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THE IMPROVEMENT AND APPLICATION OF GENETIC RESOURCES IN ANIMAL PRODUCTION IN SOUTH AFRICA

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In the process of abandoning out-dated production systems and searching for new methods and techniques which will hopefully ensure greater efficiency in the use of natural resources, labour and capital, it is obviously important to consider also improvement and proper utilization of available genetic resources.

One of the important consequences of modern developments in livestock production associated with specialization and more intensive production systems, is the narrowing down of genetic resources. This happens through the loss of breeds and strains and within populations there is a gradual reduction in the number of unrelated animals contributing to succeeding generations. The implications and gravity of the situation is recognised by the poultry industry of the world as well as the pig industries of some of the leading western countries.

Since animal breeders do not have access to the same range of tools available to plant breeders and as errors in judgement have far more serious effects in the case of animal breeding, any attempt to manipulate genetic material requires careful study of the possible medium and long-term impact on the populations concerned.

In order to narrow down the discussion one must concede that the two most important biological factors operating to optimize the use of genetic resources in this country are associated with nutrition and the health status of livestock.

Furthermore that it seems logical, in a discussion of this nature, that the emphasis should fall on –

(a) the size and nature of the genetic resources i.e. their quantitative and qualitative aspects, and
(b) the most effective means of utilizing these resources i.e. the most suitable organization and breeding programmes to employ.

The first concerns vital and comparative statistics, effective population sizes as well as criteria and measurements in respect of the conomically important characteristics and general evaluation techniques. In the second case the modeling and design of suitable infra-structures for effective breeding plans and programmes, in which genetic improvement can be optimized, are the main consideration.

Structure of the Livestock Industry

The absence of essential statistics of the structural components of the industry such as the actual numbers of the various breeds, the size and age composition of the effective breeding populations, replacement rates and general population dynamics, makes an exact description of the structure of this industry well-nigh impossible. It acts as a serious obstacle to constructive efforts to plan and programme the development and genetic improvement of the industry on a national basis.

Quantitatively the industry consists of 9,7 m cattle, 31 m sheep, (20,5 m Merinos; 2,1 m Karakul; 3,4 m other woolled breeds; 5,0 m non-woolled), 2,5 m goats (0,9 m Angoras), 1,1 m pigs and 35,1 m poultry (Abstracts of Agricultural Statistics, 1978). These latest statistics confirm the trend suggested by the Department of ATS (1977) that livestock numbers are at present increasing at a relatively fast rate. Recent studies by the ADSRI (1977) of livestock numbers also confirmed earlier indications that there has been an important shift of emphasis in the local livestock industry. Stock numbers, both cattle and sheep, have decreased in the drier, western parts and have increased considerably in the eastern areas, which have a higher production potential. It is an important development emphasising the present trend towards greater intensification in animal production.

This development and others, such as the introduction of feedlot systems over the past decade are significant in view of the interest it has occasioned on matters such as the most suitable genotypes for intensive production systems. Types and breeds or genotypes as well as breeding objectives are clearly involved.

From a genetic point of view the stud breeding section of the national herds and flocks varying in size from breed, is important. In some populations it constitutes about 1,5% while in recently imported breeds most animals are pedigree stock. The few studies conducted in this country on breed structure (Allan, 1958; Celliers, 1969 & 1978; Hofmeyr, 1966; Hofmeyr & Boyazoglu, 1966; Kotzé, 1976; Erasmus, 1977) confirm the general situation that breeds have a characteristic pyramidal or hierarchical structure which might vary according to special circumstances and the species concerned. The higher stratum is composed of the so-called top or master stud breeders with one or more layers of daughter or multiplier studs before reaching the lower ranks which consist of the commerical producers. In practice the important decisions on breeding policy are taken in the top herds. The position is in fact that a few prominent breeders dictate the policy. The consequences of their decisions gradually filter or penetrate through the various layers of the population, diminishing in effect as the gene flow spreads through each generation. The conclusions derived at from the investigations referred to above, suggest that the stud industry does not function effectively. This is due not only to the breeding policy and ineffective selection methods applied but also to the inefficient use of genetic resources resulting from breed structures where only a limited number of relatively small herds are available to effect breed improvement. Qualitatively the industry can best be described as unique. It consists of a large variety of livestock species and a wide spectrum of breeds, strains and all possible crossbred types.

