THE USEFULNESS TO THE ANIMAL PRODUCER OF RESEARCH FINDINGS ON THE GENETICS OF LACTATION

GOLDA L. MUNRO*

I. INTRODUCTION

Lactation, a characteristic of mammals, involves the secretion of milk, a product unique in nature. The length of lactation, the yield, and the composition of the milk secreted vary greatly between species. Since most work on the genetics of lactation has been concentrated on the bovine species (in particular the dairy cow), discussion in this paper will be limited to that species.

To the animal producer, genetic improvement is a matter of selecting animals from which to breed replacement stock. His concern is to improve the genetic makeup of the herd so as to provide maximum economic return. There is little point in striving for an estimated theoretical maximum gain in production if the product itself is of little economic value; Currently in Australia, the producer is paid for the milk and fat he supplies. Recommendations have been made that the protein produced be paid for on a basis with the fat. On the world market, the fat, the protein and the meat produced by the animal have each meant at certain times greatest financial returns to the farmer.

The genetics of bovine lactation can be considered from three levels - the breed level, the quantitative genetics level within breeds, and the individual gene level. Selection may occur at each level with varying degrees of success depending on the reliability of the information on which the decision to select was based. The important factors in genetic improvement per generation are the variability in the population, heritability, and intensity of selection. The importance of performance (herd) recording schemes in the estimation of the parameters, and in providing information on which to base selection, cannot be overemphasized. While these schemes in the past have concentrated on the measurement of milk and fat production only, necessitating special programmes for the measurement of other components such as protein and lactose, they still provide the geneticist with the best available information on the dairy cattle population. To the animal breeder, they provide the only reliable means of selecting superior genetic material.

II. BASES FOR SELECTION

(a) Selection on the basis of breed

The different breeds of dairy cattle have been selected for the main attribute for which each breed excels. The Friesian breed, for example, produces the greatest yields of milk, while the other common Australian breed, the Jersey, has greatest percentages of components.

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Greatest variability in yields is also found in the Friesian (or Holstein) breeds, with more variability in percentages in the Jersey and Guernsey breeds (Wilcox, Gaunt, and Farthing 1971).

### TABLE 1

| Mean (X) and standard deviations (sd) of yields and percentages of milk components from three breeds of dairy cattle* |
|---|---|---|---|---|---|---|---|---|---|
| **Yield (kg)** | Milk | Fat | SNF | Protein | Lactose | **Percentages** | Fat | SNF | Protein |
| Holstein | x | 7088 | 265 | 602 | 227 | 443 | 3.70 | 8.45 | 3.11 |
| sd | 1428 | 56 | 123 | 47 | 130 | .39 | .32 | .25 |
| Jersey | x | 4454 | 230 | 412 | 173 | 270 | 5.13 | 9.21 | 3.80 |
| sd | 1155 | 62 | 106 | 45 | 64 | .24 | .37 | .30 |
| Guernsey | x | 4819 | 237 | 437 | 177 | 274 | 4.87 | 9.01 | 3.62 |
| sd | 1097 | 56 | 101 | 42 | 79 | .45 | .29 | .29 |

*From Wilcox, Gaunt and Farthing (1971).

Changes in average composition occurring throughout the lactation appear to be different in Holsteins from those occurring in Jerseys and Guernseys (Erb and Ashworth 1963). Differences in fatty acid composition of milk from the Holstein breed compared with the Channel Island breeds were reported by Stull and Brown (1964) and higher \( \beta \)-lactoglobulin percentages were reported in Jerseys compared with Friesians by McLean, Bailey and Munro (1974).

Crossbreeding as a means of genetic improvement relies on the selection of breeds with emphasis on different traits which when combined will provide hybrid superiority. A mixture of breeds offers the greatest variability for selection, since average within breed differences are not substantially greater than between breed differences (Touchberry 1974). The scope to significantly alter the ratio of the components of milk (e.g. the fat to protein ratio) may well come from crossbreeding (Barker 1968).

