INRODUCTION

The estimation of phenotypic and genetic parameters and the evaluation of selection responses has represented the major activity of sheep geneticists in the past. Breeding objectives were most often defined verbally in a loose manner allowing a considerable amount of scope for various interpretations of what the desired improvement might be. In recent years attention has been increasingly focussed on the precise definition of breeding objectives for sheep from an economic point of view. The approach to the problem has changed from merely identifying traits of economic importance, to formally incorporating them into breeding objectives using selection index theory.

Given the multitude of breeds and the diversity of climates, management and marketing systems under which sheep are run, discussing breeding objectives for sheep on a world-wide basis would be very difficult. Thus, the more modest aim of the present paper will be to review recent advances and to highlight a number of issues which arise when attempting to develop a breeding objective for a particular breed in a given environment. In doing this, I will draw heavily on my experience in Australia, but I trust that many of the concepts put forward will find applications in other situations.

THE DESIGN OF BREEDING PROGRAMMES

The chances of success of a breeding programme will be greatly enhanced if during its formulation the following five steps are taken in meticulous order: (i) definition of the breeding objective; (ii) choice of selection criteria; (iii) organisation of the performance recording scheme; (iv) use of the information recorded to make selection decisions; and, (v) use of the selected individuals. Because the five steps are sequential the success of all other operations intended for the genetic improvement of sheep is dependent on an adequate definition of the breeding objective. Several examples could be cited of performance recording schemes established without prior detailed definition of the breeding objectives of the breeds they were supposed to service.

It is necessary to make a clear distinction between breeding objective and selection criteria. The breeding objective comprises those traits which one attempts to improve genetically because they influence returns and costs to the producer. It is the aggregate genotype (H) in Hazel's (1943) terminology. The selection criteria are the characteristics used in assessing the breeding value of individuals. The selection criteria can be combined in a selection index (I) in which each characteristic is weighed so that the correlation between H and I is maximised. Traits in the breeding objective may or may not be used as selection criteria, that is, as indicators of the breeding value of the animals. In fact, it is only rarely that exactly the same set of characteristics occurs in both the breeding objective and the selection index.
When defining the breeding objective for a particular breed it is important to identify the section of industry which is to benefit from the predicted genetic improvement because different sections may have conflicting goals (Moav 1973, Morris et al. 1979, Wilton et al. 1978, Miller and Pearson 1979, Danell 1980). In the development of sheep improvement programmes it has always been assumed that the increased output from genetic gain can be sold with no reduction in price per unit. This is a reasonable assumption because even if the whole industry increased output through genetic progress, such gains would seldom rival other forces (such as oil prices or wars) influencing the demand for food and fibre.

A breeding structure with different tiers is often observed in countries with developed sheep industries (Turner and Dunlop 1974). The top tier (studs) produces rams for the bottom tier (commercial flocks), and there may be an intermediate tier of multiplier studs. Studs normally represent only a small fraction of the total population of the breed, but they control the rate of genetic gain in the commercial flocks via the supply of rams. Therefore in order for commercial producers and the industry as a whole to benefit from genetic gain the breeding objectives at the stud level should be defined in accordance with commercial producers' interests. The nation would benefit because commercial flocks produce virtually all the wool and sheep meat.

Lack of integration between the different tiers allows the development of conflicts of interest between them. Thus, many stud breeders continue to indulge in cosmetic practices which make the animals look good, but that are of no value to the commercial producer. Sometimes they pay unjustified attention to certain traits (e.g. uniformity in wool fineness, Howe and Connors 1978). Dissatisfaction with the selection policies at the stud level has led to the creation of a new breeding structure, namely co-operative breeding groups (Turner and Dunlop 1974), which in their simplest form consist of a number of flocks which contribute selected females to form a central ram-breeding nucleus. Rams produced in the nucleus are then supplied to the contributing flocks. Because they are integrated systems co-operative breeding groups can, in principle at least, avoid the problem of conflicting objectives between the various tiers.

The tiered structure I have referred to develops among breeds that are used largely as purebreds, such as Australian Merino, Polwarth, Corriedale and Romney. When a breed is used exclusively as part of cross breeding systems, all purebred flocks function as studs supplying rams which are used by commercial producers in their crossbreeding programmes. Border Leicester, Dorset and Suffolk are examples of such breeds in Australia. Among these breeds too, the lack of integration between studs and commercial producers involved in crossbreeding programmes is an obstacle when one attempts to define breeding objectives. In the Suffolk breed, for example, a conflict of objectives between the stud and the commercial producers arises because reproduction rate is an important trait at the stud level because it affects the number of animals available for sale, but not for the commercial producer because all crossbred animals produced by Suffolk sires are slaughtered. The commercial producer is interested in reproduction rate in the stud only in so far as it affects ram prices.

While appropriate education programmes may assist in reducing some of the conflicts of interest between stud breeders and commercial producers, very often there will be little geneticists can do to avoid them because they result from an established social and economic structure. However, animal breeding research, development and extension should be conducted in a climate of awareness of the possible conflicting interests. The aim should be that stud breeders define breeding objectives according to commercial producers' interest, and that those producing
stock of superior breeding value receive a premium for it.

GENERAL CONSIDERATIONS ABOUT DEFINING BREEDING OBJECTIVES

The identification of the role of the breed in industry is a good starting point for the definition of the breeding objective. Some breeds have more than one role, but for most a predominant one can be identified. Generally, breeds are used either as purebreds (e.g. Merino, Romney), as part of a crossbred dam (e.g. Border Leicester), or as terminal sire breeds (e.g. Suffolk). Identification of the role of the breed in industry is important because it affects the fraction of the genes of the breed at the commercial level, and it determines which of the breed traits are of economic importance to the commercial producer. The primary goal of most commercial producers is to maximise monetary gains from their flock, and the breeding objective is a detailed description of the desired animal. This description can be accomplished by the development of a profit equation. The process involves: (i) identification of sources of returns and costs to the producer; (ii) determination of sheep traits which influence returns and costs; and, (iii) calculation of the economic value of each trait.

