicts, e.g. between the desires to achieve both very accurate breeding values and high selection intensity, will occur in designing a breeding programme. Thus various issues must be considered to optimise the programme. The scheme giving the theoretically highest genetic gain may not also be always the best. For instance, applying the highest

selection intensity that might be biologically possible will, in the short run lead to large genetic improvements. In the longer run, however, problems with inbreeding will show up due to a quickly 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 some time, provide the largest genetic improvements and favour certain genotypes, while later, shortages of resources may not allow the expected gains to be realised. Thus, the design of a breeding programme must accommodate a whole range of complex considerations in order to provide an optimum solution for the genetic resource utilisation. Designing a sustainable breeding programme means finding the best compromise among all factors determining the success of the programme on short as well as long-terms.

6 Monitor the breeding programme to show impact

A final, but very important, part of a breeding programme has to do with regular analyses of the outcome of the programme [CS 1.6 by Mpofu]. 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. as well as the economic impacts at both farm and national levels. Outputs should be related to inputs and the status of natural resources utilised. By regularly monitoring the breeding programme, corrective measures can be taken to improve the programme [Computer exercises: Breeding plans]; [Manual exercises: Genetic gain]. Showing the impact of the breeding programme may also be essential for future support of the programme. If regular monitoring cannot be conducted, similar studies could be done as research projects at certain intervals, whereby data of the recording scheme is used to analyse the genetic changes in different traits and to study population structure [Group discussion exercises-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 characterisation 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 utilisation 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 marker assisted selection (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 purposes. 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 familiarise 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.

8 Globalisation of breeding programmes—opportunities and threats

The dramatically increased trade in frozen semen and embryos, mainly of cattle, as well as eggs and live animals of other species has, as previously stated, led to globalisation of breeding programmes of a number of breeds. In dairy cattle breeding, bulls of six major breeds are nowadays genetically evaluated on an international basis through the INTERBULL system. Data from more than 25 countries of four continents are included. South Africa and Australia represent the tropical parts of the world, while New Zealand represents specialised grazing conditions. By utilising 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. Thus, genotype by environment interactions that exist between different regions and production systems are considered when estimating the breeding values of individual bulls. Recently, these international genetic evaluations have expanded to include mastitis resistance as a complement 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 a situation when all countries used the same top bulls [See www.interbull.org].

The intense global use of a few individual sires introduces a heavy risk that some of these sires may transmit undesirable genes that are not easily detected when used on a limited scale. Recent examples of widespread defects in the Holstein breed include the recessive immunodepressive gene (BLAD) and CVM, a vertebra malformation caused by another recessive gene contributing to increased rates of abortions and stillbirths. In both cases, carrier bulls had been heavily used around the world before the defects were discovered. Luckily, DNA-tests have been developed for both defects to detect any carrier, and are providing a means to omit such bulls from breeding. These are just examples of what can happen, and probably are happening with yet unknown defects, but also point at the opportunities to find recessives at initially low frequencies. It underlines the necessity of strict reporting mechanisms to detect any animal with congenital defects. For information on inherited diseases and defects see [OMIA].

Although globalised breeding programmes primarily seem to involve the developed part of the world, they certainly also affect the 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 reasons to be more critical in developing countries when choosing germplasm from temperate breeds than is presently the case. 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. But there is also need 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. 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. *Ex situ* conservation schemes aim at maintaining gene banks by cryo-preservation (semen and embryos) and, if possible, by maintaining the remaining small populations (see FAO Global Strategy and FAO Animal Production Health Papers 76 and 99).

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 from other populations. That way it may be possible to effectively meet the needs for certain measures to be applied to conserve the breed. Otherwise, one may consistently get stuck with projects aiming at rescuing a 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 the present and future generations!

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