ASSESSMENT OF DAIRY COW EVALUATION METHODS

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DECLARATION

This thesis was compiled by the author, based on work done by himself, and has not been presented for a degree in any other University.

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DEDICATION

To my parents, for their genes and necessary support, and everybody who might benefit, in one way or another, from this thesis.

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ABSTRACT

A total of 956 Friesian cows with lactation records covering different parities in the period 1966 to 1987, and sired by 39 bulls, were genetically evaluated for 305-day milk yield by computing for each cow the indices: Adjusted Least Squares Mean (ALSM), Expected Real Producing Ability (ERPA), Expected Breeding Value (EBV) and Predicted Breeding Value (PBV). They were then ranked according to their four indices, respectively. A rank correlation test was carried out with the view to determining whether the indices ranked cows differently. The rank correlation between ALSM and ERPA or EBV was found to be 0.99, while ERPA and EBV had, as expected, a rank correlation of 1.00 for the parameter combinations of $h^2=0.20$ and $r=0.43$ and $h^2=0.25$ and $r=0.45$. On the other hand, the rank correlation between PBV and ALSM, ERPA or EBV was 0.74 when using the parameter estimates of $h^2=0.20$ and $r=0.43$ obtained in this study and 0.80 when using the average parameter estimates of $h^2=0.25$ and $r=0.45$. The results showed that Predicted Breeding Value is the most appropriate index of dairy cow evaluation for selection.

1 INTRODUCTION

In dairy cattle breeding programmes, much attention has to be paid to the development of methods of sire evaluation. This is due to the fact that usually 60 to 70% of the genetic change in milk production can be attributed to the selection of progeny-tested bulls (Philipsson *et al.*, 1978). However, several studies have shown the importance of genetic evaluation of cows for dam selection. For instance, Skjervold (1963), Syrstad (1966), Brascamp (1973), Abubakar *et al.* (1986) reported that 20 to 49% of the genetic improvement or economic returns can be attributed to the selection of bull dams. On the other hand, the low rate of gain attributable to a somewhat inappropriate dam-dam selection is partly responsible for the lower (1%) realised annual genetic gain for milk production than is theoretically (2%) possible (Van Vleck, 1976). Besides, cow evaluation is important in that dairy farms may base their culling decisions on cow indices even in the absence of a national breeding programme.

The main purpose of this study was therefore to assess four methods of evaluating the genetic merit of dairy cows with the view to identifying the most appropriate for intra- and/or inter-herd cow selection in Kenya and other comparable countries where a genetic index on which to base selection of dairy cows is yet to be devised for adoption.

2 LITERATURE REVIEW

2.1 Cow Genetic Evaluation

Cow genetic evaluation brings together appropriately weighted sources of information (Fig. 1) about the cow of interest and/or her ancestors and progeny for computing her genetic merit, either as an estimated transmitting ability (ETA) or breeding value (BV). And although the higher the coefficient of relationship between a certain source of information and the candidate cow the better the source, the actual sources of information used depends on their availability. For example, pedigree information about the cow, that is, information about the cow's ancestors, is more often used than the information about the cow's daughters. This is due to the fact that the long period of time that has to elapse before daughter information is available serves to lower the accuracy of the cow index per generation or year.

Computation of the genetic merit of a cow involves, first and foremost, correcting for all environmental and other factors (Fig. 2) that systematically influence milk production. These include herd, age at calving, parity, year and season of calving as well as any significant interactions between any two of these factors, such as the interaction between herd and season of calving.

