Evaluation and Selection of Beef Cattle

By Dr. M. A. MacDONALD*†

"The importance of the great principle of selection mainly lies in the power of selecting scarcely appreciable differences, which nevertheless are found to be transmissible and which can be accumulated until the result is made manifest to the eyes of every beholder".

-CHARLES DARWIN.

THIS quotation is as true today as it was a century ago. Selection in breeding animals is often defined as a differential rate of reproduction and forms the basis of all animal breeding programmes. It has as its objective the identification and use of those superior animals judged capable of reproducing offspring whose average merit is superior to the parental generation.

It is obvious that great improvement may be made in the appearance of a herd by culling undesirable individuals, but unless the culling process results in an improvement in the breeding potential (genotype) the time and effort spent in selection and culling is largely fruitless.

In former times, selections in beef cattle were based on conformation alone. Today increased costs of production, competition from other feedstuffs and current exponential growth rates of human populations suggest that while energetic efficiency and volume of production are not the sole over-riding factors in beef cattle production, they are becoming increasingly important. The time has come when factors such as rate and efficiency of growth, carcass composition and dressing percentage must be identified in an empirically measurable form.

It is the intention of this paper to review some of the data available on evaluation and selection in beef cattle and to indicate how some of them may be applied to beef cattle production. Emphasis is placed on the work with which the writer was associated. No attempt is made to include between breed or between species cattle improvement programmes.

In order to fully appreciate the results which are presented, it is necessary to review some fundamental aspects of inheritance and selection.

THE PURPOSE OF BREEDING

The aim or objective of beef cattle breeding programmes based on selection is to improve production characteristics both qualitative and quantitative. It has often been suggested that such an objective may be more easily reached by improving environmental conditions, anatomical manipulation, or physiological readjustment. This is undoubtedly true in the case of characteristics such as dressing percentage. Dressing percentage is largely a measure of degree of fatness and is not directly measurable in a breeding animal. But what of factors of greater economic importance such as rate and efficiency of gain? Dahmen and Bogart (1952), and Hitchock et al. (1955) made selections based on gains during sucking, gains during test, feed efficiency during test and conformation. During approximately one generation considerable progress was made for rate and efficiency of gain as indicated in table 1.

*Ruakura Animal Research Station, Department of Agriculture, Hamilton, New Zealand.

†fin the author's absence this paper was presented by Mr. L. Williams, Department of Agriculture, Sydney, N.S.W.

TABLE 1

AVERAGE INITIAL AND PRESENT RATE OF GAIN AND FEED EFFICIENCY IN THREE LINES OF HEREFORD CATTLE (AFTER BOGART)

Line		Daily Rate of Gain		Feed Efficiency*		Inbreeding Per cent
		Initial	1952-53	Initial	1952-53	
Lionheart	Bulls	2.30	3.12	460	341	9.9
	Heifers	1.70	2.34	572	505	
Prince	Bulls	2.35	2.43	366	370	8.4
	Heifers	1.94	2.20	480	455	
David	Bulls	2.17	2.75	428	363	16.7
	Heifers	1.95	2.26	500	483	

*Pounds of Total Digestible Nutrients consumed **ad lib.** per 100 lb. liveweight gain.

These results were achieved despite a relatively low selection intensity and the counter-balanced effects of inbreeding (Burgess, Landblom and Stonaker, 1954; Koch, 1951; McCleery and Blackwell, 1954).

Bogart et **al.** (1951, 1954) and Burris et al. (1952) also studied the increase in rate and efficiency of gain obtainable using intramuscular injections of testosterone at a rate of 1 mg./kg. bodyweight per week. This treatment gave a marked increase in gains per day and efficiency particularly in females.

In somewhat similar trials Clegg et **al.** (1954) found that beef steers on full feed treated with 60 mgms. of diethylstilbestrol gained approximately 0.5 lb. per head per day more than control steers. Treated groups required from 100 to 300 lb. less T.D.N. per 100 lb. live weight gain than control groups, but heifers did not do nearly as well as steers.

It would appear that despite the exceptionally good results obtained in only one generation of breeding with careful selection, equally good average results are obtainable immediately using readily available hormones at optimum levels. Nevertheless, variations in response within groups to the environmental treatment imposed (hormone injection) indicate that breeding with selection could still be used to advantage for further returns even after optimum non-hereditary conditions have been established.