In principle, all traits influencing costs and returns should be included in the definition of breeding objectives (Gjedrem 1972, Miller and Pearson 1979, James 1982) even if one or more traits cannot be measured directly. In practice, however, there may be difficulties with the inclusion of some traits due to lack of information about them. Table 1 shows the main sources of returns and costs and the traits influencing them for breeds used in different roles. Costs listed are only those considered to vary with the level of expression of traits.

<table>
<thead>
<tr>
<th>TABLE 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sources of returns and costs, and traits influencing them in breeds used in different roles</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MOST COMMON ROLE OF BREED</th>
<th>SOURCES OF RETURNS AND COSTS</th>
<th>TRAITS INFLUENCING RETURNS AND COSTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purebred and part of cross-bred dam</td>
<td>Returns: Wool, Surplus offspring, Cull-for-age animals</td>
<td>Clean fleece weight, fibre diameter, Ewe reproduction rate, sale weight, carcase quality, Mature live weight, carcase quality</td>
</tr>
<tr>
<td></td>
<td>Costs: Feed, Wool marketing, Marketing of surplus offspring and cull-for-age animals, Veterinary treatments, Labour</td>
<td>Feed consumption, Clean fleece weight, Ewe reproduction rate, Disease resistance, Easy-care traits</td>
</tr>
<tr>
<td>Terminal sire</td>
<td>Returns: Sale of offspring</td>
<td>Lamb survival, sale weight, carcase quality</td>
</tr>
<tr>
<td></td>
<td>Costs: Feed, Marketing, Veterinary treatments, Labour</td>
<td>Feed consumption, Lamb survival, Disease resistance, Easy-care traits</td>
</tr>
</tbody>
</table>

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Morris et al. (1979), Ponzoni (1979, 1982) and Jones (1980, 1982) included increased feed requirements likely to result from genetic change in some traits (e.g. reproduction rate and live weight) as variable costs. Increased feed requirements were considered to be a function of those traits. Moav (1973) and James (1982) pointed out that in doing this one assumes that the feed requirement is exclusively a function of growth and reproduction rate and that it has no genetic variation independent of those traits. James (1982) stressed the dangers involved in making this assumption and emphasized that increased feed requirements should not be included as variable costs, but that instead, feed consumption should be a trait in the breeding objective. There are difficulties however, particularly with grazing sheep, because of lack of economic, phenotypic and genetic parameters for feed consumption. For that reason some workers may continue to prefer including increased feed requirements as variable costs until the appropriate parameters become available, or until "admissible" values are assumed and the sensitivity to deviations from the assumptions is tested.

Profit from a sheep flock may be expressed, using a format similar to that one proposed by Soller and Bar-Anan (1973) and Jones (1980, 1982), by the equation:

\[ P_{eqn} = \sum_{i=1}^{n} f_i \bar{X}_i (P_i P_i - C_i P_i^2) \]

where \( f_i \) is the fraction of the population benefitting from trait \( i \), \( \bar{X}_i \) is the average of trait \( i \), \( P_i \) is the price per unit product, \( D_i \) is the discount factor for product prices, \( C_i \) is the variable cost per unit of the character, \( D_f \) is the discount factor for costs and \( K \) are overhead costs assumed to remain constant. \( D_i \) may be equal to \( D_f \), but Bird and Mitchell (1980) suggested that they should be different. Note that for some traits there may be no product for sale (e.g. for disease resistance or feed consumption) in which case \( P_i \) is set at zero. Some authors instead of weighing each trait by \( f_i \) have used the number of expressions of the trait per lifetime, but in individual cases this does not make any difference.

The economic value of a trait in the breeding objective is the change in profit associated with one unit change of that trait, assuming a constant value of all other traits (Hazel 1943). It can be calculated either by taking the partial derivatives of \( P_{eqn} \) with respect to each trait, or by direct numerical evaluation of the change in \( P_{eqn} \) that follows and increment of one unit in a trait while all other traits are kept constant. When \( P_{eqn} \) is a linear function of traits, its association with the breeding objective or aggregate genotype (\( H \)) is straightforward. \( H \) can be defined as the sum of the additive genetic merit for the \( i \) traits in \( P_{eqn} \), the merit for each trait being weighed by its economic value:

\[ H = \sum_{i=1}^{n} v_i g_i, \]

where \( v_i \) and \( g_i \) are the economic value and the additive genetic merit of the trait, respectively. In most of the work reviewed in the next section economic values were obtained without explicitly developing a profit equation. However, a function of some sort is always assumed when economic values are derived.

DEFINING BREEDING OBJECTIVES IN PRACTICE - A REVIEW

In this section I review the work conducted on the definition of breeding objectives for general purpose breeds (i.e. used commercially as purebreds or as part of a crossbred dam) and for terminal sire breeds (i.e. those from which all crossbred progeny is slaughtered). The common feature of all the proposed definitions of sheep breeding objectives is the attempt to identify the traits that influence monetary gains of commercial producers. Important developments in the area of assigning an economic value to each trait in the breeding objective have been: (i) the consideration of differential expression of traits in an animal's lifetime or in a flock.
(e.g. a ewe is sold only once as cull-for-age but it produces several fleeces during its lifetime); (ii) the use of the concept of discounting in order to allow for the delay until returns and costs are realised; (iii) allowing for increased costs which may be a consequence of genetic change in some traits, and (iv) studies in flocks of diverse composition within a breed. Different authors contributed or incorporated one or more of these developments in their work and by presenting the information in approximately chronological order I intend to highlight the gradual refinement of the procedures used. Where appropriate I will comment on the degree of similarity between alternative objectives developed. Work in which the breeding objective was simplified to one or two traits on a priori grounds is not considered. Unless otherwise stated, all the breeding objectives discussed were linear combinations of traits.

