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GENETIC IMPROVEMENT OF LIVESTOCK IN DEVELOPING COUNTRIES USING THE OPEN NUCLEUS BREEDING SYSTEM

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Summary

The genetic improvement of ruminants in developed countries has made much progress in the last 30 years by the use of large-scale field data derived from many herds based upon the progeny testing of males. A new option is now being discussed which is to use the new technique of Embryo Transfer with Multiple Ovulation (MOET) in an Open Nucleus Breeding System (ONBS). The genetic theory of the new option has been established [1, 2, 3] and in a few developed countries trials are being established to test the feasibility in practice. Other important factors still needing investigation are the ability to use MOET successfully as a routine in a large herd, to compare the costs of the new option against the existing system and to calculate how much of the theoretical gain is achieved in practice, especially when applied to commercial conditions with a field population. This will all take time. Meanwhile, the suggestion has been made that the Open Nucleus Breeding system (ONBS) may be especially valuable for developing countries [3, 4] where the use of field progeny testing and A.I. has largely been a failure due to the need for an established infrastructure, both for field recording and A.I. This paper therefore outlines the principles of ONBS and considers its possible use related to the needs, problems and opportunities of genetic improvement in developing countries.

A genetically superior nucleus flock or herd is established under controlled conditions where testing and genetic selection are carried out. This test group is first established by screening the base population for outstanding females. They are then recorded individually in the nucleus herd and the elite females among them are used by MOET with superior sires to contribute embryos which are carried by recipient cows from the base population. The resulting offspring are reared and recorded and the males among them are evaluated genetically using the performance of their sibs and paternal half-sibs and their own performance where they exhibit the trait. From these an elite group of males with high breeding value is selected which is used in the base population for genetic improvement by natural service or A.I. The ONBS yields higher rates of genetic progress *per annum* than established progeny testing systems mainly because of the shorter generation interval. It is capable of being adapted to different species in which MOET is available. It also permits control of the mix of genes released to the base population. The ONBS is flexible for the introduction of exotic germplasm from other populations, for example semen or embryos from temperate breeds and also for the continuous addition of outstanding individuals screened from the base population.

This paper emphasizes that in theory, the ONBS offers a method for the improvement of (I) purebred exotic breeds, (II) purebred indigenous breeds and also (III) stabilized crossbred genotypes. The level of response is naturally dependent upon the scale of the ONBS testing programme, the size of the base population and the selection intensity. Individual ONBS plans need to be designed for each situation and species. The paper gives an example of an ONBS plan for dairy cattle using a female adult group of 250 milking animals plus the associated young stock.

Introduction

Successful livestock improvement needs changes in several components of production. A genetic improvement strategy in developing countries is rarely successful unless accompanied by improved nutrition and herd health together with better stockmanship and feed resources management. In practice such changes are best accompanied by genetic improvement programmes, either for the purebred indigenous breeds, by breed substitution or by crossbreeding with exotics.

In many developed countries genetic improvement is achieved by the use of field performance recording on a large scale. For example, the progeny testing of dairy bulls using daughters' records has been highly successful when combined with A.I. However, in many developing country conditions, where field recording and A.I. are not possible, genetic improvement has been limited. The advent of Multiple Ovulation Embryo Transfer (MOET) may offer a new means of achieving genetic progress by the use of Open Nucleus Breeding Systems (ONBS), using the sibling test instead of the daugther test. The genetic relationships of brother and sister are the same as those of father and daughter. The system makes use of full and half-sibs to estimate the breeding value of males under test. First, the unrecorded base population is screened to find apparently superior females. This can be done either with a very simple recording system introduced temporarily in the field or by relying upon the owner's knowledge of the animals. These exceptional animals are brought together in the nucleus flock or herd to form a test group under controlled management where recording of their performance traits can be carried out routinely and where embryo transfer facilities can be located. The elite females from this test group are brought into multiple ovulation and their embryos are transferred to the other females in the test group and unrecorded females in the base population. The offspring, both males and females, are kept in the test group where their traits of interest are recorded. Then the male offspring are evaluated on the basis of their siblings' performances and their own records where these are available for a trait recordable in both sexes. The best of males are then used extensively in the base population either by A.I. or natural service.