HERITABILITY

Variation or differences between animals are due to two main factors: heredity and environment (synonymously termed, breeding and feeding, nature and nurture). In any group of cattle similar in age, sex and breed and maintained under similar environmental conditions, some grow faster, gain more efficiently, or develop better conformation than others in the group. Using statistical procedures such as intra-sire regressions of offspring on dam, paternal half-sib or dam-offspring correlations differences due to additively acting genetic complexes may be separated from the remainder which includes both environmental and non-additive genetic factors (epistasis and dominance). The variability due to selectable inherited differences has been labelled HERITABILITY. Lerner (1950) expressed the formula for heritability as:

$$h^2 = \frac{\sigma^2_G}{\sigma^2_G + \sigma^2_E} = \frac{\sigma^2_G}{\sigma^2_P} \qquad (1)$$

where h^2 = heritability, σ^2_G = additively acting genetypic variance component, σ^2_E = the environmental variance component including the component due to non-additive genetic factors and σ^2_P = the phenotypic variance component. For example, let us assume that from a herd with an average daily gain of 2.0 lb. a breeder selects animals that averaged a daily gain of 3.0 lb. Now, if the offspring of these animals averaged a daily gain of 2.75 lb. under similar environmental conditions to those under which the parents were tested, the breeder would have obtained an average daily increased gain of 0.75 lb. Since the breeder obtained 75 per cent. of the increased gain for which he selected, the trait had a heritability of 75 per cent. Low heritabilities ($h^2 <$

15 %) indicate that direct selection on the individual's own record is relatively ineffective in increasing the records of the offspring. The breeder must under these conditions employ family selection if the factor is economically important enough to warrant the added effort. Higher heritabilities ($h^2 > 30\%$) permit selection based on the individual's own record. Selection for these factors is very effective in increasing the average merit of the offspring. Heritability provides a measure of the genetic variation upon which depends the possibility of altering a herd by breeding methods. It is a measurement of the accuracy with which the genotype may be divorced from the phenotype and, as mentioned earlier, the heritability value dictates the most efficient selection and breeding systems to be employed.

A review of literature indicates that almost all beef cattle heritabilities reported were obtained in the United States. It is well at this point to present some of these estimates.

TABLE 2

INTENSITY OF INHERITANCE IN BEEF CATTLE OF ECONOMICALLY IMPORTANT CHARACTERISTICS

Factor	Reference	Heritability (%)
Birth Weight	Dawson, Phillips and Black (1947)	11, 29
	Gregory, Blunn and Baker (1950)	45
	Knapp and Clark (1950)	53
	Knapp and Nordskog (1946)	23
Weaning Weight	Gregory, Blunn and Baker (1950)	26
	Knapp and Clark (1950)	28
	Knapp and Nordskog (1946)	12, 30, 34
Suckling Gains	Bogart (1954)	25
Rate of Gain on feed	Bogart (1954)	80
	Knapp and Clark (1950)	65, 77
	Knapp and Nordskog (1946)	97, 99
	Patterson, Jones, Bayles and Turnbough (1949)	100
	Patterson, Cartwright, Jones and Bayles (1955)	53
	U.S.D.A. (1948)	80
	Warwick, Cartwright and Hazen (1954)	21, 57
Efficiency of Gain	Bogart (1954)	60
	Knapp and Nordskog (1946)	48, 75

It may be seen that only two estimates of the economically important factors listed in Table 2 fall into the low heritability category necessitating a family selection programme; in both cases by analysing the data by alternative statistical methods higher estimates resulted. It may be disconcerting to some to note the wide range of heritabilities for each of the factors categorized However, the heritability of different characters in one herd or the same character in different herds is not constant. The lower the environmental variation, the higher the heritability becomes (refer to equation 1).