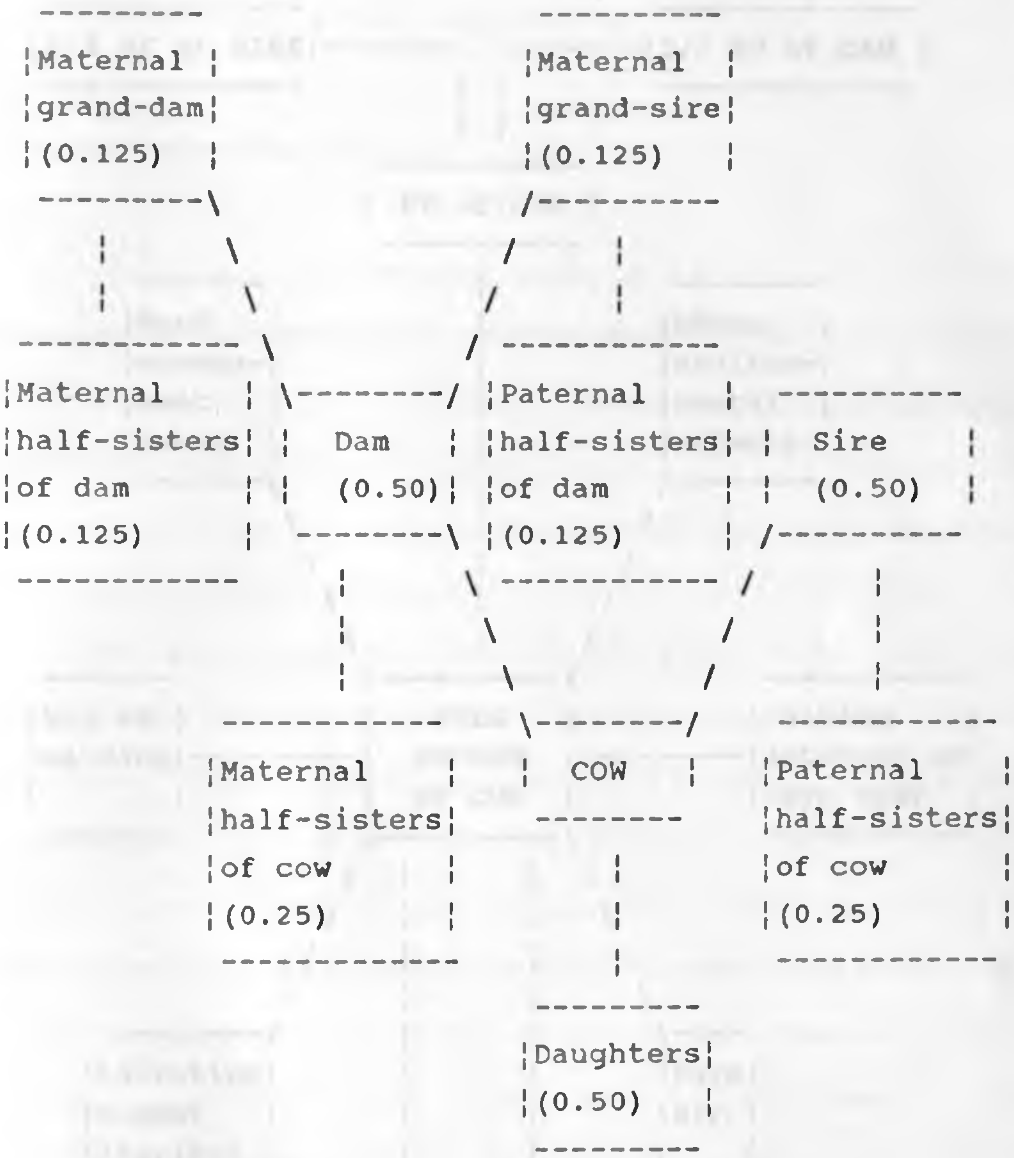

Fig. 1: Possible sources of information for a cow genetic index (in brackets = coefficient of relationship with the cow)