'New dairy cattle breeds may be developed from crossbreeding existing breeds. In the United Kingdom, a new red and white breed based on Dairy Shorthorn is being developed to compete with the Friesian (Bowman and Hocking 1974). The Australian Milking Zebu developed in Northern New South Wales from crosses of Jerseys (Bos taurus) with Sahiwals or Red Sindhis (Bos indicus) has been selected for yield and resistance to heat (Hayman 1974). By this cross, it is hoped to develop a high yielding breed suitable for tropical areas, as a means of genetic improvement relies on the selection of breeds with emphasis on different traits which when combined will provide hybrid superiority. A mixture of breeds offers the greatest variability for selection, since average within breed differences are not substantially greater than between breed differences (Touchberry 1974). The scope to significantly alter the ratio of the components of milk (e.g. the fat to protein ratio) may well come from crossbreeding (Barker 1968).

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(b) Selection on the basis of Quantitative Inheritance within a breed

Quantitative genetics has so far played the greatest role for the animal producer in genetic improvement. Within a breed, the dairy farmer selects the sire and dam from which to breed replacement stocks for his herd. Intensity of selection on the female side is hampered by insufficient replacement stock in a herd. With artificial breeding,
a bull may sire 100,000 progeny, thus selection of the male has greatest influence on genetic improvement. Unfortunately, lactation is only expressed in the female. The main role of the quantitative geneticist in dairy cattle breeding has been to define and refine the best methods for estimating a bull's breeding value.

Predictions of breeding value, genetic changes and responses to selection require knowledge of heritabilities, genetic correlations and population variation of the traits under selection. Yields of milk and components, and percentages of components have significant heritabilities and are genetically correlated. Reliable Australian estimates of these parameters do not exist, and a recent study in the United States of America on 25,000 records provides the best estimates available at present (Wilcox, Gaunt and Farthing 1971).

TABLE II

<table>
<thead>
<tr>
<th>Yields</th>
<th>Percentages</th>
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<tbody>
<tr>
<td>Milk</td>
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<tr>
<td>Milk</td>
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<tr>
<td>Fat</td>
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<tr>
<td>SNF</td>
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<tr>
<td>Protein</td>
<td>.82</td>
</tr>
<tr>
<td>Lactose</td>
<td>.99</td>
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<table>
<thead>
<tr>
<th>Percentages</th>
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</thead>
<tbody>
<tr>
<td>Fat</td>
</tr>
<tr>
<td>SNF</td>
</tr>
<tr>
<td>Protein</td>
</tr>
</tbody>
</table>

*Heritabilities (underlined) appear on diagonal. Taken from Wilcox, Gaunt and Farthing (1971) for Holsteins.

Length of lactation has a heritability not significantly different from zero, but is positively genetically correlated with yield (Barker and Robertson 1969). An estimate of .30 for heritability of feed efficiency was reported by Lamb (1972), and level of production and gross feed efficiency were highly correlated. High estimates of the heritability of the proportion of fatty acids were obtained by Edwards, King and Yousef (1973), but since these estimates were subject to large variation, they should not be considered reliable, Norman and Van Vleck (1972) stated that bulls that sire daughters with high yields tend to sire daughters with weaker udder attachments.

The repeatability of a trait is estimated from the correlation between different records for the same animal - in this case the correlation between different lactations for the same cow. It has value as a measure of the degree of permanence of trait in the cow, and can be used to help decide which cows are likely to be the best producers in the next lactation (Touchberry 1974). Repeatabilities of
yields of milk and components are about 0.5 and of, percentages of components 0.6-0.8 (Wilcox, Gaunt and Farthing 1971). These values reflect the fact that almost half the variation among lactation yields in the same herd is among lactations of the same cow. Thus there is considerable error associated with the prediction of what a given cow will product in the next lactation.

Selection for one trait will give greatest gains in that trait with less significant responses in associated traits. The estimated genetic change for a trait under selection may be given by

\[ R = i h^2 \sigma \]

where \( R \) = response to selection (or genetic gain)

\( i \) = intensity of selection

\( h^2 \) = heritability of trait under selection

\( \sigma \) = population standard deviation of the trait.

