GENETIC IMPROVEMENT IN MEDIUM- TO LOW-INPUT SYSTEMS OF
ANIMAL PRODUCTION. EXPERIENCES TO DATE

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INTRODUCTION

The briefing for this paper requested an historical analysis and synthesis of genetic improvement, including breed replacement, crossing, and straightbreeding, addressing policy, operational and technical areas of practical genetic improvement programmes. We have examined experiences that we have been familiar with or that have been described in the literature (e.g., Galal et al., 2000) and tried to identify some of the reasons behind success or failure in terms of realising rapid and sustainable genetic improvement.

HISTORICAL OVERVIEW

Although rudimentary genetic improvement in animals has existed for centuries, the most recent forms of organisation varied according to specific regional peculiarities. Breed substitution and development played an important role in Latin-American cattle, where different breeds replaced the naturalised Iberian types or criollos. In Argentina, Uruguay and South of Brazil the local cattle were absorbed mainly by British beef breeds following the access to the British market and accompanying a trend of modernisation of production systems, including fencing, initiated in the last quarter of the 19th century. In the temperate areas and in the tropical highlands of the Region, dairy cattle were upgraded to European breeds, the Holstein predominating nowadays, with genes flowing in mostly from North America and Europe. In the tropical lowlands the beef cattle are now predominantly zebus, imported by private entrepreneurs in the early 20th century. The Brahman, originated as a composite of zebu breeds, is the most popular beef breed in Colombia, Venezuela and other countries in Central America and the Caribbean, while the Nelore, an Ongole derivative, is preferred in Brazil.

Crossing of *Bos taurus* x *B. indicus* has had a major influence in the Latin-American tropical dairy cattle but not as much in beef cattle. Disorganised crossing has been practised in dairy cattle for a long time. In Brazil, some 13 million dairy cows are hybrid (predominantly Holstein/Gir crossbreds) and have been kept intermediate between both parental species for several decades, by unplanned switching of the sire species or by using hybrid bulls. Non-descript composite populations developed rather spontaneously, e.g. the “seven-colours” in Colombia and the Carora in Venezuela (a predominantly Brown Swiss and zebu that has recently turned into a formal breed). Several new dairy and beef cattle breeds were developed in various countries, generally based on the “magic” 5/8 *B. taurus*: 3/8 *B. indicus* fractions, such as the Jamaican Hope (mainly Jersey:Sahiwal), the Cuban Siboney (Holstein:Brahman).
and the Brazilian Girolando (Holstein:Gir). As in other regions, the combination of large-scale investment and managerial/commercial organisation required for optimal results has not yet been available in tropical dairy breed development (Madalena, 2002).

In the Southern cone of Latin-America, where most of the sheep population is concentrated, an initial period of grading up the local breed (Criolla) to Merino type breeds at the end of the 19th century was followed by a strong predominance of Lincoln and Romney crosses for export mutton meat at the beginning of the 20th century, and a subsequent period of alternated crossbreeding with Merino or Lincoln and Romney rams, depending on market trends for wool or mutton meat. In the 1930s and 1940s, a process of grading-up to pure breeds was initiated, the Merino, Romney, Corriedale and Polwarth being preferred in different sub-regions, which led to the disappearance of the local types and the present predominance of the wool or dual-purpose breeds. In the highlands (altiplano) of Bolivia and Peru, native breeds and Corriedale types predominate, mostly in smallholders’ flocks, contrary to the situation in the Southern countries, so there is not the same degree of breed organisation. The same may be said of tropical wool-less sheep and tropical goats, in which organised breeding is only initiating. However, the new Brazilian tropical composite breed Santa Inês has surpassed the Southern woollen breeds in that country in registry numbers.

Because of the strong influence of breed societies, the usual pyramidal commercial structure was formed in cattle in most Latin-American countries and in sheep in the Southern ones. Selection was based on type and show ring prizes commanded fame but since the 1970s and 1980s local genetic evaluations of economic traits have been in place in several countries and steadily increased their commercial influence. Breed societies/herdbooks/show rings also existed in poultry and swine, but disappeared as these industries began using germplasm from international companies mainly after World War II. In Brazil, initially the one-day chicks were imported, but later on, large parts of the breeding programmes were locally based through joint ventures with national companies. These private firms have their own undisclosed programmes, but in both species germplasm interchange is known to occur world-wide and local selection is important, including the assessment of molecular markers.