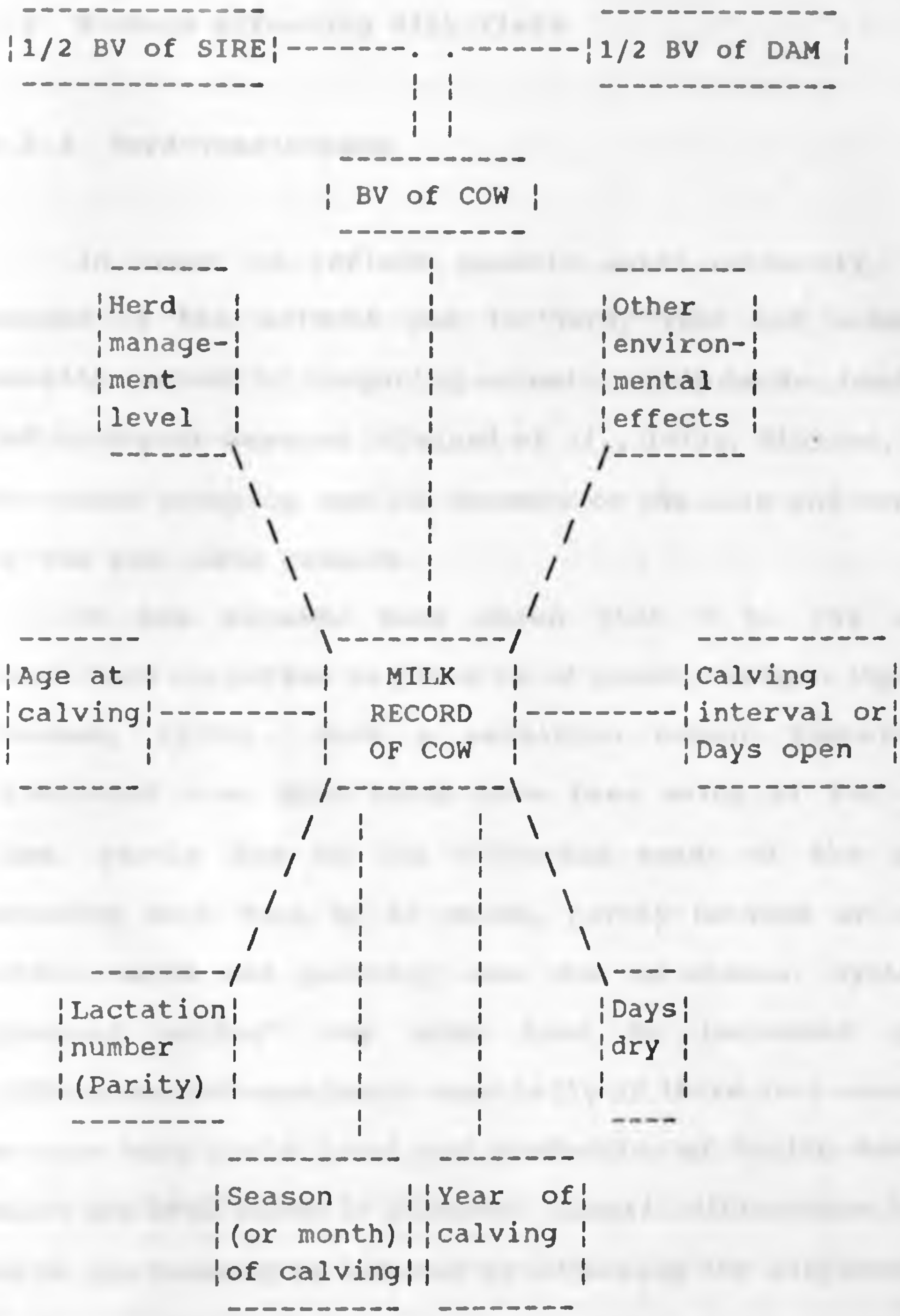

Fig. 2: Some of the factors affecting the milk record of a cow

2.2 Factors affecting Milk Yield

2.2.1 Herd-Year-Season

In order to reflect genetic merit correctly, biases caused by the effects due to herd, year and season are usually reduced by comparing animals within herds, herd-years and herd-year-seasons (Fimland *et al.*, 1972a; Hickman, 1975). The exact grouping applied depends on the size and structure of the available records.

It has already been shown that 5 to 15% of the inter-herd variation in yield is of genetic origin (Spike and Freeman, 1976b). Such a variation cannot therefore be eliminated even when herds have been using AI for a long time, partly due to the differing usage of the general breeding work done by AI studs, partly because of culling within herds and possibly even due to chance. Systems of "planned mating" may also lead to increased genetic differences between herds especially if there is a connection between herd yield level and production of "elite dams" for which the best semen is reserved. Genetic differences between herds can however be reduced by adjusting for differences in herd genetic levels.

Herd-year-seasons accounted for about 37% of the total variation of 305-day milk yield in a study using all lactations of Jamaica Hope cows raised in the tropical environment of Jamaica (Abubakar *et al.*, 1986). This concurs with the finding that herd in itself accounts for about 30 to 40% of the total variation among individual yield records in a population found in temperate regions (Van Vleck, Wadell and Henderson, 1961). Both environmental and genetic factors have been reported to explain this observation (Bereskin and Freeman, 1965; Philipsson *et al.*, 1978). The former is attributable to differences of nutrition and management practices within individual herds (Fimland *et al.*, 1972a) while the latter is due to differences in breeds and genetic constitution of individual animals.

