TECHNOLOGY AND ANIMAL BREEDING: APPLICATIONS IN LIVESTOCK IMPROVEMENT

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SUMMARY

New technologies affecting livestock improvement are identified in 1) manipulation of reproduction, 2) indirect assessment of the phenotype, 3) indirect assessment of breeding value, 4) computing and statistics, and 5) direct manipulation of the germ line. Multiple ovulation and embryo transfer (MOET) offers new opportunities in the improvement of traditional methods of livestock breeding and is a pre-requisite of many other technologies. Theoretical rates of genetic change may be doubled in beef cattle and sheep by use of MOET schemes and rates achieved in practice may be more than doubled because of the increased control over selection. Techniques to predetermine sex could affect breeding practices by creating new production systems and so consequently new breeding objectives. Improved methods of in-vivo carcass assessment are available for beef cattle and sheep improvement. Freezing of oocytes and semen or production of identical twins by embryo splitting could allow direct carcass assessment in animals. Marker assisted selection could theoretically improve rates of response but improvements would be small considering the technical effort involved. Computers make advanced systems of information use available to even small scale operations. Statistical advances tend to have concentrated on improving the accuracy of estimation of breeding values rather than the more important criterion of improving rates of response to selection. Many of the changes to the germ line that might be brought about by molecular genetic manipulation will add extra genetic variation (not always useful)for selection to exploit. Large changes will be more readily evaluated and used, and if successful this could become the main method of genetic improvement in the future.

INTRODUCTION

Genetic improvement programmes have been available for most livestock species over the past decades. Much improvement has been achieved by breed substitution and breed crossing systems which exploit heterosis and complementarity. But the main route to genetic improvement has been and remains selection within breeds. Systems of genetic improvement in most species have not been static but have evolved with time. In some cases, major changes in the structure of the industry have resulted. For example, in the UK pig industry, breeding work is now concentrated in the hands of a few large companies. By comparison, selection of beef cattle and of sheep in the UK has been less effective, with uncertainty about breeding objectives and lack of selection effort for performance traits, in a dispersed and unresponsive breeding industry. Compared with well documented genetic improvements in poultry, pigs and dairy cattle, sheep and beef cattle improvement continues to lag.

In this paper we review the effects that existing technologies are currently having in livestock improvement programmes and consider their potential. We also briefly consider the possible impact of new technologies which may soon become available. With some overlap, technological developments aid breeding programmes in the following areas, 1) manipulation of reproduction, 2) indirect assessment of the phenotype, 3) indirect assessment of the genotype, 4) computing and statistics, and 5) direct manipulation the germ line. These areas will be considered in turn.

MANIPULATION OF REPRODUCTION

New technologies in reproduction are outlined by Polge (1986) and the implications of some of the developments are considered here.

Multiple ovulation and embryo transfer (MOET) can improve rates of genetic progress by increasing reproductive rates. In beef cattle rates of genetic progress can be doubled by MOET. (Land and Hill, 1975) but this does not seem to have been applied so far despite all the MOET technology being available. Several MOET programmes are being considered for dairy cattle breeding (Van Vleck, 1986) where potential gains in the rate of genetic progress are substantial but lower than those for beef cattle.

In sheep breeding, the rates of genetic change in most traits can theoretically be doubled by use of MOET (Smith, 1985). However, to obtain high rates of response, effective MOET from juvenile (6-8 month old) females is required. This is not currently feasible, due to a lower viability of embryos transferred from juvenile females (Quirke and Hanrahan, 1977) and research is needed to overcome this problem.

In pigs, female reproductive rates are high, but effective MOET would allow increases of 15-20 percent (Smith, 1981) in the rate of genetic change. Breeders may not consider this sufficient to warrant the extra effort involved.

The comparative rates of genetic change theoretically possible for different kinds of traits in the different livestock species, with normal mating and with MOET, are shown in Table 1, following Smith (1984). The splitting of early embryos to produce sets of genetically identical progeny can add further gains. MOET schemes would allow tight control of the objectives and selection and thus are more likely to achieve their theoretical rates of response than traditional schemes. Therefore, the advantages of MOET schemes would generally be even greater than indicated in Table 1. With MOET, rates of genetic change possible in beef cattle and sheep are high and comparable with those in pigs and poultry. It is important that the cattle and sheep industries use the new MOET breeding systems to improve their meat production systems in competition with those of the other species.

TABLE 1

Rates of annual genetic change theoretically possible in farm livestock by selection (from Smith, 1984). Changes are expressed as a percentage of mean performance.