Since protein yield is less heritable than fat yield, direct selection for protein yield will make slower progress than will direct selection for fat yield. Selection for milk yield in Friesians will be more effective than selection for yield in Jerseys. Jerseys, however, will respond better to selection for percentages of components.

The response to selection for a trait other than the one under direct selection may be given by

\[ CR_y = i_x h_x h_y r_{xy} \sigma_y \]

where \( CR_y \) = correlated response in \( y \) (selection on \( x \))

\( i_x \) = intensity of selection for \( x \)

\( h_x, h_y \) = square roots of heritabilities.

\( r_{xy} \) = genetic correlation between \( x \) and \( y \)

\( \sigma_y \) = population standard deviation in \( y \).

Selection for milk yield alone would give an increase in yields of components, and decrease in percentages. On the basis of the correlated responses to selection for Holsteins given by Wilcox, Gaunt and Farthing (1971), selection for milk yield would give 67% of the response in fat yield as would direct selection for fat, and 96% of the response in protein yield as would direct selection for protein.

Indices may be constructed to allow for selection for several traits at one time, with relative economic values assigned as weights for parameters. One such index constructed by Hanna and Cunningham (1974) suggests that under a pricing scheme of 1:1 fat:protein, selection of sires on the basis of progeny records of fat and protein yields would be 22% more valuable than selection on the basis of milk yield alone. However, the more traits are selected for, the less is the response in any one trait. Legates (1964) showed that as the number of traits selected for increased from one to three, mean superiority of milk yield of daughters over herd mates' yields fell from 364 kilograms to 209 kilograms.
A bull for use in artificial breeding is generally selected on the basis of the production of his daughters as compared with that of their contemporaries. Recent overseas work has been concerned with improving the accuracy of estimates of a bull's breeding value. One such improvement has been allowance for genetic merit of contemporaries.

A bull undergoing progeny testing makes no effective genetic contribution to the population for ten years, but provides a small but constant contribution thereafter (Hinks 1971). Selection of a sire on the basis of his half-sisters' production may have some merit in shortening this interval (Owen 1975). Progeny testing requires the retention of a large number of bulls pending results of progeny production. This can become a financial burden to an artificial breeding organization. Collection of large doses of semen followed by slaughter of young bulls prior to the results of progeny production, and more extensive use of semen after selection may help to alleviate this problem.

(c) Selection on the basis of individual genes

Identification of an individual gene controlling a trait enables selection to be made with more certainty. The major milk proteins are controlled by simply inherited genes detectable by starch gel electrophoresis. Different variants for a-casein, β-casein and κ-casein, and the whey protein β-lactoglobulin have been found in all major European breeds. A variant of α-lactalbumin has been discovered in the Zebu strains of cattle. Frequencies of the variants can differ between breeds (Table III).

<table>
<thead>
<tr>
<th>Gene</th>
<th>Variants</th>
</tr>
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<tbody>
<tr>
<td>α-Casein</td>
<td>B C</td>
</tr>
<tr>
<td>Jersey</td>
<td>360 77 23</td>
</tr>
<tr>
<td>Friesian</td>
<td>410 90 10</td>
</tr>
<tr>
<td>β-Casein</td>
<td>A1 A2 A3 B C</td>
</tr>
<tr>
<td>Jersey</td>
<td>360 21 50 1 28 0.2</td>
</tr>
<tr>
<td>Friesian</td>
<td>410 47 43 1 9 -</td>
</tr>
<tr>
<td>κ-Casein</td>
<td>A B</td>
</tr>
<tr>
<td>Jersey</td>
<td>360 41 59</td>
</tr>
<tr>
<td>Friesian</td>
<td>410 66 34</td>
</tr>
<tr>
<td>β-Lactoglobulin</td>
<td>A B C</td>
</tr>
<tr>
<td>Jersey</td>
<td>360 29 65 6</td>
</tr>
<tr>
<td>Friesian</td>
<td>410 37 63 -</td>
</tr>
</tbody>
</table>

TABLE III

Gene Frequencies of major milk protein variants in two breeds from an Adelaide Hills herd recording association

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Whether selection on the basis of a milk protein polymorphism will influence yields of milk, fat or total protein has yet to be determined. Sherbon, Ledford and Regenstein (1967) found a lower fat content in \( \beta \)-lactoglobulin type A cows but this was not substantiated by other workers (Brun et al., 1968, Hoogendoorn et al., 1969). There has been determined, however, significant influence of the variants of \( \beta \)-lactoglobulin on the percentage of \( \beta \)-lactoglobulin produced (McLean, Bailey and Munro, 1974). Relationship of polymorphisms of other milk proteins and the production of these proteins are still uncertain but there appears to be scope for selection on this basis.