Morphological differences are often accentuated in their phenotypic manifestation through exposure to extreme environmental conditions and a wide range of production systems.

Comparatively speaking the most important resemblance to countries with similar conditions lies in the fact that beef cattle and wool production are still farming operations confined to the less favourable semi-arid and marginal regions while dairy, pig or poultry production is practised under intensive farming conditions.

The development of the industry and its particular pattern are largely determined by –

(a) the limitations of the natural resources,
(b) economic factors and considerations,
(c) traditional farming methods as well as by
(d) the extent and influence of technological developments.

Of these the first three sets of factors have until quite recently exerted the most influence on the distribution and composition of the national herds and flocks.

In contrast to the Americas, Australia and New Zealand the African continent was endowed with indigenous breeds which played an important role in the development of the present livestock industry and contributed also to the genetic diversity of the livestock populations. In addition a liberal import policy was followed over the past 300 years which assured the introduction of a wide range of geneotypes and provided an extensive and useful gene pool for most species. It must also be admitted that many well-known breeds have disappeared from the local scene over the years e.g. most of the British sheep breeds, at least nine pig breeds, etc. Not all the remaining breeds are economically important and numerically strong. Many are in fact minor breeds of no national significance nor with any prospect of becoming important.

Significant changes in the qualitative or genetic composition of the livestock industry have been observed in recent years. These changes are partly related to the quantitative changes referred to previously as borne out by –

(a) a changing pattern, over recent years, or registrations with the Stud Book Association* (Table 1);
(b) increases in the importation of exotic animals and semen (Table 2);

Table 1

Relative increase of registrations (Males and Females) in some cattle and sheep breeds

Species/Breeds	1967	1977	% Increase
Aberdeen Angus	531	1 277	140,5
Africander	4 387	5 825	32,8
Ayrshire	760	1 047	37,8
Brahman	976	9 863	910,6
Brown Swiss	781	701	–10,2
Charolais	268	725	170,5
Friesland	2 275	5 374	136,2
Guernsey	337	690	104,7
Hereford	3 382	7 376	118,1
Jersey	3 121	2 357	–24,5
Red Poll	388	147	–62,1
Shorthorn	750	864	15,2
Simmentaler	422	12 189	2 788,4
South Devon	507	1 434	182,8
Sussex	918	2 570	180,0
Corridale	1 260	187	–85,2
Merino Landschafe	133	597	348,9
S.A. Mutton Merino	6 087	7 444	22,3
Suffolk	156	624	300,0

(Source: Stud Book Association – 1978)

(c) a marked and growing interest in crossbreeding as can be seen from the numbers and variety of types found at abattoirs, feedlots, etc.

The Stud Book Association and its affiliated livestock breeders' societies have been committed over the past 57 years to recording the origin and preserving, perpetuating and distributing these sources of genetic material. At present 25 cattle, 13 sheep, two milch goats and two pig breeds (as well as 10 horse breeds) are registered by the Stud Book Association. (It is very likely that the Association's new constitution will provide for the inclusion of at least six additional breeds.)

For genetic purposes i.e. animal breeding and breed improvement, the effective population size within breeds is of cardinal importance. In practice this refers to that part of a breed where measurable improvement occurs and from where a significant and consistent flow of genes is assured. This involves the medium to large studs where systematic progress is recorded through genetic evaluation (performance testing, etc.) and where effective breeding plans are implemented.

* Now renamed the South African Stud Book and Livestock Improvement Association and referred to in the Livestock Improvement Act, 1977 (Act 25 of 1977) as the Stud Book Association.

