MEETING ENVIRONMENTAL CHALLENGE BY GENETIC MEANS

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Summary

The expression of the productive characters of an individual depends on its genetic makeup and the environment to which it has been exposed. Productivity may thus be increased by improving either the environment, or the genetic characteristics of the animals, or both.

Although most environmental challenges could be met by genetic means, this will not always be the optimum approach. Hence, the nature of the environmental challenges are discussed, defining them in terms of physical and biotic components. Interactions among these components in their effects on livestock are often complex, and they cannot be considered as separate entities. Examples are given of the existence in livestock populations of genetic variation available to meet the challenges.

Whether or not an environmental challenge should be met by genetic means depends on the feasibility of changing the environment, the expected improvement from the breeding programme, the expected relative net economic return from these two approaches, and human needs and values. The breeding methods that may be used are discussed.

The greatest challenge to livestock production results from the growth of the human population and the implications of this for the future of animal breeding are considered.

I. INTRODUCTION

It is likely that most environmental challenges to animal production could be met by genetic means. The aim of this review is to define the nature of the environmental challenges so that consideration can be given as to whether they should be met by genetic means. Then, where genetic programmes are desirable, their optimum strategy will be discussed. In this context, some comments will be made on the future of animal breeding.

Genotype and/or Environment

It is a basic tenet of genetic theory that the genetic makeup (genotype) of a fertilised egg determines only the potential expression of the characters of that individual. The actual expression of the characters (the phenotype) depends on the set of environments to which that individual is exposed from the time it commences its existence at fertilisation.

The environment therefore affects the productivity of all individuals and immediately poses a challenge to the maximisation of productivity. But there are two ways of answering this challenge, either modification of the genotype or modification of the environment. That is, we might initiate a breeding programme to

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select those animals that are better adapted to particular components of the environment. Over some period of generations, productivity is expected to increase as a result of this selection. On the other hand, the environment might be changed to allow maximum expression of the productive potential. But these are not clear-cut alternatives; in many if not most cases, both will be desirable, so that there should be continuing effort to optimise the environment as the genotypes change in a breeding programme.

Optimisation of the environment would normally be considered in terms of nutrition, management, disease control, etc., and there is ample evidence that quite spectacular increases in natural productivity could be achieved by such within-herd or flock environmental improvement. The best evidence is available for dairy cattle, for example, the New Zealand “Production Improvement Project” (New Zealand Dairy Board 1955). Low producing farms were selected on the basis of the willingness of their owners to cooperate. Consulting officers were each allocated some 30 farms, and by studying farm operations. were able to identify factors limiting production and advise accordingly. As a result, the average butterfat production per farm increased by 40 per cent, and average production per cow by 15 per cent over six years. Also in dairy cattle, Robertson and Rendel (1954) in England, and Brumby (196 1) in New Zealand showed that no more than 10 per cent of the variation in herd averages for first lactation milk yield was genetic, although the proportion was somewhat higher for fat percentage. Thus for milk yield, about 90 per cent of the variation among herd averages was environmental (management, nutrition, etc.), and an immediate increase in production would be achieved if the environmental levels of all herds were brought up to that of the best. The specific environmental factors contributing to differences among herd averages are not understood in detail, but “cowmanship” is certainly an important factor. To best meet this environmental challenge by genetic means would entail turning our attention to the breeding of livestock managers, and not the livestock themselves.

II. DEFINITION OF ENVIRONMENTAL CHALLENGE

So far, the environment and its effects on productivity have been referred to in general terms, but we need to determine specifically just what are the environmental challenges to livestock production, and to consider genetic improvement of livestock populations in relation to these challenges.

For present purposes, the environment may be defined as any factor other than the genotype of an individual that affects its phenotype. Although components of the environment cannot necessarily be considered in isolation, a simple classification to assist discussion is as follows:

(a) Physical — (i) Climate (1) Temperature
(2) Light
(3) Solar irradiation
(4) Water

(ii) Management
(iii) Nutrition

(b) Biotic — (i) Social environment (Interactions within species)

(ii) Pathogens, parasites and predators (Interactions between species)

(iii) Man (1) Direct effects

(2) Indirect effects through (a) (ii) and (a) (iii)

The effects on productivity of some of these components are well recognised and some evidence is available that their challenges could be met by genetic means, that is, by breeding strains adapted to the environment.