The female offspring are next considered as potential elite females to donate embryos by MOET for the following cycle. This selection involves appraising them against the elite cows already in the nucleus flock or herd which have already been used for MOET. The critical decision about which females to retain for MOET is a balance between those with the highest individual genetic merit combined with their suitability for multiple ovulation, while seeking to minimize the generation interval between each cycle of MOET.

The comparison between progeny and sibling tests is illustrated in Figures 1 and 2 for dairy cattle. Sibling test results are obtained in 4 years compared with 7 for progeny testing. This difference may be larger when, as often happens, the age of the first calving of daughters in the field progeny testing scheme is delayed. On the other hand, the female siblings in the nucleus herd under controlled conditions can be calved at younger ages. Although the sibling test is less accurate due to there being fewer siblings for each male on test in an ONBS than there are offspring in a field progeny testing plan, the shorter generation interval of the sibling test provides higher genetic gains per year.

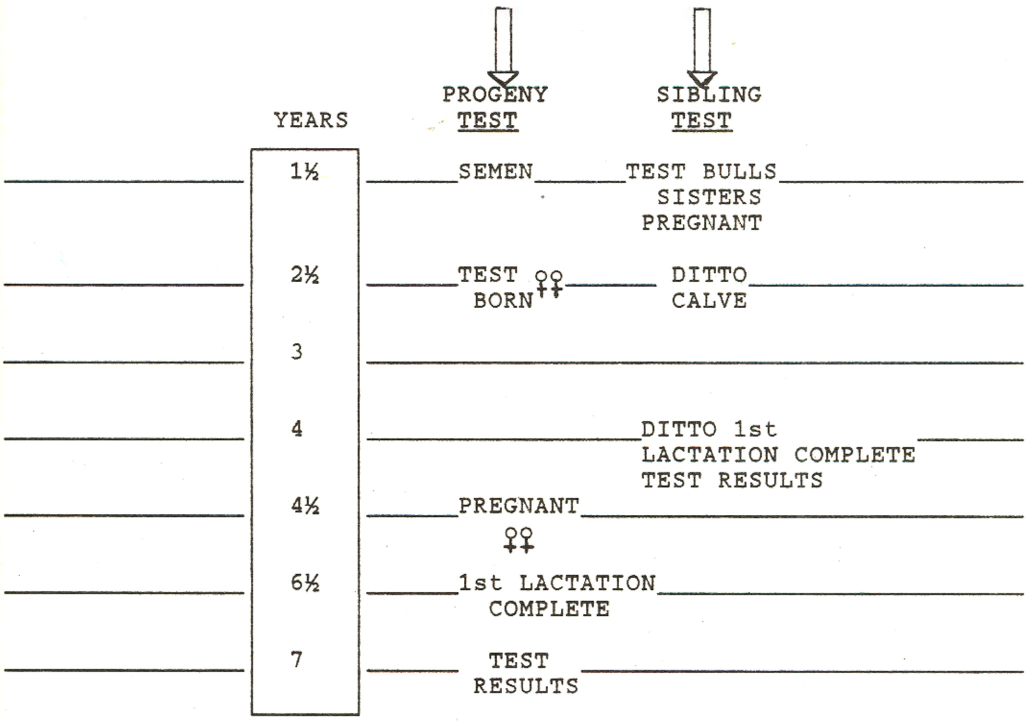

Fig. 1.

PROGENY TEST

- 30-50 DAUGHTERS
- 7 YEAR TEST

SIBLING TEST

- 4-8 SISTERS
- 16-20 HALF SISTERS
- 4 YEAR TEST
- LESS ACCURATE
- SHORTER GENERATION INTERVAL

Fig. 2.

Open nucleus breeding system for dairy cattle

The OBNS is illustrated now for a dairy cattle ONBS in a developed country (Figure 3). It is assumed in this example that when the ONBS is in full operation, the nucleus herd will comprise 250 females. These will include the elite females subject to MOET, and their female offspring in first lactation and other cows screened from the base population and on test. The younger animals must also be kept in addition. From this herd of lactating cows on test, it is assumed for the example that each year the 32 top performance animals are chosen for MOET using semen from 8 elite sires. This semen may be locally produced from previously tested males in the scheme, or it may be introduced from other improvement programmes elsewhere. In this way the Nucleus Breeding System is Open.

It should be noted that the figures here chosen for illustration are arbitrary. The genetic progress per year will depend upon the selection intensity which is determined by the actual figures used in practice. Thus numbers used here must be regarded solely as an example. The actual size of any ONBS will depend upon a variety of factors which will be discussed later in the paper.