General Purpose Breeds

Gjedrem (1966) and Cunningham and Gjedrem (1970) defined breeding objectives for Norwegian sheep. When estimating the economic value of each trait they allowed for increased costs which could result from genetic change in some traits but they did not allow for differential expression of the traits included in the breeding objective. Gjedrem's definition included fleece weight, number of lambs produced and lamb weaning weight. Cunningham and Gjedrem's objective comprised those same traits plus ewe body weight. Gjedrem (1966) did not present a detailed discussion on the consequence of his definition of the breeding objective, while Cunningham and Gjedrem (1970) focussed their attention on the consequences of restricting ewe body weight.

Clarke and Rae (1976, 1977) developed breeding objectives for general purpose breeds in New Zealand. The traits included in the breeding objective were: number of lambs born (or reared), weaning weight and greasy fleece weight. The economic value of each trait was calculated from estimates of wool and lamb prices. Some costs were deducted from the prices but no consideration was given to costs which may be a consequence of genetic improvement or to differential expression of the traits. A separate set of economic values was calculated for each of the Romney, Perendale, Coopworth, Drysdale, Merino and Corriedale breeds. For the Romney breed the percentage of total genetic gain in economic units which could be accounted for by gain in number of lambs born, weaning weight and greasy fleece weight was 65%, 28% and 7%, respectively (Clarke and Rae 1976). Assuming that the genetic parameters given by Clarke and Rae (1976) were applicable to the six breeds mentioned above I calculated the correlation between the breeding objectives of each breed with that one of every other breed. As all correlations were 0.99 or above, having a separate set of economic values for each breed seems an unnecessary complication.

Following an approach similar to that one of Clarke and Rae (1976), Elliott and Johnson (1976) defined the breeding objective for Perendale sheep in New Zealand. The percentage contribution of each trait in the breeding objective to total gain in economic units was 53.0, 24.3, 18.0 and 4.8 for number of lambs weaned, greasy fleece weight, staple length and fibre diameter, respectively.

The work of Morris et al. (1979) in New Zealand represents an important step in the development of breeding objectives for sheep, particularly in the areas of deriving economic values and distinguishing between breeding objectives and selection criteria. They calculated economic values by weighing the unit value of each trait by the number of times the trait is expressed during a ewe's lifetime, and allowed for ewe replacement before lamb sales were calculated. No allowance was made for increases in food intake which may result from genetic gain in some traits, except for increased maintenance requirements for heavier ewes. The units of measurement for the aggregate genotype were $ return per ewe lifetime. For the Romney breed the traits included in the breeding objective were: number of lambs weaned, lamb weaning weight, lamb dressing %, ewe carcase weight and greasy fleece weight. The
percentage of total gain in economic units which could be accounted for gain in each trait was 64.0, 11.4, -1.2, 0.0 and 25.9, respectively. The objective defined by Morris et al. (1979) is similar to that defined by Clarke and Rae (1976), but reproduction rate and lamb weaning weight have a slightly smaller economic value in the former objective possibly as a consequence of making allowance for replacement needs within the flock. The correlation between the two objectives is 0.98, so despite the refinements in the procedures the objective remained virtually identical to the one defined earlier.

Ponzoni (1979) defined the breeding objective of Australian Merino sheep for a breeding flock in which all surplus offspring were sold as lambs. The traits included in the breeding objective were: clean fleece weight, fibre diameter, number of lambs weaned, weaning weight and cull-for-age ewe live weight. Ponzoni gave a detailed justification for the choice of traits included in the breeding objective. Clean fleece weight and fibre diameter are the major determinants of wool value, provided there is lack of pigmented fibres, and that fleeces have 12 months' growth and do not possess any specific fault (Turner 1977, Pattinson 1981). The number of lambs weaned largely determines the number of animals available for sale. Live weight and carcase traits determine the value of slaughtered animals, but under the prevailing marketing system assigning an economic value to carcase traits was not possible, and thus, weaning weight and ewe live weight were included as traits in the breeding objective. The economic value of each trait was obtained by Morris et al.'s (1979) procedure. The percentage of total gain in economic units accounted for by gain in clean fleece weight, fibre diameter, number of lambs weaned, weaning weight and ewe live weight was 30.2, 9.9, 46.4, 10.9 and 2.6, respectively.

The composition of Merino flocks varies considerably throughout Australia. Some consist entirely of breeding ewes, while others include a high proportion of wethers. If the live sheep export market continues growing there may be a general tendency towards carrying fewer aged wethers and selling offspring at a younger age. Using the same methodology and parameter values as Ponzoni (1979), Ponzoni (1981) defined the breeding objectives for flocks of different compositions, namely: (i) a breeding flock from which all surplus offspring are sold as lambs after weaning (i.e. Ponzoni 1979) (FC1); (ii) a breeding flock from which all surplus offspring are sold at approximately 1.5 years of age after shearing (FC2); (iii) a flock consisting of 50% breeding ewes and 50% wethers (FC3); and, (iv) an all-wether flock (FC4). Overall the results suggested that despite diversity or changing trends in the market there would be no need for separate definition of breeding objectives for each flock composition.

Stafford and Walkley (1979) defined breeding objectives for Australian prime lamb production. For breeds that are used as part of a crossbred dam (e.g. Border Leicester) the traits in the breeding objective were: clean fleece weight, average fibre diameter, number of lambs weaned and lamb sale weight. The authors gave a detailed justification (similar to that one given by Ponzoni 1979) of the traits included in the breeding objective. The procedures developed by Morris et al. (1979) were used for the derivation of economic values, and allowance was made for the fact that these breeds contribute only 1/2 of the genes for lamb sale weight, whereas they contribute 1/2 of the genes for all other traits. The percentage contribution of total gain in economic units which could be accounted for by gain in each trait was 20.3, 7.3, 47.9 and 24.4 for clean fleece weight, fibre diameter, number of lambs weaned and lamb sale weight, respectively.