Heritabilities available were obtained under American conditions, the counterparts of which are not found in either New Zealand or Australia. Therefore, before cattle selection programmes may be formulated and recommended for Australasian conditions it is essential that heritabilities for economically important factors be determined under the environmental conditions in which breeding herds are to be managed. This is not easily accomplished. In the United States and Canada heritabilities are usually determined under feed-lot conditions between weight ranges of 450 and 900 lb. liveweight or for a given period of chronological time (Black and Knapp, 1936; Knapp and Nordskog, 1946; Knapp and Clark, 1951; Hitchcock **et al.** 1955; Warwick and Cartwright, 1955). There are several advantages in such a system. First, most North American carcass cattle spend some or all their post-weaning life in a feed-lot. Second, Hammond (1947) and Buchanan Smith (1948) consider that selection should take place under conditions which are optimal for the character concerned. The feed-lot divorces test animals from the marked variability of seasonal production experienced in pastoral grazing. Third, under ad libitum feed-lot conditions, growth in the weight ranges used is linear, permitting ready analysis. Fourth, under feed-lot testing conditions, rate and efficiency of gain in a weight-constant period are positively correlated (MacDonald and Bogart, 1954) making it possible to capitalise on this important genetic correlation. By selecting for rate of gain, an easily measured character in a weight constant test period, one is also automatically selecting for efficiency of gain, a difficult trait to measure (particularly under free grazing conditions).

Testing under these conditions brings out high production and the best possible phenotype, but unfortunately it ignores the possibility of genetic-environmental interaction. Years of experience in North America, New Zealand and Australia have shown that bulls of excellent conformation (phenotype) from 'studs where they were raised on nurse cows and individual feeding often produce offspring of excellent conformation in studs but do not produce well when placed under commercial stock-producing conditions. In this instance, selection under local relatively poor conditions is the only way to obtain genetic improvement in performance. Unfortunately, animal testing and the critical evaluation of results are much more difficult under variable or poor conditions than under optimum environmental conditions. Data collected at Ruakura Animal Research Station serve to illustrate this problem.

Pasture production in New Zealand is subject to marked seasonal and annual variation (McMeekan, 1953; Lynch, 1955). Feed quality is equally variable. Supplementary feeding during periods of pasture shortage is comprised entirely of hay and/or silage.

This variability in feedstuffs available is reflected in the growth patterns illustrated in Figure 1. The five animals represent a sub-group of the Aberdeen Angus bulls currently under production test at Ruakura (MacDonald, unpublished data). The test started at weaning, carried through an unusually dry autumn and winter and a good spring. It is obvious that under these conditions the normal beef cattle growth pattern did not materialise.

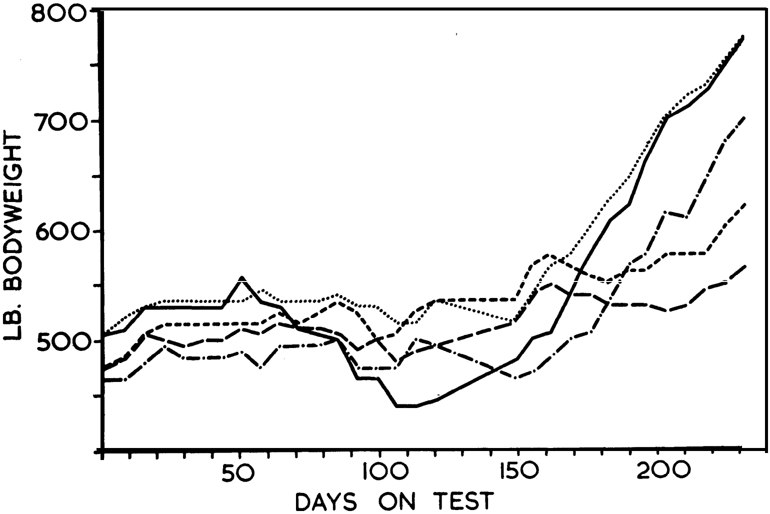

FIGURE 1: Growth pattern of 5 pasture fed Aberdeen Angus bulls.

During the initial 150 days of the test, seasonal conditions and feed supply were poor and the animals' growth patterns reflected these conditions. With the exception of No. 17 (denoted by the solid line in Figure 1) which was far less able to maintain weight than the other bulls, severe environmental conditions limited the range of variability, preventing some, if not all, genotypes from full expression. With the advent of spring pasture growth the higher plane of nutrition permitted greater differentiation in growth response. The response of No. 17 to the better feed conditions is remarkable. Had selection been attempted after a period of 120 days, No. 17 would have been culled. It is equally obvious that while it is preferable to production test animals on pasture through a weight-constant period, fluctuations of feed supply demand that animals must be grazed together through a time-constant period, preferably embracing all pasture seasons.