Figure 3 shows that in this example, it may be possible under developed country conditions to produce 500 embryos annually from the 32 elite cows, from which an estimated 260 calves are born. In developing country conditions, where local conditions for MOET are less favourable, it is sure to be considerably less. For ease of illustration, it is now assumed that all 260 animals remain alive, fertile and available for selection. In practice an inevitable but variable loss will occur from different causes such as failure of heifers to conceive or to complete a pregnancy or lactation. There will also be some loss and infertility among males. These losses, though of importance in practice, are ignored here to simplify the

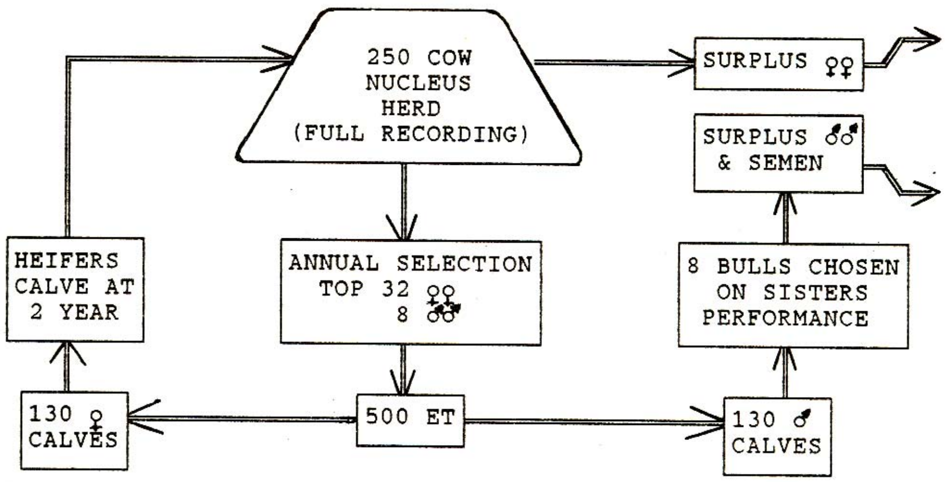

Fig. 3. Example of open nucleus breeding system for dairy cattle.

logistics which show animals moving through an ONBS for dairy cattle. The 130 females calve at 2 years of age and are milked in the test group with full recording. (In the case of a scheme combining milk and growth selection then both the males and females would be growth recorded). When the first lactation records are available, either complete or estimated from partial lactations, they are used to calculate breeding values for the sibling males. On average this will involve 4 full-sibs and 12 half-sibs per bull evaluated. The summary average logistics are given:

32 elite cows for MOET with 8 sires (4 cows per sire)
512 embryos recovered (16 per cow)
256 successful pregnancies (50% success)
(8 calves per cow - 4 females and 4 males)
(130 heifer and 130 bull calves in total)
130 bulls to be evaluated by sibling test
(4 full sisters, 12 half-sisters per bull)

An elite group from these 130 test bulls with breeding values is now chosen for extensive use when A.I. is available. Where there is need or demand for natural service, then a higher proportion of the above-average bulls is made available for use in the base population. Annually the test females whose records have been used for their brother's genetic evaluation, are then evaluated on individual performance records and the elite cows among them are retained for MOET as long as they remain responsive to the technique. This means that annually about 130 lactating cows will return to the base population leaving the best 120 cows in the test herd drawn from those who have just completed a first lactation and from older cows previously subjected to MOET. This permits the new crop of 130 replacement heifers to enter for their first lactation and thus maintain the size at 250.

EMBRYO TRANSFER

ADULT	o	AFTER FIRST LACTATION
	o	GENERATION 3.7 YEARS
JUVENILE	o	1 YEAR OLD
	o	GENERATION 1.8 YEARS

Fig. 4. (From Smith [3]).