Jones (1980, 1982) presented a method for estimating the economic values that allows for changes in feed requirements likely to accompany changes in traits such as reproduction rate or live weight. He assumed that stocking pressure was kept constant, and that economic values represented a balance between increased returns per head and decreased number of stock carried. Jones developed a profit equation similar to eqn (1) described earlier. By differentiating with respect to each trait
he obtained the appropriate economic values. The unit of measurement for the economic values was $ per year, rather than $ per ewe lifetime as in Morris et al.'s (1979) procedure. Jones gave an example for an Australian Merino breeding flock where surplus young sheep were sold off shears after the hogget (approximately 1½ years of age) shearing (FC; in Ponzoni's (1981) notation). The traits in the breeding objective were hogget live weight, adult live weight, hogget clean fleece weight, adult clean fleece weight, fibre diameter, number of lambs born and number of lambs weaned. Number of lambs born was included as a penalty related to the reduced fleece weight of ewes with greater litter size. Jones' results indicated that neglecting increased feed requirements resulted in an over-estimate of the weight given to some traits. When allowance was made for these increased feed requirements the economic value of live weight and of number of lambs weaned was reduced substantially, but he probably over-rated the reduction in the case of the latter trait because of the procedures he used and the particular flock composition he considered. Jones (1982) also examined the consequences of allowing for the delay until returns and costs were realised (discounting), and concluded that in the context of this work they were unimportant. He also investigated the effect of changing a number of assumptions, obtaining high correlation values among indices computed under the rather diverse situations he postulated.

The flock composition assumed by Jones (1980, 1982) corresponded to that one called FC; by Ponzoni (1981). The breeding objectives defined by the two authors differ in three ways: (i) the product prices assumed were slightly different; (ii) the traits in the breeding objective were not exactly the same; and, (iii) the methodology used to derive the economic values was different. The phenotypic and genetic parameters assumed were the same. When clean fleece weight, fibre diameter, dam's number of lambs born and hogget live weight were the selection criteria, the correlation between the indices computed by Jones (1980) and Ponzoni (1981) was 0.78 and it rose to 0.88 if allowance was made in Ponzoni's calculations for increased feed requirements from reproduction and growth rate (Ponzoni 1982). These results show that despite the differences between the two approaches, the economic consequences of using the indices proposed by both authors would be similar. Also, I obtained a correlation value of 0.89 between the breeding objective derived by Ponzoni (1982) allowing for increased feed requirements in reproduction and growth rate, and that one of Jones (1982) but with number of lambs born excluded from the objective.

Terminal Sire Breeds

For New Zealand meat breeds (e.g. Southdown, Dorset Down, Suffolk) Clarke and Rae (1976) identified live weight at a certain age, low lamb mortality in crosses, and increased muscling and reduced levels of fat in the carcase as desirable traits. Because of lack of economic and genetic information regarding lamb mortality and carcase traits they concluded that in practice live weight at a certain age was the only definable objective for the lamb producer. Stafford and Walkley (1979) reached similar conclusions for terminal sire breeds in Australia.

Morris et al. (1979) chose the same set of traits as Clarke and Rae (1976). They concluded that live weight at sale was the trait of major importance in the objective, and that lamb survival was half as important as live weight. It was considered that not enough was known about carcase traits. Morris et al. (1979) combined the three traits multiplicatively, but I doubt whether this represents any advantage over the simpler approach of using a linear approximation.

PROBLEM AREAS IN THE PRACTICAL DEFINITION OF BREEDING OBJECTIVES

Problem areas can be divided into those that are of a general nature, and those that relate specifically to individual traits which could be included in the breeding
objective. The separation between the two types of problems is not always clear-cut, but it is made here to facilitate the flow of the discussion.

General Problems

Allowing for increased feed consumption

In much of the reviewed work economic values were derived without consideration of increases in feed consumption which may result from greater growth rate of young sheep or from improved reproduction rate. I compared breeding objectives which ignored possible increases in feed requirements with those allowing for them in flocks of three different compositions of Australian Merinos (FC₁, FC₂ and FC₃ of Ponzoni (1981)). Increased feed requirements were calculated from the feeding standards suggested by Hughes and Burdon (1979) and the cost of additional feed, based on current prices was subtracted from the product values (see eqn (1)). The weakness of this approach, as pointed out earlier, is that it assumes that feed consumption is exclusively a function of increased growth and reproduction rate, and that it has no genetic variance independent of those traits. Product prices and phenotypic and genetic parameters were as defined by Ponzoni (1981). When allowance was made for increased feed requirements the economic value of number of lambs weaned, number of hoggets present, weaning weight and hogget live weight was reduced by factors of 0.7, 0.5, 0.9 and 0.8, respectively. The effect of making allowance for increased feed requirements on the genetic gain in each trait was small in the three flock compositions studied (Table 2). Gain in growth and reproduction traits was reduced while gain in clean fleece weight increased. The effect on fibre diameter was negligible. More importantly, within each flock composition, the correlation between breeding objectives derived either way was close to unity. So despite the slight shift in genetic gain in individual traits, the overall economic consequences of deriving the economic values with or without accounting for increased feed requirements are virtually the same. This result is comforting because this is a difficult area with grazing sheep. For example, considerations about increased feed consumption may be irrelevant for a producer who is understocked or whose lambing coincides with a period of surplus pasture production.