Table 4

Numbers and percentages of herds and animals in performance recording

Breeds	Total Number of Herds	Percentage of Herds in Recording	Percentage of Registered Animals in Recording
DAIRY			
Ayrshire	168	33,3	38,5
Friesland	658	49,0	54,6
Guernsey	119	33,6	31,2
Jersey	485	35,1	26,2
BEEF			
Aberdeen Angus	126	15,9	25,2
Africander	442	20,6	34,2
Bonsmara	275	100,0	100,0
Brahman	732	6,8	27.0
Brown Swiss	81	19,8	57,8
Chaolais	137	8.8	14.9
Drakensberger	260	22,7	34,8
Hereford	338	24,6	51,3
Pinzgauer	111	17,1	71,3
Red Poll	27	11,1	23,5
Santa Gertrudis	241	18,7	32,6
Shorthorn	83	22,9	36,1
Simmentaler	771	15,8	52,3
South Devon	127	41,7	44,3
Sussex	167	16,8	23,2

Source: Breed Societies and Department of Agricultural Technical Services, 1978

Improvement and utilization of genetic resources

Results emanating over many years from controlled experiments and standardised central testing centres indicate that there is considerable scope for increasing the efficiency of the local livestock industry. This could be achieved in several ways of which the genetic one is of concern here. Genetically speaking, the efficiency of production can be best advanced through the use of modern breeding and selection programmes based on current genetic knowledge as well as by the judicious application of the available genetic sources in suitable production systems.

The design of modern brediing programmes based upon advanced genetic theory is becoming more sophisticated as theory and technology progress. The effectiveness of a breeding scheme is generally evaluated through simulation models which are programmed for computer analyses. Model development requires that biological processess be quantitatively described in terms of mathematical functions (Cartwright, 1976).

The methods, techniques and criteria for the construction of models and the theory in respect of optimal breeding schemes are well-documented (Brascamp, 1973 & 1976; Cartwright, 1976; Cartwright & Fitzhugh; 1974, Cunningham, 1974 a; Hill, 1971 & 1974; McClintock & Cunningham, 1974).

The latest models feature cost-effectiveness and economic consequences as important ingredients of their structure. This has become necessary in view of recent results suggesting that genetically optimum schemes are not necessarily the most economical (McClintock & Cunningham, 1974). Genetic theory also provides the underlying principles on which practical, acceptable and logical techniques for the evaluation and appraisal of breeding values of livestock are founded.

The practical institution of national livestock improvement programmes demands a clear definition of the main objectives of breeding and more suitable techniques for measuring them. Furthermore, the proper means must be devised to ensure optimum utilization of the best breeding stock.

Practical problems arise where there is no general acceptance or agreement among breeders (and/or producers) on what is desirable or important and where objectives and emphasis are subject to periodic changes.

Important decisions have to be made on different levels in any organized and systematic programme to ensure its general efficiency and the optimum utilization of resources.

Figure 1 presents a general design of a livestock breeding and improvement programme (adapted from Cunningham, 1974 a) in which the factors influencing the design are illustrated.

The first and most important decisions concern national livestock production policy and its objectives. This involves economical, social and political considerations and concerns the strategic importance of the livestock industry as well as that of its various individual sectors. Decisions on this level will indicate the nature (market requirements, etc.) and extent of any planned expansion and future objectives in production.

Once decisions have been taken at this level it is important that the policy-making bodies ensure that the activities of breeders are consistent with national interest.

Since stud (pedigree) breeders will continue to be an influencial group in respect of any effort to breed and improve livestock (particularly because of their entrenched position in this country) it is of cardinal importance to induce greater and increased acceptance by breeders (producers) and their organization of modern breeding programmes, with their built-in genetic principles based on objective measurements and advances in technology. If recommendations to the stud industry concerning livestock improvement can be framed to centre on acceptable aims and methods of selection applicable to within breed improvement it would constitute a tactical move within the wider strategy. However, it is important to impress on breeders that improvement is paramount. Progress cannot be allowed to be hampered by protection against competition.