(a) ***The Physical Components***

Most attention undoubtedly has been given to the effects of high temperatures on cattle productivity, some aspects of which have been reviewed at meetings of this Society by Turner (1964) and Yeates (1968). The latter also drew attention to the interaction between the components of temperature and water, that is, the need to consider separately hot-humid and hot-dry environments. Bianca (1965) extensively reviewed the effects of heat on structural and functional features of cattle, while Mahadevan (1966) has discussed the breeding of dairy cattle adapted to hot environments.

Less information is available on the other climatic components and certainly less attention has been given to the possibility of meeting their challenges by genetic means. Light, in terms of the annual cycle of changing daylength, is important in determining the expression of various physiological phenomena in livestock, e.g. hair shedding in cattle (Yeates 1965), the breeding season in sheep (Yeates 1949; Hafez 1952; Radford 1966). Cattle of European breeds generally show a well-marked seasonal change in coat character. The long, curly winter coat sheds in the spring, giving rise to a summer coat that is short, flat and glossy. However, there is considerable variation among breeds and among individuals within breeds in their expression of shedding, so that selection to develop strains best adapted to particular environments should be possible. The duration of the breeding season in sheep varies between breeds and is related to their latitude of origin. Most of the British breeds exhibit a short season commencing in late autumn, while tropical breeds are essentially non-seasonal. The efficiency of prime lamb production could be increased by extended breeding seasons and the opportunity for two matings per year. No information is available on the heritability of duration of breeding season within breeds. But given the variation among breeds, it should be possible to develop strains otherwise adapted to a given environment and capable of mating twice each year.

Although effects of solar irradiation are intimately related to those of temperature in hot climates, a specific effect is exemplified by “cancer eye” in cattle. This condition is particularly important in the Hereford breed, and is responsible for significant economic loss through reduction in average productive life and in market value of affected animals. Selection for resistance to cancer eye would be possible, although slow, due to age differences in lesion manifestation (Vogt and Anderson 1964). However, Guilbert et *al.* (1948) found that cancer always developed first in the unpigmented portion of an eyelid. As pigmentation can be scored in young animals and has a high heritability (French 1959; Vogt, Anderson and Easley 1963), selection for a high degree of eyelid pigmentation should be successful in reducing the incidence of the condition.

Water may pose a challenge through either insufficiency or excess, and either as ground water (drinking water, boggy conditions, etc.) or as humidity. In cattle, breed differences in the effects of drinking water deprivation have been demonstrated (Bonsma 1949), as have differences in water conservation (Payne and Hutchison 1963). In Merino sheep, Dunlop and Hayman (1958) have shown strain differences in susceptibility to fleece rot, the strain developed in a low rainfall environment being markedly more susceptible than other strains when all were exposed to high rainfall. With increasing use of intensive housing for poultry, pigs and cattle, high humidity may pose a challenge to these species. Possible direct effects of high humidity are of uncertain importance, but with increased crowding, would certainly allow increased opportunity for pathogen survival and transmission.

Although management and nutrition can be strictly defined as physical components, they will be discussed later as indirect effects of man.

(b) *The Biotic Components*

Effects of the social environment are well recognised in poultry (McBride 1962, 1964) and social status can influence growth rate in pigs (McBride, James and Wyeth 1965; James 1967). McBride *et al.* (1967) reviewed behaviour of domestic animals and emphasised the inadequacy of present knowledge of the relationship between behaviour and productivity. The trend to intensification in animal production (higher stocking rates, intensive indoor systems) means that behavioural effects will become more important (Ewbank 1969). Increased density may lead to modification of social behaviour, probably increasing social stresses resulting in increased aggressiveness (Scott 1948; McBride 1964), and perhaps in reduced productivity.