<table>
<thead>
<tr>
<th>TRAITS IN THE BREEDING OBJECTIVE</th>
<th>FC₁ (a)</th>
<th>(b)</th>
<th>FC₂ (a)</th>
<th>(b)</th>
<th>FC₃ (a)</th>
<th>(b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFW (kg)</td>
<td>0.09(25.0)</td>
<td>0.10(33.8)</td>
<td>0.09(29.4)</td>
<td>0.12(45.2)</td>
<td>0.12(45.1)</td>
<td>0.13(52.1)</td>
</tr>
<tr>
<td>FD (microns)</td>
<td>-0.44(17.7)</td>
<td>-0.45(20.4)</td>
<td>-0.46(19.9)</td>
<td>†</td>
<td>†</td>
<td>-0.49(26.4)</td>
</tr>
<tr>
<td>NLW</td>
<td>0.028(40.0)</td>
<td>0.025(28.9)</td>
<td>†</td>
<td>†</td>
<td>0.021(21.1)</td>
<td>0.018(13.6)</td>
</tr>
<tr>
<td>NHP</td>
<td>†</td>
<td>†</td>
<td>†</td>
<td>†</td>
<td>†</td>
<td>†</td>
</tr>
<tr>
<td>WW (kg)</td>
<td>0.58(14.2)</td>
<td>0.54(13.7)</td>
<td>†</td>
<td>1.15(15.4)</td>
<td>0.94(12.2)</td>
<td>0.42(3.3)</td>
</tr>
<tr>
<td>HW (kg)</td>
<td>†</td>
<td>†</td>
<td>†</td>
<td>1.5(2.8)</td>
<td>0.78(2.4)</td>
<td>0.67(4.0)</td>
</tr>
<tr>
<td>MW (kg)</td>
<td>0.95(3.0)</td>
<td>0.88(3.2)</td>
<td>†</td>
<td>0.94(2.4)</td>
<td>0.78(2.4)</td>
<td>0.67(4.0)</td>
</tr>
</tbody>
</table>
| R₀                               | 0.99 | 0.96 | 0.99 |}

Genetic gains calculated assuming that CFW, FD, dam's NLW and HW were the selection criteria, and that the selection intensity was of one standard deviation on the index. In brackets the percentage of total gain in economic units accounted for by gain each trait.

†Trait not in the breeding objective.
Price fluctuations

Prices and the relative values of wool and meat may change considerably with time. Because breeding programmes are long-term an assessment of the consequences of variations in the economic value of wool, surplus offspring and cull-for-age animals is important. Morris et al. (1979), Ponzoni (1979), Stafford and Walkley (1979), examined the effect of variations in wool and sheep meat prices and concluded that the effect on the genetic gain of individual traits was small, despite the imposition, in some cases, of drastic changes in the relative economic value of the traits in the breeding objective. Work with other species has led to similar conclusions (e.g. see Ronningen 1978/79). Correlations I calculated between breeding objectives defined using current "accepted" wool and sheep meat prices for the Australian Merino, and those defined after: (i) halving the economic value of wool traits, and (ii) halving the economic value of sheep meat traits, in three flock compositions (FC1, FC2 and FC3 of Ponzoni 1981) were all 0.95 or above. Jones (1982) recently obtained similar results. However, this evidence should not be taken as an indication that accuracy in the estimation of economic values is unnecessary, but rather, as an encouraging result for practical breeders. Provided they choose the economic values well initially, commonly experienced price fluctuations should have negligible consequences on the overall effectiveness of their breeding programmes. Danell (1980) draws attention to the possible undesirable long-term effects of using false economic values.

Sensitivity to values of genetic parameters

Attempts are often made to define breeding objectives for breeds for which there is little reliable information on genetic parameters, especially on genetic correlations. For example, in defining the breeding objective for the Australian Merino, clean fleece weight and reproduction rate are often the two most important traits in terms of their contribution to total genetic gain in economic units (Ponzoni 1979, 1982) if it is assumed that the two traits are uncorrelated genetically. However, there is considerable uncertainty regarding the magnitude and even the sign of the genetic correlation between the two characters (McGuirk and Atkins 1976) and the assumption made regarding this estimate may affect the relative importance of the traits in the breeding objective, as well as the total gain in economic units. Table 3 shows the genetic gain for the traits in the breeding objective and "possible" genetic gain (qg) (James 1981) in Australian Merino flocks of the three compositions defined earlier, when three different genetic correlation values between clean fleece weight and reproduction rate are assumed. All the resulting phenotypic and genetic variance-covariance matrices were positive-definite. The genetic gain in clean fleece weight decreased as the magnitude of the negative genetic correlation increased, and this was accompanied by an increase in the gain in growth traits. The gain in reproduction rate decreased with the increase in the value of the genetic correlation in two of the flock compositions (FC2 and FC3), but it varied in an odd manner in one of them (FC1), namely, decreasing at r = -0.2, and then increasing at r = -0.5. Note the great difference between flock compositions in the relative importance of different traits at r = -0.5. There was also a reduction in "possible" genetic gain in economic units (qg) as the magnitude of the genetic correlation increased, but this reduction was small when compared with the changes in genetic gain in individual traits.

Table 4 shows the correlations between "correct" and "incorrect" indices, where "incorrect" implies use of a genetic correlation value different from the actual one. The correlations among the indices are high, the lowest value being 0.82. This means that the loss in economic gain resulting from use of the "incorrect" indices would often be small, but under some circumstances it could become a matter of concern (e.g. assumed r = 0.0, but actual r = -0.5). The relatively small loss in economic gain is the result of greater gain in some traits compensating for loss in other traits. However, the genetic gain in individual traits can be affected to an extent that the accuracy of our predictions can be seriously undermined (Table 3). This not only
TABLE 3

Genetic gain per generation in clean fleece weight (CFW), fibre diameter (FD), number of lambs weaned (NLW), number of hoggets present (NHP), weaning weight (WW), hogget live weight (HW), and mature live weight (MW), and "possible" genetic gain ($\sigma_H$) in three different flock compositions (FC1 to FC3) assuming different genetic correlation (r) values between CFW and reproduction traits (NLW and NHP).