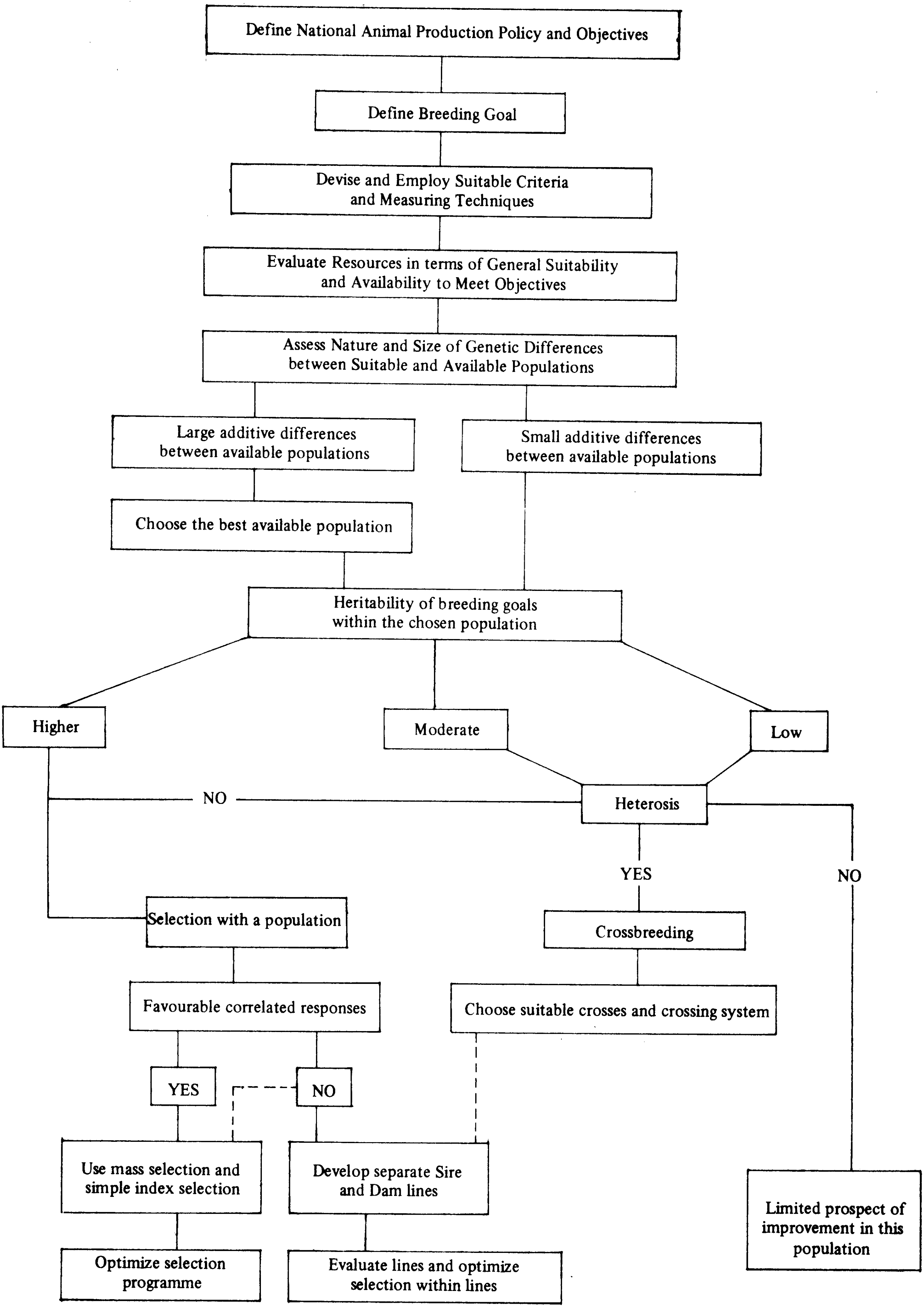

Fig. 1 General design and strategy of livestock improvement

Following the decisions and the declared objectives, the breeding goals should be defined in simple and explicit economic and biological terms. The breeding programme must be directed towards persuading and encouraging breeders to –

(a) accept and participate in performance testing and recording with a view to applying the resulting information to the selection of their animals:
(b) put greater emphasis on higher reproduction rates as this is imperative not only in respect of increasing potential selection differentials but also of reducing the generation interval;
(c) reduce the number of traits selected for by excluding those of doubtful importance, and to
(d) maintain effective herd/flock sizes and compositions (age structure, etc.).