The economic costs to the animal industries of pathogenic diseases and parasite infestations are unknown but undoubtedly immense and the possibility of selection for disease resistance is receiving increasing attention (Hutt 1958; Fredeen 1963; Goodwin 1966). Successful selection for resistance to leucosis in poultry has been demonstrated by Hutt (1958), and in a commercial breeding flock by Goodwin (1966). Recent work characterising the causative viruses of the leucosis complex has shown that resistance to some forms of the complex is simply inherited (Biggs 1966). Further development of these studies on virus-host relationships could simplify the identification of highly resistant individuals and greatly facilitate the development of resistant strains. Other major diseases and parasites for which genetic variation in resistance has been demonstrated, but which are not adequately controlled by the present procedures of veterinary medicine (vaccination, antibiotics, etc.), include mastitis (Schmidt and van Vleck 1965) and ticks (Hewetson 1968; C.S.I.R.O. 1969) in cattle, scrapie in sheep (Draper and Parry 1962), atrophic rhinitis in pigs (Fredeen 1963), and general respiratory infections in poultry (Goodwin 1966).

Man has been included as a specific category of the biotic environment although in the broadest sense, all environmental components of interest result from his specification of where and how he attempts to raise livestock. Nevertheless, the most obvious indirect effects of man are through management and nutrition. Our knowledge of these is continually increasing, but this does not necessarily mean that present systems do not impose environmental challenges. Possible effects of intensive systems have already been referred to. Nutritional effects are obvious in the metabolic diseases such as milk fever and bloat.

But man does have direct effects on livestock production. Market requirements or particularly a change in requirements may pose a strong challenge. In late 1969, the news media gave some prominence to the development of Sykes International in Great Britain of a high production poultry strain laying exclusively brown-shelled eggs — a development to meet the preferences of a proportion of British housewives. Similarly, broiler breeders here have had to produce strains with white feathers and white skin, while yellow skin is preferred in some other countries. In dairy production, a change in emphasis from milk fat content to solids-not-fat (particularly protein) content is currently receiving increasing attention.

Social factors, such as labour costs and availability, may also be important, although these are perhaps more likely to be overcome by increased mechanisation and application of technology. In terms of economic factors, changes in the structure of costs of production could become increasingly important. In egg production, the annual replacement of the birds is one of the most important cost items. Consideration therefore could be given to the development of strains that are efficient producers in their second or even their third year.

The greatest challenge due to man, namely the growth of the human population and the resulting demands for increased food production, supersedes all others. Before discussing this in detail, however, I want to consider one other aspect of the environmental challenge and the general question of meeting the challenges.

III. GENOTYPE-ENVIRONMENT INTERACTIONS

So far, components of the environment have been considered individually,. although some of the many interactions among them have been noted. A further major environmental challenge stems from the fact that the environment is not static, but changes in both space and time. All genotypes will not necessarily react to this environmental variation in the same way, that is, a genotype-environment interaction may exist. For example, the rankings of a group of bulls on progeny tests done in the different environments of southern and northern Australia might be quite different. Where such interactions are important, and this can only be determined experimentally, the important question concerns the optimum strategy of breeding programmes — should selection be carried out separately in each environment to develop separate strains, or should selection be for general adaptability to develop one strain suitable for all environments? (James 196 1; Dickerson 1962.) The answer will depend at least partly on the nature of the environmental variation; for large-scale climatic differences, the former would probably be the answer, while for more subtle variation, as between management practices and disease incidence in commercial farms, the latter would be the method of choice.

Environments changing in time present a problem that is likely to become more important. In a fluctuating environment with significant genotype-environment interaction, rates of genetic improvement would be less than in a stable environment. In the extreme case of a cyclical environment with a cycle length equal to the generation interval, the genotypes selected as best in one envircnment produce off spring that develop and would be selected in the other environment.

With the increasing tempo of change in agricultural technology, we are faced as well with directional changes in the environment. These should be considered in determining present breeding programmes, so that we need to ensure that present selection criteria are defined not only in terms of the present environment, but as well in terms of expected future environments. That is, we can only hope to adequately meet this challenge where some thought and effort are devoted to prediction of the nature of future environments.