<table>
<thead>
<tr>
<th>TRAITS IN THE BREEDING OBJECTIVE</th>
<th>FC1 r = 0.0</th>
<th>FC1 r = -0.2</th>
<th>FC1 r = -0.5</th>
<th>FC2 r = 0.0</th>
<th>FC2 r = -0.2</th>
<th>FC2 r = -0.5</th>
<th>FC3 r = 0.0</th>
<th>FC3 r = -0.2</th>
<th>FC3 r = -0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFW (kg)</td>
<td>0.10 (33.8)</td>
<td>0.06 (23.9)</td>
<td>-0.01 (-4.8)</td>
<td>0.12 (45.2)</td>
<td>0.10 (40.8)</td>
<td>0.05 (24.5)</td>
<td>0.13 (52.1)</td>
<td>0.11 (50.1)</td>
<td>0.07 (38.0)</td>
</tr>
<tr>
<td>FD (microns)</td>
<td>-0.45 (20.4)</td>
<td>-0.51 (26.4)</td>
<td>-0.57 (31.9)</td>
<td>-0.45 (24.1)</td>
<td>-0.51 (30.1)</td>
<td>-0.59 (39.6)</td>
<td>-0.48 (27.7)</td>
<td>-0.55 (35.1)</td>
<td>-0.65 (49.0)</td>
</tr>
<tr>
<td>NLW</td>
<td>0.025 (28.9)</td>
<td>0.021 (28.1)</td>
<td>0.033 (47.1)</td>
<td>$\text{§}$</td>
<td>$\text{§}$</td>
<td>$\text{§}$</td>
<td>0.018 (13.6)</td>
<td>0.008 (6.4)</td>
<td>0.001 (1.2)</td>
</tr>
<tr>
<td>NHP</td>
<td>$\text{§}$</td>
<td>$\text{§}$</td>
<td>$\text{§}$</td>
<td>0.020 (16.0)</td>
<td>0.012 (10.5)</td>
<td>0.011 (11.0)</td>
<td>$\text{§}$</td>
<td>$\text{§}$</td>
<td>$\text{§}$</td>
</tr>
<tr>
<td>WW (kg)</td>
<td>0.54 (13.7)</td>
<td>0.61 (17.5)</td>
<td>0.67 (20.8)</td>
<td>$\text{§}$</td>
<td>$\text{§}$</td>
<td>$\text{§}$</td>
<td>0.37 (2.9)</td>
<td>0.42 (3.6)</td>
<td>0.49 (5.0)</td>
</tr>
<tr>
<td>HW (kg)</td>
<td>$\text{§}$</td>
<td>$\text{§}$</td>
<td>$\text{§}$</td>
<td>0.94 (12.2)</td>
<td>1.07 (15.5)</td>
<td>1.27 (20.9)</td>
<td>$\text{§}$</td>
<td>$\text{§}$</td>
<td>$\text{§}$</td>
</tr>
<tr>
<td>MW (kg)</td>
<td>0.88 (3.2)</td>
<td>1.00 (4.1)</td>
<td>1.12 (5.0)</td>
<td>0.78 (2.4)</td>
<td>0.87 (3.0)</td>
<td>1.01 (4.0)</td>
<td>0.59 (3.7)</td>
<td>0.67 (4.8)</td>
<td>0.80 (6.7)</td>
</tr>
<tr>
<td>$\sigma_H$ (%)</td>
<td>100.0</td>
<td>92.8</td>
<td>80.9</td>
<td>100.0</td>
<td>92.3</td>
<td>79.2</td>
<td>100.0</td>
<td>91.8</td>
<td>77.8</td>
</tr>
</tbody>
</table>

+Economic values as in (b) of Table 2.

+ Genetic gains calculated assuming that CFW, FD, dam’s NLW and HW were the selection criteria, and that the selection intensity was of one standard deviation on the index. In brackets the percentage of total gain in economic units accounted for by gain in each trait.

§ Trait not in the breeding objective.

$\sigma_H$ expressed as a percentage of that one obtained when r = 0.0.
constitutes a problem in itself, but could have other undesirable repercussions, such as loss of credibility in the breeding programmes recommended by scientists. It is difficult to feel at ease when designing a breeding programme if one is not sure about the value of the genetic correlation between two economically important traits in the breeding objective. There is an urgent need for further information on this area in breeds such as the Australian Merino.

TABLE 4
Correlations between "correct" and "incorrect" indices

<table>
<thead>
<tr>
<th>GENETIC CORRELATION VALUES</th>
<th>FC₁</th>
<th>FC₂</th>
<th>FC₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual: -0.2</td>
<td>0.98</td>
<td>0.99</td>
<td>0.99</td>
</tr>
<tr>
<td>Assumed: 0.0</td>
<td>0.92</td>
<td>0.97</td>
<td>0.97</td>
</tr>
<tr>
<td>Assumed: -0.5</td>
<td>0.82</td>
<td>0.92</td>
<td>0.94</td>
</tr>
<tr>
<td>Actual: -0.5</td>
<td>0.92</td>
<td>0.97</td>
<td>0.97</td>
</tr>
<tr>
<td>Assumed: 0.0</td>
<td>0.82</td>
<td>0.92</td>
<td>0.94</td>
</tr>
<tr>
<td>Assumed: -0.2</td>
<td>0.92</td>
<td>0.97</td>
<td>0.97</td>
</tr>
</tbody>
</table>

+The indices included clean fleece weight, fibre diameter, dam’s number of lambs weaned, and hogget live weight as selection criteria.

Multiple role of some breeds

The ewes of some breeds, such as the Australian Merino and the New Zealand Romney, are mated either to sires of the same breed or to sires of another breed. The definition of the breeding objective for purebreeding can differ from that one for crossbreeding for the following reasons: (i) the fraction of Merino or Romney genes present in the production system depends on the mating programme adopted; (ii) for Merinos at least, the composition of the flocks in which ewes are mated to rams of the same breed is often different from that in which ewes are mated to sires of another breed; (iii) generally when ewes are mated to a ram of another breed all of the offspring are sold; and (iv) product prices and means for some traits may change (e.g. a crossbred lamb may be heavier and have a greater value).