Modern measuring and evaluation techniques employed by livestock improvement authorities or organizations have been proved satisfactory and successful in establishing criteria for the identification of superior genotypes. Research and advances in technology will, however, continue to contribute further refinements. The impact of an extension of modern computing facilities and their use in animal breeding has not yet been fully experienced or appreciated. It is only when the consequences of sophisticated integrated feed-back programmes against alternative procedures have been worked out and demonstrated to breeders that full appreciation will be forthcoming.

The evaluation of genetic resources constitutes a very important facet in any national livestock improvement programme. Changed production circumstances, new market requirements etc., necessitate a continuous assessment of available genetic resources. The possible inclusion of exotic genotypes in evaluation programmes might obviously also be justified. This is perhaps a task best accomplished by an independent organisation such as the State – as is the present case in this country.

An important consideration is whether differences in characteristics are heritable and to what extent. If these differences between populations are large and additive in nature then it would seem obvious to acquire and settle for the best of the populations. This could in practice amount to population substitution which, incidentally, has been the main mechanism for genetic improvement in most countries. (Cunningham, 1976).

It also follows that where population substitution can be affected rapidly and easily as in the case of poultry then even a small genetic advantage could justify replacement. With larger animals it is common to use a systematic grading-up breeding system. In the case of dairy cattle a replacement policy is not recommended as a real option unless the mean difference between the existing and replacement (imported) breed exceeds 20% (Cunningham, 1974 b).

Within the chosen population it is important to assess as a following step, what portions of the observed differences in performance are heritable i.e. the heritability of economically important characteristics. If they are moderately to highly heritable, selection within the population is advocated. If not, the problem of dealing with the situation becomes more difficult and one is left with the option of examining the feasibility of utilizing non-additive genetic variation or heterosis effects.

Heritability estimates in respect of most of the economically important traits in the different livestock species and populations are readily available and are in fact being regularly updated. Cunningham (1976) suggests that modern computer programmes (e.g. sire evaluation programmes) could be designed to contain an annual review of genetic parameters which could be used for periodic revision or servicing of the selection programmes. Where heritability estimates are moderate to high and the characteristics concerned show no negative genetic correlations, selection should be effective. Breeding and selection programmes for such situations are easy to construct and are simply based on mass selection in which a simple index selection system operates. The usual factors which optimize any selection programme would obviously be built into such programmes.

Where antagonism exists between characteristics the problem is immediately complicated and the best way of dealing with such situations in practice might be to develop separate male and female lines within the population (breed). Selection within these lines would be directed towards improving one or more of the negatively correlated traits. The selection programme would continue on the same basis as in the previous case.

Low heritability or the absence of sufficient additive genetic variation is often compensated for by the presence of a considerable amount of potential heterosis. This is particularly true for characteristics concerned or associated with viability or adaptability, reproduction and fitness in general, which show hybrid vigor (heterotic effect) in response to crossbreeding. The common explanation for this phenomenon is that natural selection has probably greatly reduced the additive variation and ensured specific and different gene complements consistent within the population or strain but different from one population or strain to another (Cunningham, 1976). This explains the observed heterotic (overdominance) effects which are derived from increased heterozygosis where breeds and strains are crossed. Where successful selection within a population or strain produces small cumulative improvements or increases from generation to generation, crossbreeding usually gives rise to a significant singular heterotic result which requires replanning in order to be repeated in each generation.

Sophisticated crossbreeding systems have been developed in recent years for various livestock species which consist of breeds and strains that show favourable or exceptional combining ability and are complementary in respect of ensuring and maximising the exploitation of heterosis. (Lerner & Donald, 1966). These systems can be very useful in that they provide an opportunity to accommodate genetic antagonisms i.e. where desired characteristics are strongly negatively correlated. This is accomplished by selecting within the separate breeds for different sets of traits.

Organisation required to improve and utilize genetic resources

The responsibility to promote livestock production in South Africa in the past was largely vested in various government authorities, private breeders and producers. State involvement dates back through the years to the very first importations of sheep, cattle, horses and other farm animals (Hofmeyr, 1976). The general livestock policy in the past was to import various exotic breeds in order to improve and replace the "inferior" indigenous livestock.