IV. MEETING THE CHALLENGES

Given that genetic variability in ability to respond to any environmental challenge exists in our livestock populations, the challenges could be met by genetic means. But this is not to say that it will always be the best answer. Although there is good evidence of genetic variability in resistance to pullorum in poultry (Hutt and Crawford 1960), selection for such resistance in a poultry breeding programme would not be warranted as the disease is adequately controlled in other ways. The possible utilization of genetic means must be considered separately for each case, questioning the desirability of this approach as compared with any others available. The major question in this evaluation is the economic one. Firstly, will the gains achieved in productivity be sufficient to compensate for the costs and effort of obtaining them? Secondly, will the nett economic return be maximised by this approach or by another such as changing the environment? It should not be forgotten, however, that in some cases the economic analysis might be tempered by human needs and values; for example, in national or international programmes designed to produce strains suitable for use in the developing countries. In considering utilization of genetic means, it is also 'important to note that each additional character included in a selection programme reduces the rate of improvement in all characters.

For any case where utilization of genetic means appears desirable, one or more of a number of methods may be used. Selection within currently existing breed populations is one obvious method, but I consider this likely to become less the one of choice (Barker 1967). More rapid progress towards the goal of productive and adapted animals is likely to be obtained by crossbreeding, generally followed by some form of selection. Such crossbreeding may be done to broaden the base of available genetic variability for selection, to introduce into a relatively productive strain a desired adaptive character from an unimproved strain, or to introduce a desired major gene. Thus the development of cattle strains suited to a tropical environment has been based on crossbreeding productive European strains with the adapted but relatively less productive ***Bos indicus*** strains, followed by selection in the crossbred population. There are probably many hundreds of livestock strains throughout the world and although we know very little about most of them, it is certain that at least some could contribute significantly to crossbreeding programmes designed to meet many of the environmental challenges (Hodgson 196 1; Turner 1967; Barker 1969). An example of the utilization of a major gene is provided by the sex-linked dwarf gene in poultry (Jaap 1969). When incorporated into the dam line of broiler chickens the gene reduces the body size and the maintenance requirement to about 66 per cent of normal. Yet the egg production of these females is equal to that of normal birds and the growth rate of their progeny by normal sires is depressed very little, if any.

V. THE FUTURE

It has been pointed out that human activities essentially determine the nature of all of the environmental challenges, but that the greatest challenge stems from the growth of the human population. This is obvious in terms of the demands for increased production, but there are other more far-reaching implications. The pressure on land use will mean that land currently used for animal production will be increasingly devoted to crop production, so that animal production will tend to become both more intensive and more extensive. Environmental challenges that we can already perceive will be accentuated, and new ones may arise, but this is the prospect to which we must look forward and which we must be prepared to meet. In the developing countries, the pressure of human population will be such that large animal production is likely to be possible almost exclusively under intensive systems, if at all. New challenges will arise in the utilization of species such as fish, game animals and micro-organisms, and from changes in product requirements. For example, in dairy production there is currently a change in emphasis from fat production to protein production. But milk protein is not a homogeneous entity and there is some evidence that the types and proportions of protein variants present in milk may have considerable significance in manufacturing processes (Barker 1968), so that we might need to consider the development of strains with specific milk protein composition.

Meeting these challenges will depend not only on application of present knowledge, but on a much better understanding of the nature of genetic variation and of the genetic basis of physiological differences among individual animals in relation to productive and adaptive characters (Robertson 1963; Barker 1967).

In relation to meeting the challenges of the future, some comment should be made on the structure of animal breeding. Recent evidence from laboratory selection experiments (Barker 1967, 1969) emphasises the importance of maximising population size in any breeding programme so as to maximise both short-term and long-term responses to selection. In animal breeding, the potential of this has been seen in poultry breeding and in the use of artificial insemination in dairy cattle (Lerner and Donald 1966), and I believe these point the way for animal breeding in other species.

Thus, the traditional structure of a multitude of breeders each operating with relatively small herds or flocks should be replaced by a much smaller number of breeding units each of larger size. Essentially two approaches to this are possible, *viz*. cooperative breeding organisations and national (or even international) breeding schemes. In the developed countries, emphasis should be placed on the former approach, at least initially. Those breeders who are far-sighted enough to appreciate the advantages of working with large populations and who have the initiative to develop cooperative breeding organisations will be the successful breeders of the future. In the developing countries, with no tradition of breeding as we know it, the development of national schemes would seem the best approach.

At this time when already a large proportion of the human population are suffering from various degrees of malnutrition, where the shortage of animal protein is particularly acute, and where the population is increasing exponentially, every effort must be devoted to increasing productivity. This is the greatest challenge animal breeders have ever had to face.

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