In Kenya, several studies have reported the effects of herd as well as year and season of calving on milk yield of Friesian cattle. Lindstrom and Solbu (1978) and Mosi (1984) reported significant ($P<0.001$) effects of herd-year-season of calving, while Rege and Mosi (1989) found the effects of year and season of calving on 305-day milk yield significant ($P<0.01$) and non-significant respectively. Kiwuwa (1974) did also find non-significant seasonal differences in milk yield. Similar results were reported for Kenyan Sahiwal cattle by Kimenye (1978), Mwandotto (1985) and Wakhungu (1988).

Generally speaking, varying effects of herd-year-season on milk yield may be due to differences in breeds, herd management, season definitions and the number of years and lactation records included in the analyses as well as changes in climatic conditions and therefore availability of pasture.

Appropriate correction for herd as well as year and season of calving should therefore be done in analyses involving several herds, years and seasons.

2.2.2 Parity

Parity, otherwise known as lactation number, has got a remarkable influence on milk yield. Milk yield increases with parity at decreasing rates until its maximum, when maturity in growth and udder development is achieved (Mahedevan, 1966; Kiwuwa, 1973), and thereafter decreases at increasing rates with advancing parity (Johansson, 1961). Generally speaking, the rates of increase in milk yield from the first to the third parities are around 10 to 15% for *Bos indicus* and about 25 to 30% for *Bos taurus* breeds (Ngere, 1970).

European dairy cows tend to reach peak production in later parities because of early age at first calving. Phipps (1973), Kiwuwa (1974), Lindstrom and Solbu (1978), Mosi (1984) and Rege and Mosi (1989) did not only demonstrate that parity has a significant ($P<0.01$) effect on milk yield of European dairy cows but also that peak production can occur in later parities (5th or 6th) under tropical environments. Romero *et al.* (1986) did however find a non-significant variation in parity of Holsteins in Puerto Rico.

It is evident, from the above, that milk yield by the same cow changes with parity. Consequently parity should always be corrected for in any analysis involving dairy records with multiple lactations.

2.2.3 Age at Calving

In order to estimate the specific effects of age, a distinction must be made between parity and the actual age of a cow at calving. This is achieved by, 1) grouping dairy records according to age within parity, and 2) comparing records of the same cow in successive years (Syrstad, 1965). However, age at first calving is more important than that at any subsequent calving because of its direct influence on 1) the lifetime production of a healthy cow, and 2) how early in life an animal's BV may be estimated (Kiwuwa, 1968).

According to Ronningen (1967), age at calving accounted for 4% and 2.25% of the total variation in milk yield of Norwegian cattle in first and second lactations respectively. Fimland *et al.* (1972) on the other hand estimated that age at calving accounted for 3% of the total variation in milk yield of Israel Friesian cattle in the first two lactations.

Kiwuwa (1974), Maarof (1980), Mosi (1984) and Parekh and Singh (1987) observed a significant ($P<0.05$) effect of age at calving on milk yield in the first three lactations, first lactation, first two lactations and first lactation respectively. Lindstrom and Solbu (1978) did however estimate a non-significant age effect on milk yield in the first two lactations while Barker and Robertson (1966) suggested that the specific effect of age on milk yield in the first three lactations of Friesian cows appear to be too small to justify the use of a correction factor.

It should however be noted that parity, especially in herds under sound management, usually suggests the age of the cow at calving and adjusting for both might be superfluous. A lot of caution should therefore be exercised whenever such adjustments are being made. For instance, when parity is corrected for, the effect due to age at calving could perhaps be investigated as a within-parity component. Otherwise, varying effects of age at calving on milk yield may be due to differences in breed and herd management.

2.2.4 Calving Interval

Simply put, calving interval is the period between two consecutive calvings. Previous calving interval precedes the lactation in question while the current calving interval runs concurrently with the same lactation.

Calving interval comprises both the service and gestation periods, whereupon the latter shows little variation in cattle (Mahedevan, 1966). The service period does, therefore, seem to be the main factor underlying the effects of calving interval on dairy traits.