GENETIC CORRELATIONS

According to Lerner (1950), when a relationship between two characteristics expressed by an animal is discovered it may be due to two types of causative forces. First, the genes affecting the two characteristics may be the same or may be linked. Second, the correlation may result because environmental influences affecting one trait also affect the other. To the animal breeder, the genetic portion of the total correlation is of importance for two reasons. First, when selection results in genetic changes in one characteristic; changes also occur in correlated characteristics. Second, correlations may be used to increase the efficiency of selection. Improvement in a characteristic that is difficult to measure may be achieved by a selection programme utilising a correlated characteristic that is easily measured. However, if a negative genetic correlation exists between two characteristics, selection for both may result in genetic homeostasis and wasted effort (Rae, 1952).

Most of the experimental data indicating selection is effective in bringing about genetic change, is based on single factor selection experiments. Multiple factor selection indices indicate that correlations between characteristics are far more numerous than formerly realised. This is nicely illustrated by work undertaken in Colorado (Stonaker, 1951). Using data from 61 animals by 14 pure-bred bulls, "paper culling" was set at a level permitting only the top 25 per cent. to breed. Single factor selection was practised to determine whether or not positive or negative selection occurs automatically in the traits on which no purposeful selection pressure had been applied. Selection criteria were all of direct economic importance. They were: (a) high grade at weaning; (b) high commercial grade at slaughter; (c) compactness; (d) high weaning weight; (e) high final feed-lot weight (f) fast daily gain; (g) high efficiency of feed utilisation.

Results for single factor selections had the following effects on the characteristics recorded:

TABLE 5

EFFECT OF SELECTION FOR A SINGLE FACTOR ON OTHER FACTORS OF ECONOMIC IMPORTANCE IN A CATTLE POPULATION. CULLING RATE AT 75 PER CENT.

Single Selection Factor	Initial Grade (a)	Commercial Grade (b)	Compactness (c)	Weaning Weight (d)	Final Weight (e)	Daily Gain (f)	Efficiency of Gain (g)
Initial Grade	—	M<A	S>A	M>A	A	M<A	VM<A
Slaughter Grade	S>A	—	M>A	M>A	M>A	S<A	A
Compactness Grade	A	VM>A	—	S>A	M<A	M<A	S>A
Weaning Weight	M>A	M>A	A	—	M>A	A	M<A
Final Weight	M>A	M>A	S>A	VM>A	—	VM>A	A
Daily Gain	S<A	M>A	S<A	M>A	VM>A	—	VM>A
Efficiency of Gain	VM<A	M<A	M>A	VM<A	VM<A	M>A	—

Legend: A = average, S = slightly, M = much, VM = very much, < = less than, > = more than.

Thus, for example, it may be seen that after selecting for initial grade only, the herd replacements were of much lower than average commercial grades, slightly better than average compactness, much better than average weaning rate and average final weight, much lower than average daily gaining ability and very much lower than average efficiency. It must be concluded that selection pressure on any one of these economically important traits has other than random effects on other traits. In order that selection may be more effective it is imperative that more be known of the causes of these and similar correlations. Otherwise, breeders may, in changing some characteristics in a positive direction, be automatically selecting against other characteristics of economic importance.

Show-ring judging enthusiasts have at various times expressed belief that based on certain visual observations, one is able to predict the future conformation, rate of gain, efficiency of gain, and transmitting ability of animals observed. The advisability of selecting animals of a certain breed type with uniform colour markings, head and body type has been emphasised. Positive genetic correlations between show-ring type and production characteristics are inferred. MacDonald and Bogart (1954) studied correlations to determine whether or not these beliefs are founded on fact when beef breeding animals are involved.