Morris et al. (1979) defined the breeding objective for the New Zealand Romney when mated to a ram of another breed and compared it with the objective defined for the purebreeding situation. The genetic gain in individual traits differed very little between the two definitions. The authors concluded that in practice making distinction between the objectives for the two situations was not worthwhile. I compared the breeding objective for Merino used in purebreeding with that for the crossbreeding situation. The four factors that may give rise to difference between purebreeding and crossbreeding objectives were taken into account. The correlation between the two objectives was 0.99 so it appears that Morris et al.'s(1979) conclusion regarding the New Zealand Romney applies to the Australian Merino as well.

In Australia the Dorset breed is used as: (i) terminal sire; (ii) part of a crossbred dam which is mated to a sire of another breed; and (iii) part of a crossbred dam mated to a Dorset sire. Ponzoni and Walkley (1981) found that the generalised use of indices derived for the third role would result in a negligible loss of gain for the other two objectives, and they too concluded that separate definitions of breeding objectives for the three roles of the Dorset were not warranted.

Non-linear economic values

The value of a unit change in a given trait may vary according to the mean of that trait or of another trait, in which case the relation between profit and the trait is said to be non-linear. For example, the effect on the value of wool of a
unit change in fibre diameter may be smaller, the greater the average fibre diameter of the flock. Wilton et al. (1978), Miller and Pearson (1979), Bulmer (1980) and Danell (1980) have discussed the problem of non-linearity of economic values. Almost without exception the authors developing breeding objectives for sheep have assumed a linear relationship between profit and individual traits. Though linear approximations are often satisfactory, developments dealing with non-linear relationships may be required for more elaborate definitions of breeding objectives for sheep.

Problems Related to Individual Traits

Carcass traits

Few people would dispute the view that any future change in carcase characteristics should be in the direction of reducing the amount of fat and increasing the content of lean meat in lamb and mutton carcases. However, carcase traits have seldom been included in sheep breeding objectives. The fact that carcase traits are difficult to measure in live animals should not be looked upon as an obstacle in a breeding programme because carcase traits could be included in the breeding objective without them necessarily being selection criteria, but a lack of relevant estimates of phenotypic and genetic parameters is an impediment whether the trait is actually measured or not. In Australia, for example, we lack estimates of genetic parameters for carcase traits in Merino sheep. Also, assigning an economic value to carcase traits is difficult because the existing marketing system does not offer an effective price structure involving an economic reward to producers improving the desirable carcase traits. It will not be possible to recommend breeders to consider carcase traits in their breeding programmes unless clear guidelines are given to producers regarding the carcase attributes they should aim for, and the marketing system offers a monetary incentive to those producing carcases which possess the desired attributes. A review of sheep recording and evaluation of breeding sheep in Europe (Croston et al. 1980) indicated that performance recording schemes in several countries already include carcase traits in the breeding objectives.

Easy-care traits

Easy-care traits can be defined as those which are associated mainly with a reduction of labour costs. Freedom from lambing troubles is an example, and Knight et al. (1979) found evidence of genetic variation in this trait in the New Zealand Romney. When the financial situation is not favourable approaches which increase net farm income by cost cutting are likely to be more readily accepted by the farming community than those where extra output increases net farm income, but that imply greater production costs. This may explain the current interest in easy-care traits in sheep.

Dun and Eastoe (1970) reported that skin wrinkle was associated with the time required to shear in Australian Merino sheep, while McGuirk et al. (1981) found that greasy fleece weight was also associated with time required to shear, the time increasing with increases in either of the traits. That part of the shearing cost payable to the shearer is a fixed amount per animal, but other labour during shearing is paid according to time. Using current shearing costs McGuirk et al. (1981) derived the economic value of time required to shear, and included it in a breeding objective similar to that one defined by Ponzoni (1979). Time required to shear made a negligible contribution to total genetic gain in economic units and the conclusion was that it was not a trait worth including in the objective for the Australian Merino. McGuirk et al's (1981) calculations apply only to the traditional methods of wool removal, and Maher and Jefferies (1979) noted that as wool harvesting research proceeds, the cost structure and physical limitations of automated mechanical wool removal may become better defined and some traits may acquire greater economic significance.
Selection for resistance to disease is a special case of selection for easy-care traits. Evidence of genetic variation in resistance to illnesses that can cause substantial economic losses has been reported by Atkins et al. (1980), Campbell (1978/79) and Le Jambre (1978), in relation to fleece-rot and fly strike, facial eczema, and internal parasites, respectively. Knowledge about the genetic association between these characteristics and the production traits (wool, reproduction, growth) is, however, scarce. Also, assigning an economic value to any disease resistance trait is extremely difficult. The level of exposure to the agent causing the illness and the type of treatment programme anticipated can have an important effect on the economic value of disease resistance in a particular flock. Assessing the costs associated with the disease is a problem. While veterinary costs may be easy to obtain, estimates of the losses in wool and meat production are difficult to quantify. At present we do not know enough about resistance to disease, from an economic or from a genetic point of view, to be able to incorporate it as a trait in a formal definition of breeding objectives for sheep. Geneticists working with other livestock species face similar problems (Lindhe 1978, Dickinson 1979, Pearson and Miller 1981).

A problem with easy-care traits is that producers tend to become interested in them without there being a sound economic basis for that interest. McGuirk et al.'s (1981) results alert us in this respect. A safe way of deciding on the value of an easy-care trait is to examine it within a formal definition of the breeding objective, but in practice there may be difficulties because of lack of knowledge about economic, phenotypic and genetic parameters.