According to Johansson (1961), the length of both current and preceding calving intervals significantly affect milk yield of the present lactation. As a result, he suggested that the effect so introduced by calving interval be reduced by averaging several lactation records per cow. Kiwuwa (1974), Shinde, Nawarade and Chavan (1981), on the other hand, found a non-significant phenotypic correlation between current calving interval and first lactation milk yield. However, the correlation coefficient estimated between the second lactation milk yield and the preceding calving interval was highly significant.

In Kenya, Lindstrom and Solbu (1978) reported a significant effect of preceding calving interval on milk production in current lactation in that cows with calving intervals shorter than 608 days produced 100 kg less milk than the population average while those with calving intervals of 608 to 912 and over 912 days respectively produced 84 and 24 kg more milk. The optimum calving interval under Kenyan conditions should be about 365 days (Elving, Githendu and Osinga, 1974).

The length of calving interval and therefore its influence on milk yield does seem to depend on the breed, herd breeding policy and also the individual cow herself. These factors bring about differences in the various components of calving interval namely lactation length and dry and service periods. Consequently, dairy records should be adjusted for the effect of calving interval.

2.3 Genetic and Phenotypic Parameters of Milk Yield

2.3.1 Heritability

The first essential step in the application of genetics to livestock improvement is to determine the heritabilities of the characters it is desired to improve. This is necessary for the purposes of predicting breeding values of individuals, formulating effective breeding plans and also for predicting response from selection. Heritability, whose narrow sense expresses the proportion of the average effect of genes, could indeed be said to be the cornerstone upon which much of quantitative genetics theory, practice and accomplishment is built (Hohenboken, 1985).

Heritability determination may be carried out either by measuring the extent to which differences between animals are, on the average, exhibited in their offspring or variation between animals as judged on their offspring. In the case of dairy characteristics, the two approaches are illustrated by the daughter-dam regression and the paternal half-sib correlation methods.

Heritability estimates of dairy production traits are influenced by such factors as the method of estimation (Bradford and Van Vleck, 1964; Van Vleck and Bradford, 1965), differences in the intensity of selection between the two sexes particularly in AI bred populations (Harville, 1970), level of herd production in that heritabilities of yield traits increase with the herd average production level (Averdunk and Alps, 1971; Maijala and Hanna, 1974; Danell, 1982; Hill *et al*., 1983), and the number of progeny per sire per herd (Van Vleck, 1966; Lindstrom and Solbu, 1978).

Table 1 gives some of the reported heritability estimates of milk yield in dairy cattle. Most of them are higher in the first than in second and third lactations (Freeman, 1960; Barker and Robertson, 1966; Tong *et al*., 1979; Powell and Norman, 1981; Mosi, 1984). Fewer are higher in the second or third lactation than in the first (Barr and Van Vleck, 1963; Molinero and Lush, 1964; Fimland *et al*., 1972). Ragab *et al*. (1973) and Romero *et al*. (1986) reported estimates of 0.26 and 0.24 respectively, on first lactation records, while Rege and Mosi (1989) reported an estimate of 0.19 on all lactation records.

Table 1: Reported estimates of heritability for milk yield in dairy cattle

Source	Country	Breed	Analysis method	Lactation 1	2	3
Freeman, 1960	USA	Holstein (H)	Daughter-dam regression (DD)	0.33	0.22	0.33
Barr and Van Vleck, 1963	USA	H	Half-sib Correlation (HS)	0.31	0.38	
Molinero and Lush, 1964	USA	H	DD	0.16±0.03	0.23±0.05	
Baker and Robertson, 1966	Britain	Friesian (F)	HS	0.21	0.18	
Fimland *et al.*, 1972	Israel	F	HS	0.17±0.04	0.24±0.08	
Ragab *et al.*, 1973	Egypt	F	HS	0.26±0.14		
Tong *et al.*, 1979	Canada	H	HS	0.25	0.20	
Powell and Norman, 1981	USA	H	HS	0.36	0.24	0.26
Mosi, 1984	Kenya	F	HS	0.19±0.04	0.15±0.04	0.15±0.05
Romero *et al.*, 1986	Puerto Rico	H	Henderson's Method 1	0.24		
Rege and Mosi, 1989	Kenya	F	HS	0.188 for all (1-5, 6+) lactations		

The reviewed literature show that heritability values for 305-day milk yield for the same breed vary due to differences in the country of study, method of analysis and the number of lactations and dairy records included in the analysis. All in all, the average heritability value of 0.25 for milk yield in dairy cattle is widely used.