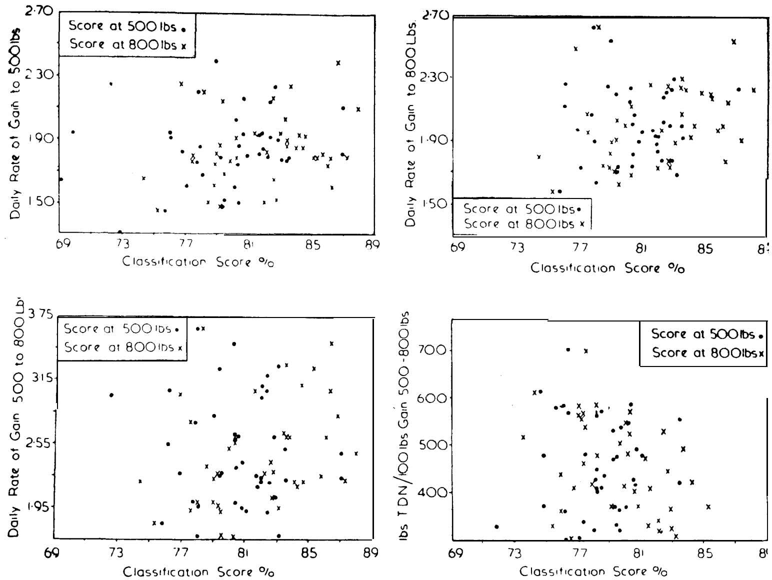

FIGURE 2: Relationship between type classification scores and production factors.

Upper left: Rate of gain: birth to 500 lb. body weight.
Upper right: Rate of gain: birth to 800 lb. body weight.
Lower left: Rate of gain: 500 lb. to 800 lb. body weight.
Lower right: Efficiency of gain: 500 lb. to 800 lb. body weight.

Neither type score at 500 lb. nor type score at 800 lb. body weight was significantly correlated with any of the production factors studies. Hankins and Burk (1936) reported a study employing feeder cattle from many experiments. They found little or no relationship between feeder grade and subsequent gain of cattle in the feed lot. Paterson et al. (1949, 1955), Durham and Knox (1953), Knapp et al. (1941), and Knapp and Clark (1951) found practically no correlation between type score or grade and subsequent rates of gain. It was concluded that there is little value for selecting for these production characteristics if sole dependence is placed on visual methods of selection. Performance testing in addition to type classification is, therefore, essential if overall genetic improvement through selection is to be realised.

Correlations between production characteristics and blood born chemical metabolites such as amino acid nitrogen, urea nitrogen, non-protein nitrogen, creatinine. uric acid (MacDonald, 1954; MacDonald and White, 1955), and protein-bdund iodine (Reid, Ward and Salisbury, 1948; Kidwell, Wade and Hunter, 1955), have been studied. In like manner, relationships between production factors and nitrogen retentions, total urinary creatinine, uric acid, ammonia, urea and total nitrogen excretion rates (MacDonald, 1954), heart rates (Williams, Krueger and Bogart, 1954), rectal temperatures (Williams, Krueger and Bogart, 1953) and digestibility (Nelms, Price and Bogart, 1955) have been studied in an attempt to establish the basis for physiological differences in inheritable production characteristics.

TYPE OF PERFORMANCE TEST

Three factors determine the speed with which cattle breeders may achieve genetic progress in a herd (Lerner, 1950). These factors are:

Table I. shows the analyses of variance; Table II., the variance components derived from them. In these tables the weights which were taken in ounces have been converted to grams for comparison with the weights on the other balance. Table III. shows intra-class correlations, and Table IV., the full-sib estimates of heritability.

In Table II., it can be seen that the full-sib estimate of heritability is:

$$\frac{2\,(\sigma^2_S + \sigma^2_D)}{\sigma^2_S + \sigma^2_D + \sigma^3_I}$$

The σ^2_I term is the variance component which includes the errors of measurement (σ^2_{EM}). If, as was assumed above, the spring balance is subject to greater errors than the gram balance, the individual variance component for gram measurements should be less than that for the ounce measurements. It can be seen from Tables I. and II. that in all instances the above prediction holds; the differences, however, are not large.

The correlation co-efficients for sires, dams and full-sibs are, with one exception, higher for the gram measurements. The average increase in heritability by the use of the gram-balance is only 1.5 per cent (Table IV.). This is not considered to be of any great importance with the high heritabilities involved, so that the continued use of the clock-face scale seems justified.