In West Africa, rudimentary improvement predates the advent of the European colonialists to the region. Traditional cattle keepers, for example the Fulanis or Puehls, were known to improve the quality of their stock through the retention and exclusive use of outstanding bulls in their herds for breeding. Formal organised animal genetic improvement of domestic livestock, however, started in most of West Africa when colonial settlers with intimate knowledge of performance of specialised breeds in their home countries introduced some of the special attributes into animals in their new adopted homelands. It is, therefore, not surprising that modern history of animal genetic improvement in the region, and elsewhere in sub-Saharan Africa, usually starts with the story of crossbreeding. In Cameroon, Nigeria and Ghana, crossbreeding involving exotic and local breeds for improvement in meat and milk took place in the early decades of the 20th century. This initial effort in crossbreeding was followed by experimentation in the improvement of promising local breeds either by selecting within breeds or crossing of two local breeds. The attendant slow progress made in this direction discouraged breeders and policy makers in pursuing this route to improvement. Crossbreeding
was believed to produce faster results and so in the 1950s and 1960s exotic-based crossbreeding was popular in the region. Lack of funds to sustain these projects and lack of adaptation of the crossbreds to the deteriorating feed and health environment raised serious doubts on the sustainability of crossbreeding in the region. Recognising the adaptive features of local breeds attention was then re-focused from crossbreeding in the 1980s to their improvement through straightbreeding.

In India, primary poultry breeding started more than three decades ago in the public sector. Later, a few great parent imports based companies in the private sector created the necessary infrastructure and took up primary breeding. In cattle, selection of indigenous breeds was intended, and several crossbreeding experimental programmes were carried out, including new breed formation, such as the Sunandini, a composite of mainly Brown Swiss, Holstein and B. indicus breeds developed by the Indo-Swiss Project (Taneja, 2000).

MORE RECENT DEVELOPMENTS

Performance recording schemes in woollen sheep were started in South Africa and South America in the 1970s, run by private and/or public institutions. In Argentine, 50 studs are currently involved (J. Mueller, personal communication) and in Uruguay, 150 (75 to 95% of the main studs in six breeds) with 20,000 wool samples being analysed annually. Wool samples are taken at shearing time, when the breeders record greasy fleece weight, body weight and a visual appraisal of the quality of the wool; scouring yield percentage, fibre diameter and staple length are assessed in the laboratory. The service provides the breeders with EPDs for all traits, plus selection indexes (Cardellino and Ponzoni, 1986). The testing costs are met by the breeders. Across-flock genetic evaluations became very important in Uruguay in the 1990s. There are at present six programmes of central progeny testing sire evaluation run by the breeders’ associations and the Uruguayan Wool Secretariat (SUL). These stations also allowed the possibility of comparing the value of “genetics” imported from other countries to assess whether to “buy genetic merit rather than creating it” (Smith, 1989). The genetic response in greasy fleece weight varied between 0.2 and 1.4 % in different studs, compared to a potential rate of 1.5% (maintaining fibre diameter constant).

In Brazil, performance recording programmes in beef cattle developed in the last two decades. There are currently eight multi-herd programmes recording liveweights of some 250,000 young animals annually. EPDs (estimated using animal model-BLUP procedures) are used by the industry. Some programmes include other traits, such as scrotal perimeter, mature weight and muscling score. Many bulls in the AI studs have EPDs, which influence the sales of semen and also the price of bulls at auctions. This was not the case a few years ago, when semen prices were only affected by the winning of show ring prizes, having no relation to genetic evaluation. These programmes are run by breed societies, group of breeders or private firms (including an AI stud) in cooperation with universities, research institutions or private firms that process the data and elaborate bull summaries. The costs are met by the breeders.