2.3.2 Repeatability

One of the most important parameters in the analysis of milk production, and one very simply calculated, is the correlation between performance in different lactations of the same animal, often given the name "repeatability". This measures the proportion of the variation between animals within herds, which is common to the lactations concerned and therefore includes all hereditary differences (which affect both lactations alike) as well as some environmental similarities. The repeatability value found in literature usually refers to the average correlations over a series of lactations and can therefore be considered as the proportion of the total variation due to differences between cows which persist over all the lactations concerned.

Table 2 gives some of the reported estimates of repeatability. Lindstrom and Solbu (1978), for instance, reported a repeatability estimate of 0.24. Others like Abubakar *et al.* (1986), Romero *et al.* (1986), Parekh and

Singh (1987) and Rege and Mosi (1989) reported estimates of 0.45, 0.56, 0.50 and 0.49 respectively. Kimenye (1978) and Wakhungu (1988) reported estimates of 0.43 and 0.46 respectively in the Kenyan Sahiwal cattle. On the average, repeatability for milk yield in dairy cattle is 0.45.

It would appear, from the above, that differences in the country of study, breed, method of analysis and the number of lactations and dairy records used give rise to different repeatability values. It might, therefore, be that repeatability is population specific and should, if required, be estimated from the data being analysed.

Table 2: Reported estimates of repeatability for milk yield in dairy cattle

Source	Country	Breed	Analysis method	Estimate
Lindstrom and Solbu, 1978	Kenya (K)	Friesian (F) Ayrshire, Guernsey, Jersey, etc.	-	0.24
Kimenye, 1978	K	Sahiwal(S)	-	0.43
Abubakar <u>et al</u>., 1986	Jamaica	Jamaica Hope	Henderson's Method 3 (HM3)	0.45 (within herd-year-seasons)
Romero <u>et al</u>., 1986	Puerto Rico	Holstein	HM3	0.56
Parekh and Singh, 1987	India	Friesian half-breds	-	0.50±0.05
Wakhungu, 1988	K	S	-do-	0.46±0.02
Rege and Mosi, 1989	K	F	Harvey's Least-Squares Procedure	0.487

2.4 Types of Cow Indices

There are principally two different types of cow indices as given here below.

2.4.1 Genetic Index

This index, which is often expressed as breeding value, relative breeding value, predicted difference or estimated transmitting ability, reflects the expected genetic merit of a cow. It may be a more or less complete selection index utilizing varying amounts of information from the relatives and the cow herself in relation to her herdmates, and about the genetic level of the herd in relation to the population in question. Each source of information is weighted by factors obtained by solving normal index (linear) equations like those in Section 2.5.8. The factors, referred to as partial regression coefficients or index weights or weighting factors, differ for various combinations of information. Noteworthy also is the fact that the index takes into account all factors that systematically influence milk production. In other words, individual lactation records are adjusted for all possible sources of variation such as herd, age at calving, lactation number, days open, year and season (or month) of calving. The index so computed is therefore a reliable basis for identifying the best cows to produce bull calves and heifer replacements.

2.4.2 Production Index

This index, often expressed as estimated producing ability, either as an absolute or relative value, reflects the expected production capacity of a cow. It predicts the most probable producing ability of a cow based on information about her previous lactations. Repeatability is used instead of heritability in its computation. More sophisticated analytical procedures may also show the expected effects of calving interval and season or month of calving on the next lactation. The index should mainly be used as a within-herd culling guide.

2.5 Methods of Cow Evaluation

In this section, some methods of dairy cow evaluation which have been used practically in various breeding schemes worldwide are reviewed.

2.5.1 Most Probable Producing Ability

The Most Probable Producing Ability (MPPA) gives the expected future performance of an animal based on its available records. It is applicable to traits, such as milk yield, which can be measured more than once. According to Lush, J.L. (1945),

$$MPPA = \overline{H} + \{nr/[1+(n-1)r]\}\{\overline{Y}_n-\overline{H}\}$$

where, $\overline{H}$ is the herd average performance,

$\overline{Y}_n$ is the animal's average milk yield of n lactations,

n is the number of lactation records by the animal,

and r is the repeatability of the trait under study, that is, milk yield.