The use of average weights taken on consecutive days in all cases gives a reduction in individual variance, as predicted, the average increase in heritability being 4.6 per cent. However, in this reduction in variance, not only σ^2_{EM} is involved, but also some of σ^2_{RE}. The total gain in heritability, using the average of two days on the gram balance, compared with one on the spring balance, is only 6.12 per cent. The use of average weights under these conditions does not appear justified, but under conditions of low heritability, techniques giving a lift in heritability of this order might be worthwhile.

(b) Use of heritability estimates to predict genetic progress

When animals are measured for selection, variability in the measurements contains all of σ^2_{RE}, σ^2_{KE} and σ^2_{EM}. Heritability estimates which have been raised by using correction factors to remove σ^2_{KE}, or by varying the measurement technique to reduce σ^2_{EM}, are not applicable for prediction of genetic progress unless selection is based on measurements obtained by the same technique and corrected by the same factors. For example, the heritability value of 0.940, obtained for male chicken weights based on a two-day average with the gram balance, would not be valid for predicting genetic progress if selection were based on a single weight on the ounce balance.

This point has perhaps not been sufficiently stressed in the literature. It becomes very important in work with dairy cattle where the number of environmental factors is large, and may include some or all of the following:

1. Measurement technique;
2. Sampling technique;
3. Years;
4. Seasons;
5. Length of dry period;
6. Lactation number;
7. Length of gestation involved in the lactation period;
8. Feeding practice.

Studies have been made of all of these except "feeding practice" and the errors involved in each are quite high. By "feeding practice" is meant the feeding of animals according to production. This practice presumably causes an appreciable increase in phenotypic variance. Its effect in a selection programme would be twofold; firstly, it would increase the magnitude of the selection differential, and secondly, it would lower the heritability. The net effect of these two factors has never been investigated.

Removal of all these known factors from the environmental variance would be a tedious process, but would presumably give a high value for the heritability. However, unless the raw data were corrected for all of them in selecting animals, the high heritability value would not give a valid estimate of the rate of genetic progress. Further, in applying a large number of correction factors, it should be remembered that the law of diminishing returns applies, as each correction factor is itself subject to error.

(a) Selection intensity; (b) heritability (selection accuracy), and (c) generation turnover.

Lerner gives the relationship between these factors as:

$$\Delta \text{ Gy} = \frac{ih^2}{A} \qquad (2)$$

where Δ Gy = yearly rate of change in the average value of a genotype, i = selection intensity, h^2 = the degree of heritability and A = average age of the parents weighted for the number of offspring.

Progeny Testing: Selection accuracy may be increased by the use of the progeny test. In the United States, beef cattle progeny testing follows a fairly standardised procedure. It is customary to test the bulls only since cows leave so few offspring they do not warrant the expense of testing them. Cows that have been selected at random are mated in single sire groups. The breeding season is usually limited to 6 or 8 weeks so that all calves are produced within approximately an 8 to 10 week period. Except during the breeding season, all cows with calves run together. The calves are weaned at an average age of 5 to 6 months or under good conditions at approximately 450 to 500 lb. live weight. From the entire steer crop of each bull, a randomly selected group of 4 to 8 steers is picked and individually fed to weights of approximately 800 to 1,000 live weight. Rations are designed to give each steer an equal opportunity to grow and fatten towards ideal slaughter weights (MacDonald, unpublished data), so that differences observed between the progeny of different bulls may be attributed to the inherent ability of that bull. Unfortunately, each of these steps takes so much time that a tested bull is invariably mature if not aged. It may be seen (formula 2) that under a progeny testing system selection intensity decreases because testing facilities limit the number of progeny groups testable compared to individual selection of bulls. The denominator in formula 2 also increases. Therefore, the increased genetic gain realised from increasing the precision of selection through a progeny test is offset by a lower selection intensity and a slower generation turnover.

An important factor in the rate of generation turnover is the age at first calving. Walker (1955) studied the effect of age at first calving on Aberdeen Angus heifers. Two comparable groups of heifers were treated similarly except one group calved at two years, the other at three years of age. There was no difference between groups at maturity. At Ruakura, all beef heifers are now bred to calve at two years of age. This procedure is also common practice in North America (Burke, 1954).