The milk protein variants have been found to influence the processing properties of the milk produced. The B variants of \( \beta \)- and \( \kappa \)-casein produce milk with firmer curds and shorter rennet clotting times i.e. milk more suitable for making cheese. (Feagan et al., 1972). Milk of the \( \beta \)-lactoglobulin A variant produces a more heat stable milk powder, due to the higher level of \( \beta \)-lactoglobulin. To an industry based economically on milk powder and cheese manufacture, the gene distribution of the suppliers of a factory may be of importance.

Use of the milk protein polymorphisms in conjunction with blood polymorphisms in determining genetic distances between breeds may enable wider genetic variation for selection (Kidd, 1974). Studies on the polymorphism frequencies of the South African South Devon breed and the German Gelbvieh breed proved the similarity of the breeds (Kidd et al., 1974). To the breeders of South Africa this meant greater scope for selection in their population, whilst still retaining the purity of their breed.

Polymorphisms in enzymes in the milk may provide future information on the control of lactation. Xanthine oxidase, an enzyme which controls the last stages of purine catabolism, has been found to have two alleles \( XO-A \) and \( XO-B \) with high and low activity respectively (Zikakis and Tresone, 1971). This enzyme has been implicated in development of undesirable oxidized flavours in market milk, and selection on the basis of the polymorphism may be of value.

### III DISCUSSION

The theoretical rate of genetic improvement in mean milk yield for a breeding population of 10,000 cows is 2.1% per annum (Syrstad, 1972). Current Australian estimates based on the recorded Friesian and Jersey populations of N.S.W. do not differ significantly from zero (Hammond, 1974 personal communication). Part of the reason for this low level of genetic improvement is due to lack of participation in herd recording schemes and inadequate use of artificial insemination. Only 27% of the dairy cattle population in Australia is under herd recording, and only 30% are artificially bred. This, along with lack of co-ordination of information between states and organisations in the proving of bulls and the collection of information has hampered the adequate use of the breeding population for selection of superior stock. Moves now afoot for a national herd improvement scheme co-ordinating herd recording and artificial breeding services on a national level must be supported.
In using selection, the animal producer must have a view to the.

economic trends in his industry. More emphasis is being placed by the
consumer on the quality of the product supplied. In addition, 
efficiency of production will assume far greater importance in the
future. Performance recording schemes will need to be more flexible and cater for information on feeding and breeding, and measurement of 
milk, fat, protein, lactose, and possibly even the protein fractions. 
As the capacity to change ratios of components (e.g. protein to fat 
ratio) appears limited within existing breeds, traditional ideas of 
breeds may need to be abandoned. Crossbreeding and development of 
new breeds may be required. Selection on the basis of the simply 
held milk protein polymorphisms appears to have a role in improving the quality of the product. Individual genetic variants of enzymes and 
other milk and blood parameters may hold a key to an effective way of selecting for increased production.

One area in which research findings appear to be lacking is in knowledge of genotype-environment interactions in dairy cattle. 
Brantone et al (1974) found no genotype-climatic interactions over a 
temperature range of -1°C to 30°C. Interactions of genotype with 
level of feed intake, feed conversion efficiency and other aspects of 
nutrition need to be examined in more detail.

The Friesian breed and selection for milk yield currently still appear to be the most economic programme for the animal producer to follow. However, care must be taken that significant downturns in other traits do not occur. Lower percentages of components can cause factory problems in reaching requirements of composition. Selection for milk yield should not be practised to the complete exclusion of all other traits. Loss of genetic variability which may result from such unidirectional selection would have serious repercussions if later trends dictate more emphasis on components.

IV. REFERENCES