	Cattle	Sheep	Pigs	Poultry
Growth traits				
Normal mating	1.4	1.4	2.7	3.2
Embryo transfer	2.6	2.4+	3.2	-
Lean percent				
Normal mating	0.5	0.9	1.6	2.2
Embryo transfer	1.0	1.8	1.9	-
Sex limited traits	Milk yield	Litter size	Litter size	Egg production
Normal mating	1.5	2.1	4.7$	2.1
Embryo transfer	2.0	3.4	5.5	-

+ Juvenile transfer
$ Avalos and Smith (1985)

Efficient and cheap sexing of sperm or early embryos (White et al, 1984) could affect production systems with indirect effects on genetic improvement. Taylor et al. (1985) have shown that a beef production system consisting entirely of females which are slaughtered after weaning their first (and female) progeny could be 50% more efficient than current systems of lean beef production. An important selection objective in such a system would be for early reproduction with ease of calving. With semen sexing, in dairy cattle all female replacements would be bred by dairy bulls and the rest would be males by terminal sires for beef production. With embryo sexing and commercial embryo transfer, separate maternal and paternal lines would be selected for different objectives, since maternal (recipient) lines would contribute maternal effects but no genes to the commercial product. Cheap and efficient embryo transfer in pigs could have a similar outcome. Hyperprolific (Chinese) pigs might be selected to farrow even larger litters, whilst ignoring growth and carcass traits since they would not contribute genes to the commercial product.

Less dramatic but still important improvements are being made through advances in existing technology. For example, improved dilution rates and length of storage life of fresh semen has led to very intense selection and use of dairy sires in New Zealand (G. Stitchbury, personal communication). With sheep, although frozen semen is generally less effective than fresh semen in AI (Langford et al. 1979), Fukui and Roberts (1976) have demonstrated that intra-uterine insemination with frozen semen can be as effective as AI with fresh semen. Further developments along these lines could lead to widespread use of AI and MOET from nucleus stocks reducing the time taken to spread genetic improvements into the national population.

INDIRECT ASSESSMENT OF PHENOTYPE

In many species the improvement of body composition and efficiency of production are the primary selection objectives. In vivo techniques for assessing the body composition of breeding animals are thus important, as for example ultrasonic fat measurements in selection of pigs for increased lean content. Developments in this area were recently covered by an EEC workshop (Lister, 1985) where improved ultrasonic measurements were shown to be of potential use in beef cattle and sheep breeding and X-ray computed tomography (X-ray CT) to be of use in sheep and possibly pig breeding. Real time linear array ultrasound measurements have also recently been suggested for a further improvement of in-vivo pig carcass evaluation (Molenaar, 1985).

An alternative to in-vivo body assessment was proposed by King (1985). Following early collection and freezing of oocytes and semen, potential breeding animals could be slaughtered and posthumously selected on the basis of carcass dissection and meat quality results. Alternatively, embryo splitting to produce identical twins could be used to produce one twin for test and slaughter and the other for breeding if selected on the basis of its identical twin's performance. Both techniques would have the advantage of greater accuracy than in vivo assessment.

Better understanding of biological processes should allow information on physiological traits to improve accuracy and response to selection (eg, Walkley and Smith, 1980). Plasma lipoprotein concentrations are highly correlated with body fatness in chickens (Whitehead and Griffin, 1982) and are now being used in commercial selection programmes. The activity of lipogenic enzymes might also have potential in selecting against backfat in pigs (Muller, 1985).

INDIRECT ASSESSMENT OF THE GENOTYPE

It has been proposed that it might be possible to measure physiological and metabolic processes in an animal which are closely related to the genetic potential of that animal. In particular this would have great advantages with sex limited traits (such as milk yield or female reproductive performance) if tests could be carried out in early life in males (eg, Tilakaratne et al, 1980). Work along such lines has yielded significant biological results (Larsen, 1982) but no practical aids for selection so far.

Indirect assessment of the genotype is also possible through marker assisted selection of quantitative trait loci (QTL) (Soller and Beckman, 1983). With a very large number of polymorphic markers (such as restriction fragment length polymorphisms and hypervariable DNA sites), unique haplotypes of the QTL and linked markers may be available so that selection can act as if it were on the QTL themselves. However, it has been shown (Stam, 1985; Smith and Simpson, 1985) that the additional gains in genetic response may not be large, and that the systems are limited by sampling errors in estimating family effects, by crossover losses, undetected crossovers and the frequency of the (non-unique) haplotypes.

COMPUTING AND STATISTICS

New computing and data handling and analysis systems offer advantages in improving the accuracy of selection by including family and prior statistical information in selection, and by reducing the time delay from completion of the record to evaluation and selection. Systems of incorporating extensive familial data (eg. for substantial gains in litter size of pigs, as proposed by Avalos and Smith, 1985) need good data handling facilities for modern small computers. Development of statistical methodologies continues but they tend to deal with specific problems (eg. all or none traits) or are minor improvements to existing methodology. Too often concern has been with accuracy of estimating breeding values, rather than with the rate of genetic response achieved. In most situations the limitations to progress are in organising good information collection and collation and not in computing power or statistical methodology.