Milk recording existed for many years in several Latin-American countries, usually government subsidised, but its main function is to certify yield for commercial purposes, rather
than for management, so selective recording of the best cows is practised rendering data
unsuitable for genetic evaluation. A programme of progeny testing of dairy Gir sires, based on
own recording, was initiated in Brazil in 1985, which up to now has sampled 168 young bulls,
74 of which have already completed their test, with an average of 34 daughters and 92 herd-
mates per sire. Both straightbred and crossbred (x "B. taurus") daughters are included, since
crossbred performance is the main commercial objective. Temperament and milking ease are
scored. Milk composition is assessed at a central laboratory. The programme is jointly run by
the breed society and the Federal Research Organisation (EMBRAPA). This has been a
successful partnership, as it allied the technical proficiency of the research staff with the
operational ability of the private sector, thus overcoming the clumsiness inherent in public
administration. A similar programme initiated in the Guzerá breed in 1994, also including a
linked MOET selection nucleus (Penna et al., 1998). These programmes are funded by the
breeders except for the salaries of the institutional staff, with occasional governmental grants.

In West Africa, concerns about improvement programmes of local breeds being restricted to
research stations and much of the gains realised not being transmitted to farmers’ herds and
flocks led to the concept and designs of breeding schemes that portend to involve farmers or
producers not only in using improved genotypes, but also participating in defining the breeding
goals and selection criteria. Thus, in the 1980s and the 1990s, nucleus breeding schemes
(closed or open) were being advocated and in few cases being implemented (Etse, 1999; Yapi-
Gnoare, 2000). Although the overall experiences from crossbreeding as a strategy to improve
meat and milk production have not been positive, it is generally been accepted that under
certain market and economic considerations such breeding programmes are justified and
crossbreeding programmes in dairy cattle have been in operation for some years in Mali
(Jersey, Montbéliard, Red Steppe with N'Dama and Zebu), Senegal (semen of Holstein,
Montbéliard and Abondance breeds to inseminate approximate 4,000 cows a year) and Gambia
(an ITC programme of continuous F1 production of Jersey or Friesian x N'Dama using AI).

Experimental results in Brazil indicated a large economic superiority of the F1 and suggested a
strong recombination loss for milk yield (Madalena et al., 1990). Farmers have now grasped
this superiority and a commercial market has developed for F1 females (Madalena, 1998) as it
is also the case in Venezuela and Colombia. A New Zealander firm (J.D. & R.D. Wallace)
exports some 2,000 first cross Sahiwal heifers to tropical countries world-wide. In Brazil
crossing of European beef breeds (mainly Red Angus and Simental) with zebu has increased in
later years to some 2 million semen doses sold in 2000, although it is generally accepted that
crossbreds demand better pastures. Extensive research by Plasse (e.g. 2000) has shown that "B.
taurus x B. indicus" composites retain only some 10% of the 25 to 30% superiority of the F1 for
maternal traits. Nonetheless, several composite programmes are ongoing. The Montana
programme has several unique characteristics, as it is a large scale operation run as a joint
venture of an international and a national firm (Leachman Cattle Co. and CFM), involving
some 55,000 females in AI in more than 20 ranches under a franchise system that keeps genetic
control centralised. Besides the Nelore, British and Continental breeds, adapted breeds are
being used, including the Senepol, Belmont Red, Bonsmara, Romosinuano and Tuli.
Trivedi (2000) presented a neat example of a functional breeding programme under village conditions in a network of cooperatives in Guajarat, India. Three regional programmes aiming at increasing buffalo milk fat production have been implemented since 1987 by the National Dairy Development Board. The programme involves some 30,000 buffaloes in 220 villages of seven cooperatives. Together they have been putting annually some 40 buffalo young bulls sampled. Some 270 bulls have completed test matings and breeding values of 123 have already been estimated using 35-50 first lactation daughter records. All young bulls sampled are now coming through nominated inseminations of top recorded cows with semen of the top three or four proven bulls. All 4,250 villages having AI facilities receive semen of proven bulls. A high number of daughters is needed because each farmer (household) has one to five cows, so the village is taken as a “farm” effect. On the other hand, the logistic of AI is tremendously facilitated as the cows are walked into the AI facility of the village and milk recording does not require transport expenses. The programme is funded by the milk cooperatives. The participant farmers receive cattle feed as an incentive and do not pay for the recording. Data are centrally processed. Genetic evaluations make use of animal model-BLUP procedures. An open nucleus breeding system involving Sahiwal and crossbred cattle is also run by the same organisation (Trivedi, 2002).