POSSIBLE RATES OF GENETIC CHANGE PER YEAR FOR MILK YIELD IN DAIRY CATTLE WITH DIFFERENT BREEDING SELECTION SYSTEMS

	GENETIC RESPONSE (% per year)
PROGENY TESTING SCHEMES	
•RATES CURRENTLY ACHIEVED	0.2 - 1.1
RATES POSSIBLE	
•CURRENT SYSTEM	1.5
•EFFICIENT SYSTEM	2.0
•EFFICIENT SYST. WITH FEMALES SELECTED & BRED WITH ADULT MOET	2.0 - 2.3
•EFFICIENT SYST. WITH FEMALES SELECTED & BRED WITH JUVENILE MOET	2.1 - 2.3
MOET NUCLEUS HERD SCHEMES	
RATES POSSIBLE:	
°ADULT MOET NUCLEUS SCHEME	1.8 - 2.4
°JUVENILE MOET NUCLEUS SCHEME	2.6 - 3.5
(WITH EMBRYO SPLITTING x 2)	2.7 - 3.8
(WITH EMBRYO SPLITTING x 16)	2.9 - 3.9
°JUVENILE MOET NUCLEUS SCHEME WITH INDICATOR TRAIT (Co-heritability = 0.25)	2.7 - 4.8

The range in response within a system refers to moderate and high MOET rates. Moderate 4 males, 4 females per full sibship at selection; 8 donors per sire. High 8 males, 8 females per full sibship at selection; 16 donors per sire. Coefficient of variation = 0.15.

Fig. 5. (From Smith [3] after Woolliams and Smith [5]).

Genetic progress in ONBS

First, it is appropriate to define "Adult" and "Juvenile" MOET. These alternatives are applicable in principle to several species, but illustrated for dairy cattle (Figure 4). Adult MOET means that embryo transfer takes place only after the first lactation when the individual cow records of performance are available. Juvenile MOET means embryo transfer at about one year of age when the heifer is sexually mature, but has no lactation records on which evaluate her genetically. Adult MOET with dairy cattle gives a generation interval of about 3.7 years, whereas Juvenile MOET reduces this to 1.8 years. Figure 5 shows the theoretical rates of genetic change per year for milk yield in dairy cattle using different selection systems. These are potential changes. The actual gains will always depend upon the numbers of animals and the selection pressure. The theoretical gains show that ONBS using MOET may be a worthwile alternative to progeny testing. In developing countries the ONBS merits further research to test its practical feasibility since field progeny testing is rarely possible, whereas governments often have livestock station facilities already in their control which may be used for ONBS.

Figure 6 shows the annual rates of genetic change which may be expected on theoretical grounds from use of ONBS for traits other than milk in cattle and also traits in sheep and pigs.

RATE OF ANNUAL GENETIC CHANGE (% MEAN)

	CATTLE	SHEEP	PIGS
GROWTH	1.4	1.4	2.7
	2.6	2.4*	3.2
LEAN	0.5	0.9	1.6
	1.0	1.8*	1.9
SEX LIMITED TRAITS	MILK YIELD	LITTER SIZE	LITTER SIZE
	1.5	2.1	4.7
	2.0	3.5*	5.5

* JUVENILE EMBRYO TRANSFER; NORMAL REPRODUCTION EMBRYO ——TRANSFER

Fig. 6. (From Smith [6] quoted in Smith [3]).

The scale of each ONBS needs to be designed individually for actual conditions and species. It is not possible to give these in the abstract and expect that they will automatically fit any or all circumstances. Some of the critical issues are the size and distribution of the base population, the management system under which the base population is kept, the numbers of animals which can be accomodated in the nucleus herd facilities and the level of success with MOET. Calculations to take account of animals being held while awaiting test must be made and cost-benefit evaluations are needed on the advantages and disadvantages of alternative strategies for age at first parturition and use of Juvenile or Adult MOET. Another important point is whether semen is to be used by A.I. from the elite proven sires or whether genes from the elite proven animals are to be spread through the base population also or only by natural service.

A most important issue in developing countries relates to the genetic improvement strategy (Figure 7). Is it designed to improve the purebred indigenous breed, as for example in an environment with highly specific adaptability needs - or can exotics be introduced as purebreds where the environment and management can be adapted to their needs?. Very often in developing countries the first option is not desirable and the second is not possible. Therefore crossbreeding is often the preferred route. ONBS could be adapted for controlling the gene mix in a base population. The type of semen used for MOET on the elite indigenous females must be adjusted subsequently as the base population becomes crossbred. When the exceptional females resulting from the sib test are crossbreds and are themselves treated by MOET with semen from crossbred males, they maintain the desired gene mix.