Body size

Some traits acquire great importance in the mind of breeders and commercial producers. Size, often assessed by liveweight, is one such trait ("big" regarded as intrinsically better). Cardellino and Oficialdegui (1981) reported that sheep producers in Uruguay, where Corriedale is the main breed, have been particularly interested in the genetic improvement of live weight. Within some sections of the Australian Merino industry there has possibly been a similar trend triggered by the growth of the export market for live sheep. After a detailed examination of the problem Cardellino and Oficialdegui (1981) concluded that the improvement of live weight should receive only minor emphasis within the Uruguayan sheep breeds. Ponzoni (1982) calculated the contribution of live weight traits (live weight of offspring and of cull-for-age animals) to economic gain for a range of economic values in the Australian Merino. The contribution of all live weight traits considered together was never greater than 35%, and it was often considerably less (clean fleece weight and reproduction rate were more important). Jones (1982) also concluded that live weight was relatively unimportant. Unwarranted emphasis on body size or live weight can be avoided by considering it within the context of a formal definition of breeding objectives, rather than letting it become the major objective in itself.

Other traits considered in a breeding programme

There are a number of sheep characteristics usually considered by breeders in their selection programmes and almost always ignored by scientists in the formulation of breeding plans. Morris et al. (1979) and Ponzoni (1979) gave examples of such traits. Little is known about the economic importance of minor malformations of jaws, backs, legs and feet. It is difficult to obtain accurate information about them because often they cannot be assessed objectively, and also because some culling against animals showing the defect is constantly taking place in most flocks. In practice, provided the amount of culling on the basis of these traits is small, it is unlikely to affect seriously the effectiveness of a breeding programme. The elimination of a few aesthetically unsatisfactory individuals may contribute towards the breeder's interest in the breeding programme.
CONCLUSIONS

The formal definition of the breeding objective is an essential step that must be taken before other phases of a sheep improvement programme are considered. Even when information on economic, phenotypic and genetic parameters is scarce, as it is in many developing countries, an attempt at defining the breeding objective will be useful because it will reveal areas in which knowledge is deficient. If the deficiency cannot be remedied promptly, as will be the case most often, at least it will have created an awareness about existing limitations. In the case of the Australian Merino, for example, recent attempts at defining its breeding objective have shown that refinements would be possible if soundly based information about economic, phenotypic and genetic parameters for feed consumption and for carcase traits were available. It has also become evident that no experiments have been conducted selecting Australian Merino Sheep for a comprehensive multi-trait objective, though validation of the theory seems essential. Perhaps these areas could be given priority when future research is planned.

Several authors compared breeding objectives developed under different assumptions. Generally, the results have shown that genetic gain in individual traits may be affected, but the total gain in economic units is less sensitive to changes in the assumptions since loss of genetic gain in some traits is compensated for by greater gain in others. These results are encouraging because they suggest that many of the approximate objectives one is compelled to define due to limited knowledge are unlikely to have serious detrimental economic effects. They should not, of course, serve as an excuse for vague or incorrect definitions of breeding objectives. If several assumptions are wrong the effects may be cumulative, and may lead to genetic change in the wrong direction in some economically important traits.

Sheep improvement programmes should offer breeders the possibility of combining various selection criteria in an index. This development would flow naturally from a formal definition of breeding objectives. Even if selection procedures are not always carried out by means of selection indices an accurate definition of breeding objectives is essential so that emphasis on unimportant traits is avoided.

Finally, I wish to stress that while the diversion of selection pressure to traits of no economic importance at the commercial level implies a waste of genetic resources and refinements in the definition of breeding objectives are desirable, the breeding operation should not be expected to rely completely, at least in the near future, on a set of equations. There are still many traits considered important by breeders and about which we have virtually no scientific information. Judicious use of breeders' experience may be necessary in some cases, and it is often very difficult to incorporate this type of information into a simple equation.

ACKNOWLEDGEMENTS

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SUMMARY

The definition of the breeding objective is the first and most important step in the design of a breeding programme. The section of industry benefitting from the breeding programme and the role of the breed must be established. Maximising monetary gains is the goal of commercial producers. It is thus necessary to identify the sources of returns and costs, the traits influencing those returns and costs, and
to calculate an economic value for each trait. Practical definitions of breeding objectives are reviewed. For general purpose breeds reproduction rate, wool traits and live weight (often in that order) are the important traits, but their relative ranking varies with the specific case being studied. For terminal sire breeds live weight at sale, lamb survival and carcass traits are important, but consideration of the latter two traits is hampered by several factors. Problem areas in the definition of breeding objectives are discussed. Economic gain in multi-trait objectives was found to be influenced little by changes in assumptions. Aspects requiring further attention are emphasised.

RESUMEN

La definición del objetivo de selección es el primer y más importante paso en el diseño de un programa de mejoramiento. Debe establecerse qué sector de la producción se beneficiará con el programa de mejoramiento, así como el papel desempeñado por la raza en cuestión. El objetivo de los productores comerciales es maximizar la ganancia monetaria. Para ello, es necesario identificar las fuentes de ingresos y costos, los caracteres que influyen en esos ingresos y costos, y calcular el valor económico de cada carácter. Se revisan las definiciones prácticas de objetivos de selección. Para razas de propósito general la tasa reproductiva, los caracteres de producción de lana y el peso vivo (a menudo en ese orden) son los caracteres importantes, pero su importancia relativa varía según el caso específico que se estudia. Para razas usadas en cruzamiento terminal el peso vivo en el momento de la venta, la sobrevivencia de corderos y las características de la res son importantes, pero la consideración de los dos últimos caracteres se ve dificultada por varios factores. Se discuten áreas problema en la definición de objetivos de selección. Se encontró que cambios en las suposiciones tienen escasa influencia en la ganancia económica en objetivos que incluyen varios caracteres. Se hace énfasis en aquellos aspectos que requieren más estudio.

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