The first efforts to apply advanced methods of breed evaluation or performance testing was the introduction in 1906/07 of the first egg-laying tests at the Western Province Agricultural show by a few poultry breeders and milk recording by the Friesland Cattle Breeders' Association in 1917. The establishment of the South African Stud Book Association in 1905 was the first effort to record the breeding particulars of farm livestock in a systematic way. (This organisation was incorporated as a statutary body under the Pedigree Livestock Act, 1920 (Act 22 of 1920) in 1921.) It has, with the support of its affiliated societies, since become the bastion of the pedigree breeders in this country. However, in spite of its importance as the home of the stud industry its powers and influence ceased at the level of pedigree registration. The responsibility for the promotion of livestock evaluation and improvement was largely that of the State. The latter's involvement with scientific methods dates back to the stage when milk recording services became its responsibility in 1919 and when the first two official egg-laying tests were introduced in 1914 (Potchefstroom) and 1917 (Cedara). This was followed by the introduction of various other livestock improvement schemes – for pigs (1956), beef cattle (1959), wool sheep (1965) and mutton sheep (1965).

Efforts to increase the impact of the State's modest contribution proved extremely difficult. An excellent opportunity, however, presented itself during the 50th anniversary of the Stud Book Association when it was challenged to accept a new task and role in the livestock industry of this country. The ensuing discussions at the Association's level was followed by certain recommendations to the Minister of Agriculture. This incidentally coincided with the submission of three reports by the Animal and Dairy Science Research Institute on more or less the same topic but covering a wider range of associated aspects. These reports, in which the existing situation and projection of future developments in the industry were documented plus the initiative displayed by the Stud Book Association culminated in the final decision of the Minister to introduce the new Livestock Improvement Act, 1977 (Act 25 of 1977).

This Act has stirred up wide interest among livestock breeders and scientists alike as it constitutes the first consolidated effort to actively promote general development and scientific animal breeding in this country. The Act provides for legalized improvement schemes through which the efforts and co-operation of all groups and bodies with vested interests in the various sectors of the livestock industry can be combined (Figure 2):