DIRECT MANIPULATION OF THER GERM LINE

Molecular genetics has not yet advanced to the stage where commercially valuable genetically modified animals have been produced. However much of the technology is available and it can only be a matter of time before genetically altered animals result. The consequences for genetic improvement programmes will clearly depend upon the type of genetic modifications made but a few broad generalities are clear. If transgenic modifications are relatively small, assessment of their effects, stability and economic merit would require large numbers of animals and the effort may not be worthwhile. In this situation transgenics may be simply a method of increasing genetic variation available for selection. But there would be risks in introducing untested material into the selection nucleus population. Proper evaluation of transgenic modifications of large effect would also take much time and effort but the possible returns would be greater. All transgeneic modifications need to be carried out in genetically superior animals if their effects are not to be reduced by genetic lag for improvement by conventional methods. Only large, stable and balanced transgenic modifications are likely to greatly alter genetic improvement programmes. If, however, molecular genetic methodology can achieve this goal it may become the main method for genetic improvement in the future.

The alternative possibilities of producing high-value novel products (Lathe et al, 1985) or altering existing products to fit new markets (eg, lactose-free milk) would not greatly affect conventional breeding methods since either small numbers of animals will ultimately be involved or conventional methodology will be required to breed and further improve the small nucleus population of transgenic animals.

TECHNOLOGIES OUTSIDE GENETIC IMPROVEMENT

Technological advances in other areas may make genetic improvement seem less important. Understanding the physiological basis of growth and production may allow direct manipulation with new factors. Good examples of this are the use of somatotropin to increase milk production and efficiency (Bauman et al., 1985), and passive immunisation against feed back hormones to increase ovulation rate in sheep, (Land et al., 1982). A recent report of passive immunisation against adipocytes (Flint, 1984) could possibly lead to a control or elimination of fat production in pigs and sheep. This would have radical effects on breeding objectives. Therapeutic control allows much more flexibility than genetic control, and may be preferred, but requires continuous treatment and may draw adverse public reaction. Meat quality as a breeding objective, especially in pigs, may also moderated by new handling, stunning, manipulation and processing techniques, (Pearson and Tarbet, 1984).

ORGANISATION

Embryo transfer and other new technologies are often expensive, laboratory based and depend on technical expertise. It may not be possible to employ them widely, among many dispersed breeding units. Thus with their application, breeding may become more centralised, based on elite nucleus breeding units on which the technical and selection effort can be concentrated. This would overcome many of the difficulties met in the past in animal improvement, of getting accurate unbiassed estimates of breeding values across many herds, motivating and rewarding breeders, and disseminating improved stock to commercial producers. Concentration on nucleus units allows more detailed study of individuals, more accurate recording, measurement of feed intake and control over selection and breeding operations. Thus more of the genetic improvement possible may be achieved in practice.

Methods of funding new developments in genetic improvement need consideration (King, 1985). National groups may support applications, as proposed with MOET in dairy cattle breeding in Denmark (Christensen and Liboriussen, 1985). But often the initiative is left to industry and the take up of new methodologies may be slow. The anomaly exists that the benefits are much larger to the consumer than to the breeder with his limited sales and competition.

International competition is now common, with control of disease and effective semen and embryo technology to distribute germ plasm. Evaluation and substitution by the currently superior stocks is expected. There may then be concern about the small genetic base on which world wide production is based. National effort might then be put into conservation, especially in developing countries with adapted indigenous stocks. Another role for national or international effort would be to select stocks from different genetic bases and for different objectives, which may have economic importance in the future, so that uncertainties about future needs and conditions could be met.

SOCIAL REACTION

The biological revolution of the second half of the century has been compared in importance with the revolution in nuclear physics in the first half. The tools are now becoming available to affect the biological revolution. Society is beginning to become aware of its potential for good, and for evil. The implications for application to man may lead to some concern. With more activity, application and publicity, Society may wish to consider controls on its development. For example if there were an increase in the frequency of abnormal types, or if novel types were unnatural in their appearance or behaviour, public reaction might be strong. The use of meat animals might be reconsidered, and synthetic methods of production of animal proteins or substitution by plant proteins, may be preferred. Competitive pressures drive producers to use the most profitable (and extreme) methods, so agreement on common standards and acceptable norms among countries would be required. The unpredictability of social reaction ultimately makes the long term future of genetic improvement very uncertain.

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