<u>OPEN NUCLEUS BREEDING SYSTEM</u>

- o PUREBRED IMPORTED BREEDS
- o INDIGENOUS PUREBRED BREED
- o INDIGENOUS FEMALES (ADAPTED) & IMPORTED MALES/SEMEN (HIGHER PERFORMANCE)
- ● CONTROL % GENE MIX

Fig. 7.

Conclusions for developing countries

The benefits of ONBS combined with MOET, compared with field breeding schemes are summarized in Figure 8. The specific advantages and expected rates of annual genetic gain should be assessed in each case and must include not only the genetic aspects, but also the logistic and economic factors.

Another important concern should always be training of the staff at all levels so that they fully understand the theoretical basis of ONBS and MOET. The staff to be trained naturally must include the station personnel who are responsible for the livestock in the nucleus herd or flock. The training of extension staff is vital as they will be involved in sharing the details with the livestock owners in the area whose animals form part of the base population. The success of such a system is dependent upon the willing cooperation of the owners of the livestock. They, as always, need to be convinced of the value of this new scheme being proposed by the government. Patience and skill in describing its operation, benefits and posible risks must be employed. Ideally the ONBS/MOET system should have a cooperative aspect which brings the leaders of the local livestock owners into the disscussions and decisions, especially concerning the evluation of the animals and choice of which males are to be in the base population.

ADVANTAGES

> GENETIC LIFT IN ESTABLISHING THE UNIT
> FASTER RATES OF GENETIC CHANGE
> CONTROL OVER HUSBANDRY & TESTING
> MORE EFFECTIVE SELECTION POSSIBLE FOR ECONOMIC MERIT
> USE OF TRAITS DIFFICULT TO RECORD IN FIELD
> CONCENTRATION OF BREEDING RESOURCES
> POSSIBLE USE OF EXPENSIVE TECHNOLOGIES
> ECONOMIC BENEFITS OBTAINED SOONER
> LOW COSTS ON A NATIONAL SCALE
> SEPARATE NUCLEUS UNITS FOR DIFFERENT SETS OF BREEDING OBJECTIVES/ENVIRONMENTS

DISADVANTAGES

> RISK OF DISEASE, AND LOSS (avoid by dispersing age classes)
> RISK FROM CONCENTRATING STOCK & RESOURCES IN ONE UNIT
> POSSIBLE GENOTYPE x ENVIRONMENT INTERACTIONS IN COMMERCIAL PRODUCTION
> NEW FUNDS NEEDED TO SET UP AND OPERATE
> RE-EDUCATION OF PRODUCERS TO ACCEPT MOET BRED STOCKS

Fig. 8. Advantages and disadvantages of nucleus breeding units compared with field breeding schemes (from Smith [3]).

An old problem with trying to buy outstanding animals from local owners for a government programme, has been their natural reluctance to part with their best animals. It is understandable. Cooperation between the government who operate the nucleus flock or herd and the owners may be made more productive and successful if the females screened from the base population are loaned rather than bought. As borrowed females they then enter the test flock or herd for a period of recording. When they return to the owner it should be possible to provide a genetically superior offspring to accompanying them as a return to the owner.

The theory of ONBS appears to be very attractive. The system is already being tested in some developed countries in Europe for dairy cattle. It now needs to be tested and practical protocols designed for application in developing countries. Only then will it be possible to calculate how much of the theoretical genetic gain can be achieved in practice with defined species and traits and whether the needed levels of success with MOET can be achieved with indigenous animals.

Finally, it may be asked what all this has to do with biotechnology? The answer is that Embryo Transfer is an essential part of biotechnology for mammals, since it is by the manipulation of the embryos that molecular genetics is applied to livestock. In the longer term future, biotechnology with ET is likely to open up new means of producing animals with the desired mix of genes, whether as improved purebreds or by bringing together the desired high performance traits of one breed with the adaptive traits of an indigenous breed.

While the molecular engineering techniques are still very imprecise and the results variable, intensive research is taking place in developed countries. Also the sexing and cloning of mammalian embryos is the focus of much research activity. ONBS and MOET appear to be key techniques for channeling biotechnology into genetic improvement of livestock in the future.

At present, without molecular genetics ONBS and MOET have theoretical advantages which if adapted successfully to the conditions of developing countries, could offer a new approach to livestock improvement. They also offer a vehicle which, if successfully established, will be suitable for conveying expected benefits of future biotechnology research and development in embryo manipulation and gene transfer.

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