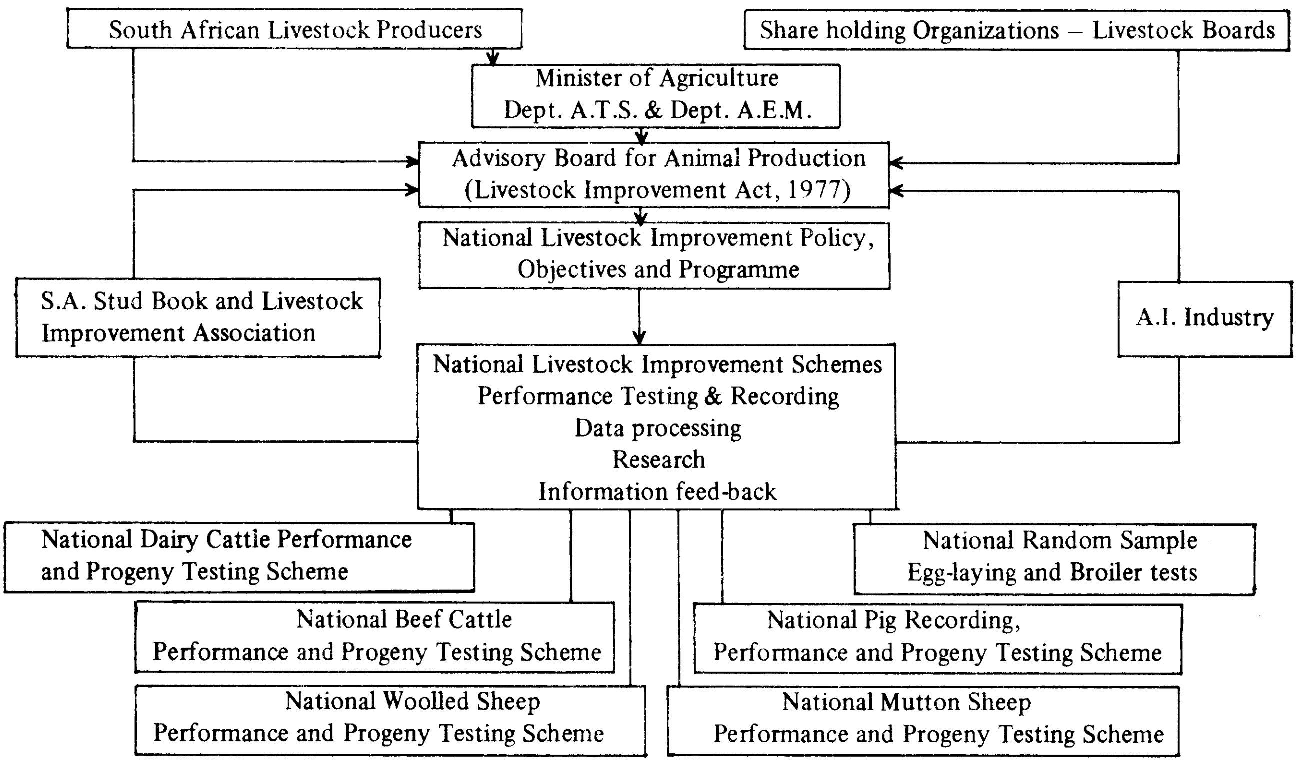

Fig. 2 National Livestock Improvement Organization in South Africa

A few very important moves have already been effected since the Act was promulgated last year (1977) and others will soon follow, e.g.

(a) Legal status has been granted to the different livestock improvement schemes.
(b) The Stud Book Association is committed to accepting performance standards for registration purposes.
(c) An extended computerization programme for the integration of the pedigrees and performances of animals in the livestock improvement schemes is in the progress of being involved.
(d) A highly selective import policy for animals and germ plasm (semen and ova) has been introduced.
(e) Requirements and standards for A.I. sires have been raised.
(f) The expansion, reorganization, updating and improvement of techniques of livestock improvement schemes initiated during the past few years have gained new stimulus. The next phase of these schemes (i.e. after successful computerization) will be the setting up of national breeding programmes for the industry.

Conclusions

A study of successful livestock improvement efforts in most western countries clearly suggests that the organization of livestock improvement requires a body with vision, power and finance to carry out policy on a country-wide scale. Until recently it was obvious that no single body could address itself to this task in this country.

In the past expansion of production was the critical objective in animal production policy. In any production set-up changing circumstances require effective adjustments to market needs and opportunities. Policies for animal breeding must increasingly challenge current utilization of genetic resources and consider alternatives. In this country there has up to now been a sad lack of dynamic initiative in this respect.

The new Livestock Improvement Act has tried to remedy this and has introduced what hopefully ushers in a new era for livestock production in this country. The Advisory Board for Animal Production will soon be called upon to lay down a broad policy for the national industry from which the objectives will emerge as guidelines for the improvement and utilization on the country's genetic resources.

In view of this country's peculiar situation and the strategic importance of food production, the State will always be deeply involved in all efforts to promote livestock production and it is in the light of this fact that its involvement in all aspects of livestock production has been entrenched in the Act.

The Stud Book Association has undertaken the task of inspiring its members to make the transition to a more effective and scientifically orientated industry. It is encouraging to record the progressive steps already taken by this organization and to note the amount of fresh air blowing through the corridors of the stud industry.

The South African livestock industry is looking forward to a new era and will move away from a situation where the stud industry had a rather uninspiring future for the following reasons –

(a) pedigrees hardly served more purpose than to avoid unnecessary inbreeding;
(b) effective breed promotion (advertising) was regarded as a substitute for performance;
(c) claims for hardiness were used as a cover up for a lack of potential to produce a saleable commodity;
(d) spurious elegnat clip preparation was given preference over the inevitable move towards objective measurement;
(e) the value of some breeds did not extend further than the minds and ambitions of their owners;
(f) the artists believed they could go it alone in a rapidly developing, challenging and competitive world with its modern science and technology.