Production Testing: While the progeny test increases selection accuracy, the reduction in rate of generation turnover slows genetic improvement. Fortunately, heritabilities for most of the economically desirable traits in beef cattle are high (Table 2), permitting individual rather than progeny testing. Individual testing is termed "Production Testing" throughout much of North America to distinguish it from progeny testing. While production testing does not permit selection accuracy of as high an order as is made possible through progeny testing, the high heritabilities of most production characteristics result in an increased rate of genetic gain through a marked reduction in generation turnover time.

In Australia and New Zealand, findings to date are totally inadequate and North America techniques are sufficiently impractical under our conditions to suggest that it is impossible to employ an overseas production testing procedure for beef breeding stock evaluation. Heritability estimates, economic values and genetic correlations between factors must be determined under reasonably practical conditions.

RECOMMENDATIONS FOR BEEF CATTLE IMPROVEMENT SELECTION

1. Breeding animals must be performance tested under the conditions in which their progeny will perform.
2. The "total score" index is the most efficient system of selection (Hazel and Lush, 1936). Breeding animals should be selected by this method.
3. Factors to be included in a selection index and the weight given to each will result from determining under prevailing environmental conditions:
   (a) the relative value of the economically important characteristics;
   (b) the heritability of these characteristics;
   (c) genetic correlations between the important characteristics.
4. Characteristics which are strongly inherited should be evaluated through a "production" test while those which are weakly inherited, if economic-

ally important, must be evaluated through a "progeny" test or alternatively through a correlated highly heritable characteristic.

REFERENCES:

Black, W. H., and Knapp, B., Jr. (1936). Proc. Amer. Soc. Anim. Prod. 29.: 72.

Bogart, R., Warnick, A. C., Dahmen, J. J., and Burris, M. J. (1951). J. Anim. Sci. 10: 1073.

Bogart, R. (1954). "Factors Associated with Growth and Feed Efficiency in Beef Cattle". Oregon Chapter of Sigma XI Honorary Lecture.

Burgess, J. B., Landblom, N. L., and Stonaker, H. H. (1954). J. Anim. Sci. **13: 843.**

Burke, L. R. (1954). Proc. West. Sect. Amer. Soc. Anim. Prod. 5: 249.

Burris, M. J., Bogart, R., Oliver, A. W., and Mackey, A. 0. (1952). J. Anim. Sci. **11: 789.**

Burris, M. J., Bogart, R., Oliver, A. W., Mackey, A. O., and Oldfield, J. E. (1954). Tech. Bull. Ore. Agric. Exp. Sta. No. 31.

Clegg, M. T., Albaugh, R., Strong, H., and Cole H. H. (1954). Circ. Calif. Agric. Exp. Sta. No. 441.

Dahmen, J. J., and Bogart, R. (1952). Tech. Bull. Ore. Agric. Exp. Sta. No. 26.

Dawson, W. M., Phillips, R. W., and Black, W. H. (1947). J. Anim. Sci. 6: 247.

Durham, R. M., and Knox, J. H. (1953). J. Anim. Sci. 12: 771.

Gregory, K. E., Blunn, C. T., and Baker, M. L. (1950). J. Anim. Sci. 9: 938.

Hammond, J. (1947). Biol. Rev. 22: 195.

Hankins, 0. G., and Burk, L. B. (1936). Tech. Bull. U.S. Dep. Agric. No. 665.

Hazel, L. M., and Lush, J. L. (1942). J. Hered. 33: 393.

Hitchcock, G. H., Sawyer, W. A., Bogart, R., and Calvin, L. (1955). Tech. Bull. Ore. Agric. Exp. Sta. No. 34.

Kidwell, J. F., Wade, M. A., and Hunter, J. E. (1955). Proc. West. Sect. Amer. Soc. Anim. Prod. 6: 43.

Knapp, B., Jr., Baker, A. L., Quesenbury, J. R., and Clark, R. T. (1941). Bull. Mont. Agric. Exp. Sta. No. 397.

Knapp, B., Jr., and Clark, R. T. (1950). J. Anim. Sci. 9: 582.

Knapp, B., Jr., and Clark, R. T. (195 1). J. Anim. Sci. **10: 365.**

Knapp, B., Jr., and Nordskog, A. W. (1946). J. Anim. Sci. 5: 62.

Knapp, B., Jr., and Nordskog, A. W. (1946). J. Anim. Sci. 5: 194.