In some countries, like India, Bangladesh, Sri Lanka, Pakistan and Nepal the backyard poultry is steadily changing into intensive poultry farming. In India, where more than 100,000 farmers are engaged in this vocation, the number of improved layers increased from 1 million in 1961 to 120 millions in the year 2000 while the country chicken only increased from 63 millions to 73 millions. In addition, 900 million broiler chickens were grown in the year 2000 compared to nil in 1961. Projects to improve the productivity of the backyard scavenging birds by distributing improved birds to villagers have been undertaken, e.g. in Bangladesh (Jensen, 2000) and in Bhutan, where RIR (coloured) birds have become much more popular as scavenging backyard poultry compared to the country chickens, primarily because of their better egg production. Here the Government Agencies produce one-day-old chicks, rear them up to 8 weeks of age, give all necessary vaccination and then distribute them to the villagers at a subsidised rate. This approach prevents the outbreak of diseases like Newcastle, a major problem of the scavenging chicken (even the country birds). However, similar Government schemes in India had limited success as most beneficiaries either sell the birds in the market or eat them away, while some (may be 5%) really take up the poultry as vocation. On the other hand, poultry cooperative societies have become very successful in certain States. Here, the villagers have share holding in a cooperative society, which runs a large size poultry farm (20 to 50,000 birds) in the villages. Such units provide required inputs like feed, vaccine and medicine, etc., and also can market their own products due to their large size.

LESSONS FROM PAST ACTIVITIES
It would seem apparent that major genetic changes occurred in regions where livestock development took place, oftentimes due to the introduction of improved germplasm followed by local programmes. Thus, genetic improvement seems to be a consequence of the existence of a market spurring investment in animal breeding. The magnitude of the genetic changes has been quite impressive, as tens to hundreds million animals, within the different species, were genetically changed in some decades, e.g., in Latin-America. Erosion of genetic variation has been reported in some cases as a result of intensive use of popular sires (Faria et al., 2002).
Most change has been effected by private breeders and companies. Few successful stories were reported in an extensive review of governmental programmes (Payne and Hodges, 1997). These authors indicated that with certain exceptions the importation of some 50,000 European-type cattle financed by the World Bank in various countries had not been satisfactory and substantial stock losses and poor production records were encountered. Vaccaro (1990) reported that Holstein cows in Venezuela left only 0.7 first-calving daughters in their lifetime, so they were not able to sustain their numbers. Behind such imports, generally a government subsidy scheme from the importing country operates, or a loan or gift from the exporter.

Agyemang and Fall (2002) reported that in West Africa several programmes of crossbreeding involving exotic and indigenous cattle breeds failed due to lack of adaptation, both biological and socio-economic, while public administration problems, such as weak managerial capacity and excessive bureaucratic constraints were oftentimes identified as major failure factors. They did however report a few successful stories, principally in crossing undertaken by the producers themselves, both with exotics and involving only indigenous cattle, sheep or goats. Although there were exceptions, many selection and multiplication programmes funded by central governments had ceased operation, mainly because of lack of funds and manpower.

In a recent discussion in the AGDG (6/13/2001), Dr. Paul Miller noted that successful programmes are initiated and/or supported by local people to meet local needs and to establish realistic short and long term goals; are driven by the goals and desires of the participants and their social and financial benefits; and achieve financial rewards for participants that are generated from their efforts and not from subsidies. He further observed that programmes are not likely to succeed if they focus on grandiose schemes, are run by governments or international agencies or are driven by societal goals with few benefits to participants.

In many West African countries, attention is now focused on the improvement of indigenous animals. Crossbreeding with exotic breeds is implemented only under careful defined conditions and clearly stated objectives. More countries are adopting open nucleus breeding with screening of animals from a larger population as an option. The absence of legalised autonomous institutions to coordinate breeding programmes is often cited as a bottleneck and the emerging new policies seem to have taken this into account. The new policies also recognise the need to get stakeholders, especially producers, to participate more in genetic improvement programmes. Mechanisms to diffuse improved genetic material and services such as AI are also being considered in such policies.