The available breeds and their different strains are the genetic resources of the livestock industry. In order to ensure their effective and optimum utilization the stud industry will have to co-operate closely with all concerned. There are basic problems which must be solved. It is obvious that the improvement of the present ineffective structure of breeds must be given priority. The stud industry can ill-afford to lose the genetic potential locked up in the large numbers of small herds and flocks of the various breeds. A group breeding system within the stud breeding context, in which individuality need not necessarily be sacrificed but through which resources are pooled and effectively utilized, warrants serious consideration by many breed societies since it offers tremendous scope particularly in conjunction with A.I. It is also evident that the inclusion and expansion of performance requirements for registration purposes will enhance breed improvement in more than one way. It will assist in creating a new stratification of the breeding population as well as a new class of animal breeder.

References

ADSRI, 1977. Unpublished report: Animal and Dairy Science Research Institute, Irene.
ALLAN, J.S., 1958. A genetic analysis of the development of the Jersey breed in South Africa. *S. Afr. Jersey.* 7, 24.

BRASCAMP, E.W., 1973. Effect of costs on the optimum breeding plan. *Z. Tierzücht. Zücht. Biol.* 90, 126.

BRASCAMP, E.W., 1976. Criteria and methods to detect optimal breeding schemes. Proc. of E.E.C. Symposium on Optimization of Cattle Breeding Schemes. Dublin. EUR 5490e.

CARTWRIGHT, T.C., 1976. Uses of modeling cattle breeding systems: Optimization of breeding schemes and optimization of research resources. Proc. of E.E.C. Symposium of Optimization of Cattle Breeding Schemes, Dublin. EUR 5490e.

CARTWRIGHT, T.C. & FITZHUGH, H.A., 1974. Efficient breeding systems for commerical beef production. 1st World Cong. on Genet. Applied to Livestock Prod. 1 : 643.

CELLIERS, B., 1969. *Die teeltstruktuur in 'n genetiese analise van die Friesras in Suid-Afrika;* M.Sc. Agric.- verh., Univ. O.V.S.

CELLIERS, B., 1978. *'n Ontleding van die genetiese bydrae van K.I. bulle tot die samestelling van die Friesras in Suid-Afrika.* Ph. D-proefskrif. Univ. Natal.

CUNNINGHAM, E.P., 1974a. Cost-effectiveness and population structure in cattle breeding programmes. *Ann. Génét. Sél. anim.* 5, 239.

CUNNINGHAM, E.P., 1976. Current developments in the genetics of livestock improvement. *Anim. Blood Grps. biochem. Genet.* 7, 191.

CUNNINGHAM, E.P., 1974b. Crossbreeding strategies in cattle populations. Proc. Work Symp. Breed Evaluation and Crossing Exp. Farm Anim. (Zeist). 107.

DEPARTMENT OF AGRICULTURAL TECHNICAL SERVICES, 1977. Livestock numbers in the Republic of South Africa, Division of Veterinary Services.

ERASMUS, G.J., 1977. *Die teeltstruktuur van die Suid-Afrikaanse Merino.* M.Sc. Agric.-verh., Univ. O.V.S.

HILL, W.G., 1971. Investment appraisal for national breeding programmes. *Anim. Prod.* 13, 37.

HILL, W.G., 1974. Prediction and evaluation of response to selection with overlapping generations. *Anim. Prod.* 18, 117.

HOFMEYR, JAN, 1966. Science and Sheep Breeding. Symposium on Genetics in Agriculture. *Technical Comm.* 86, 23.

HOFMEYR, J.H., 1976. Breeding policies and progress in relation to wool and meat production in the Republic of South Africa. *Proc. Aust. Soc. Anim. Prod.* XI : 517.

HOFMEYR, J.H. & BOYAZOGLU, J.G., 1966. Preliminary notes on vital statistics of selection in the Merino Sheep industry of South Africa. *Proc. Third Congr. S. Afr. Genet. Soc.* 75.

KOTZÉ, F. DE K., 1976. *Die teeltstruktuur en 'n genetiese analise van die S.A. Vleismerino in Suid-Afrika.* D.Sc. Agric.-proefskrif, Univ. Pretoria.

LERNER, I.M., & DONALD, H.P., 1966. *Modern Developments in Animal Breeding.* London & New York. Academic Press.

McCLINTOCK, A.E. & CUNNINGHAM, E.P., 1974. Selection in dual purpose cattle populations: defining the breeding objective. *Anim. Prod.* 18, 237.