Koch, R. M. (195 1). J. Anim. Sci. **10: 768.**

Lerner, J. M. (1950). "Population Genetics and Animal Improvement". (Cambridge University Press: London).

Lynch, P. B. (1955). Proc. N.Z. Agric. Ext. Conf. (Department of Agriculture: Wellington). Mineo.

McCleery, N. D., and Blackwell, R. L. (1954). Proc. West. Sect. Amer. Soc. Anim. Prod. 5: 223.

MacDonald, M. A., and Bogart, R. (1954). N.Z. J. Sci. Tech. Sect. A. 36:

MacDonald, M. A., and White, R. R. (1954). N.Z. J. Sci. Tech. Sect. A. 36: 460.

MacDonald, M. A., and White, R. R. (1955). N.Z. J. Sci. Tech. Sect. A. 37: 259.

McMeekan, C. P. (1953). N.Z. Sci. Rev. **11:** 115.

Nelms, G., Price, D. A., and Bogart, R. (1955). Proc. West. Sect. Amer. Soc. Anim. Prod. 6: 217.

Patterson, R. E., Cartwright, T. C., Jones, J. H., and Bayles, J. J. (1955). J. Anim. Sci. 14: 1034.

Patterson, R. E., Jones, J. H., Bayles, J. J., and Turnbough, R. V. (1949). J. Anim. Sci. 8: 608.

Rae, A. L. (1952). Proc. N.Z. Soc. Anim. Prod. **11: 104.**

Reid, J. T., Ward, G. M., and Salisbury, R. L. (1948). Amer. J. Physiol. 152: 633.

Simms, B. T. (1948). Rep. U.S. Bur. Anim. Ind. 1947/48.

Smith, A. D. Buchanan (1948). J. Frms'. Cl. (Lond.). 1948 (7): 36.

Stonaker, H. H. (1951). "Overall Effects of Single Trait and Index Selection in Beef Cattle". (Colorado Agricultural and Mechanical College: Fort Collins). Mineo.

Walker, D. E. K. (1955). Proc. Ruakura Fmrs'. Conf. 1955. 27.

Warwick, B. L., and Cartwright, T. C. (1955). J. Anim. Sci. 14: 372.

Warwick, B. L., Cartwright, T. C., and Hazen, M. W (1954). Bull. Tex. Agric. Exp. Sta. No. 570.

Williams, C. M., Kreuger, H., and Bogart, R. (1953). Proc. West. Sect. Amer. Soc. Anim. Prod. 4: vi.

Williams, C. M., Kreuger, H., and Bogart, R. (1954). Proc. West. Sect. Amer. Soc. Anim. Prod. 5: 299.

DISCUSSION

Mr. PANARETTO: With reference to the graph showing the growth rates of five Aberdeen Angus bulls, what has Dr. MacDonald to say about the optimum period for testing bulls? One animal showed a marked loss in weight during the period 50-100 days, but thereafter was one of the two best growing animals. If selection had occurred after the first 100 days this animal would have been culled.

Mr. WILLIAMS: American investigators have a set period of test, but there is the problem of finding the optimum test period — should it be fixed on a time-constant basis or a weight-constant basis. Under pasture conditions Dr. MacDonald has this same problem and he considers that animals should be observed over a full 12 month period to include all seasons. In Oregon, bulls were grown under range conditions with limited hay supplement during winter and gave heritabilities of 17 and 39 per cent. for yearling weights.

Mr. SKALLER: With regard to the slide showing the advance in weight gain made by selection in one generation, it does not seem to be clear as to how much of this progress was due to environmental conditions prevailing during the test of the second generation as apparently no control group was maintained.

Mr. WILLIAMS: It must be admitted that due to high costs and limited space control animals were not maintained. It must be assumed that the attempt on behalf of the research group to maintain a constant set of environmental conditions has been successful. A secondary measure of appraisal will come from the progeny of range groups bred by selected animals from these studies.

Mr. DAVIES: Is there any information on using either full sibs, half sibs or identical twins reared on two planes of nutrition in order to select at any earlier age instead of waiting until the bull has reached 800 lb. live weight?

ANS.: Many investigators have been and are studying systems of appraisal with the objective of gaining earlier, less costly and more accurate methods of genotype evaluation. To date the situation is not sufficiently well understood to advocate one method.