**ARE MEDIUM-TO LOW-INPUT SYSTEMS RELEVANT?**

It seems necessary to address this question because it has been argued that only the high input production systems are economic, so breeding for low- to medium-input systems would not be justified. For instance, McDowell et al. (1996) stated that “the estimated marginal level of milk yield per cow that is needed to support commercial dairying is 4400 kg” and recommended “that the policy makers in countries of the warm climatic zones invest efforts toward commercial dairying with high grade or pure dairy breeds”. That yield limit disqualifies the pasture based dairy production systems of Latin-America, Australia and New Zealand, which clearly are commercially sound. In Brazil alone, some 1.2 million farmers produce about 21
million tons of milk per year, and in the past 30 years production steadily grew at an average annual rate of 3.8%. The economic efficiency of production systems depends on an appropriate combination of land, labour and capital determined by their relative prices in each country, thus generating variation in farming practices. The use of high levels of concentrated feeds and other inputs in the dairy systems of North America and Europe are justified and made possible because of the high support prices received. On the other hand, the production strategy with tropical pastures relies on making use of the plentiful solar energy for the efficient photosynthesis of fast-growing \( \text{CH}_4 \) grasses. Pasture quality is not high and concentrates are expensive, needed as they are to feed the humans, but very high stocking rates are possible. Adapted cattle may graze those pastures, so expensive buildings or equipment to control the environment are not needed and chemical control of parasites is minimal. As an example, a system based on F\(_1\) Holstein x Guzerá cows on irrigated pastures in Brazil, supplemented with 3 kg concentrates and yielding 12.9 kg of milk per cow per day, obtained an annual average stocking rate of 4.2 cows per ha, had production cost of US$ 0.08 per kg of milk and 36% p.a. profitability of the invested capital (Alvares et al., 2001). This compares extremely favourably to the situation in the OECD countries, where just the government price support amounts to US$ 0.20 to 0.91 per kg (Howse, 1998).

In chickens, the climatic conditions, husbandry practices and market requirements of the developing countries of Asia and Africa are also different from those existing in North America and Europe. The temperature in the open sided houses in which most birds are kept may vary from 10\(^\circ\)C in winter nights to 40\(^\circ\)C in summer days, with large daily fluctuations. The farmers and breeders do not install environment control devices due to high capital and electricity costs, frequent blackouts in villages and availability of cheap labour. High-energy rations are non-available. Due to religious reasons, use of beef tallow in animal feed is banned in India. Inclusion of vegetable oils is not cost effective. Therefore, a typical Indian layer ration would have only 2,400 to 2,550 kcal/kg of feed compared to 2,800 kcal/kg of feed used in Western countries. Similarly, broiler ration would have 2,850 kcal/kg compared to 3,200 kcal/kg used in Europe and North America. Also, since a village may have a number of small farms, the desired quarantine and hygienic standards are seldom maintained. The international leading poultry breeding companies keep and select their elite stock in temperate climate with optimally controlled facilities. By realising the importance of genotype environment interactions while marketing their product world wide, these companies advise the poultry farmers to modify the climate by housing design and specific devices to control the environment, to provide conditions in the broiler/ layer houses which represent nearly the same environment in which the birds have been selected. For the small poultry farms in Asia and Africa, this is an expensive proposition and mostly impracticable. Moreover, the depressed broiler growth or reduced egg production due to high temperature cannot be completely alleviated by such measures (Cahaner and Leenstra, 1992). The other alternative is to breed the chicken in the climate in which they have to perform. Singh (1992) observed that compared to an U.S. bred broiler line, its counter part that had been selected in India for 10 generations exhibited better adaptation to the local environment.

In many developing countries a vast majority of animals is kept by smallholders, in low input systems making use of available resources including residual feeds, such as straws, or in semi-
scavenging conditions. This will continue to be so for long time to come, although market-oriented systems are emerging, hence the need to continue breeding efforts to make livestock more efficient while paying attention to disease resistance and other adaptive traits.

OPERATIONAL AND TECHNICAL ASPECTS
Inadequate or lack of sustained funding is a major limitation to the implementation of breeding programmes. It may be that there are other more profitable or less risky private investments to be made in capital hungry developing countries than in breeding operations, although investment is growing along with the market development. Whereas in some regions (e.g. West Africa) governments often do not have difficulties in starting projects usually funded under donor agreements, there appears to be a lack of a long-term commitment on the part of the decision-makers to secure funds on a sustained basis to run these programmes.

In some countries the lack of expertise trained to design and run effective breeding programmes is a major constraint. Although in other countries that is not the case, as formal training is available in local or foreign universities, the study programmes are oftentimes too academic and too far removed from the issues of practical breeding in developing countries. Major subjects that are oftentimes overlooked include the design of crossbreeding programmes, the economic evaluation of genetic differences and breeding objectives, the economic optimisation of breeding programmes and the genetics of adaptation traits, such as heat tolerance and resistance to parasites. Complementary programmes between universities in developed and developing countries could help reduce this problem. Also, meetings bringing together practical breeders and technical personnel of breeding companies with academic staff/students should be considered for essential interactions between those parties. In Brazil, a formal Society of Animal Breeding proved valuable to this end, but many other structures may be instrumental.

Although breeding for lower input systems involves no new principles, the application of the existing ones to the sound design of breeding programmes requires research results that are oftentimes lacking. There is no space here for discussion of the many peculiarities of genetics in lower input systems that require specific research since results may not be adopted from elsewhere. The heritabilities and genetic correlations between the most common traits in cattle are similar to those in temperate countries, but there are exceptions. Moreover, there is a dearth of estimates for many economically important traits, including adaptation traits (Lôbo et al., 2001). Recombination loss in crosses of \textit{B. taurus} x \textit{B. indicus} seems to be much larger than in crosses of \textit{B. taurus} breeds (e.g. Fries et al., 2000), which has implications in the design of crossbreeding programmes to capitalise on heterosis. Advances in the biotechnology of reproduction may have important implications in the more widespread utilization of cattle F\textsubscript{1} systems (Teodoro et al., 1996).

CONCLUSIONS
Breeding programmes are driven by investment and management (Bichard, 1996). Private investment is slowly but steadily increasing in some regions and may be accelerated by demonstrating to the producers the economic benefits of using truly improved stock, which requires teaching them to keep and use accounting records. Large private firms take care of
managing their own breeding programs but the smaller ventures may profit from joint programmes with institutions providing scientific expertise. Getting an active involvement of the breeders and producers and the continuous co-participation of scientists and breeders are essential components of realistic programmes.

The vast majority of smallholders will not be able to buy improved stock and will not attract investment from private companies in animal breeding for their systems, so funding is needed from other sources, such as cooperatives, governments and international organizations. In view of the grim picture of past experiences, programmes run on public funds should avoid the many vices mentioned (and unmentioned), perhaps by implementation through NGOs. At any rate, funding must be adequate for the long-term nature of breeding operations. An efficient legal framework is needed for the operation of the programmes and the diffusion of the improved genetic stock and materials.

The genetic resources used should match the climate and the feed, health, management and other production circumstances. Different strategies –breed substitution, crossbreeding, new breed development and/or improvement within local populations- may be appropriated in each particular case. Each course of action should be assessed according to the particular biological, socio-economic and logistic circumstances. However, sound decision-making requires factual information based on solid regional research, a point only too often overlooked, that has led to unsuccessful programs in the past. Importation of stock/genetic materials has been and will continue to be an important option, again to be judiciously assessed in each case. New programmes in tropical countries are becoming increasingly important in this context.

Programmes of breed substitution or crossbreeding promote fast genetic changes, but by the same token they are particularly risky if based on empirical trial and error. Within population selection programmes, on the other hand, have lower rate of change, and it seems appropriated to initiate them even when the estimates of economic values of traits, $h^2$ and $r_g$s are not complete, provided information is simultaneously collected for early optimised re-design.

In some countries one of the major constraints to the achievement of genetic gains in a sustainable basis is the lack of manpower to run breeding programmes, so strengthening the local education programme is needed. Although this is not the case in other countries, there is ample opportunity for improvement of teaching and research focusing in the application of genetics to the specific peculiarities of medium to low input systems and the socio-economic entourage in which they occur, as present programmes are oftentimes too academic and too far removed from the issues of practical breeding in developing countries. Complementary programmes between universities in developed and developing countries could help reduce this problem. Promoting the interactions of practical breeders and research and academic staff/students may help to increase the relevance and effectiveness of breeding programmes.

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