However, in order to account for seasonal variations in herd average, particularly in dairy production, this expected future performance may alternatively be expressed thus:

$$MPPA = \{nr/[1+(n-1)r]\}\{\Sigma(Y_i-\overline{Y}_{Ci})/n\}$$

where, n and r are as described above,

Y_i is the i^{th} record of the animal, and

$\overline{Y}_{Ci}$ is the average of the animal's contemporaries.

MPPA is widely used in beef cattle for culling poor breeding cows. In dairy cattle, however, it may be used for not only culling purposes but also for the initial selection of the cows to be subjected to further evaluation. It should never be used for selecting bull-dams, since it is not a genetic index, and cannot also be used across herds.

2.5.2 Johansson's Cow Index (I_1)

Johansson's Cow Index (Johansson, 1961) is based on a cow's own performance estimated within herd. It is calculated by applying the formula:

$$I_1 = h^2(P_x - \overline{A}) + \overline{A}$$

where, h^2 is the heritability of the trait (milk yield in this case),

P_x is the within herd, year and season performance of cow X, and

$\bar{A}$ is the average performance of herdmates within year and season of calving.

The index is a simplification of expected breeding value (Section 3.6), where the deviation of records from the average are weighted by heritability. It predicts a cow's breeding value within herd and may, therefore, be used for intra-herd cow selection.

2.5.3 Index utilizing cow and sire performances (I_2)

This index utilizes a cow's own performance and that of her sire's progeny. It is computed according to Skjervold, (1962) as:

$$I_2 = \frac{0.84h^2(P_x-\bar{A})+0.1(\bar{A}-\bar{P})100}{\bar{P}+(0.5-0.4h^2)(S-100)+100}$$

where, P_x, $\bar{A}$ and h^2 are as described above,

$\bar{P}$ is the population mean, and

S is the sire's progeny performance in percent of the herdmate evarage.

Unlike I_1 above, I_2 can also be used for between-herd comparison of cows.

2.5.4 Norwegian Cow Index (I_3)

The Norwegian Cow Index (Syrstad, 1971) is based on a cow's average annual performance, the relative breeding values of her parents (sire and dam), and the corresponding herd yield and breed average. It is computed in accordance with the formula:

$$I_3 = [b_C(C-H)+b_H(H-B)]100/B + b_{SD}(RBV_S+RBV_D-200) + 100$$

where, C is the average annual fat-corrected milk yield (kg) of the cow,

H is the corresponding average herd yield,

B is the corresponding breed average,

RBV_S and RBV_D are the relative breeding values of sire and dam respectively,

b_C and b_{SD} are the weighting factors for information about the cow and her parents respectively, and

b_H is the weighting factor for genetic differences between herds.

The index, which reflects the cow's relative breeding value, can be used for comparing and selecting cows both within and across herds. The inclusion of both herd and breed averages in the index make the latter application possible.

2.5.5 Danish Cow Index (I_4)

The Danish Cow Index (Ovesen, 1971) utilizes a cow's own lactational performance, the relative breeding values of her parents, and the corresponding herd and breed average. It is calculated thus:

$$I_4 = k_1(P_1-H_1) + b_1(H_1-B_1) + k_2(P_2-H_2) + b_2(H_2-B_2) + k_3(P_3-H_3) + b_3(H_3-B_3) + k_D(RBV_D-100) + k_S(RBV_S-100) + 100$$

where, P_1, P_2 and P_3 are the corrected fat yield of the 1st, 2nd and 3rd 305-day lactations,

H_1, H_2 and H_3 are the corresponding herd averages consisting of corrected 305-day lactations,

B_1, B_2 and B_3 are the corresponding breed averages,

RBV_S and RBV_D are as described above,

k_1, k_2, k_3, k_S and k_D are the weighting factors for information about the cow, her sire and dam, and

b_1, b_2 and b_3 are the weighting factors for genetic differences between herds.

This index reflects the cow's relative breeding value and offers a reliable basis for selecting cows across herds.

2.5.6 Swedish Cow Index (I_6)

The Swedish Cow Index (Gustafson *et al.*, 1975) gives an estimate of a cow's relative breeding value, for milk production, with a mean of 100. The main purpose of the index is to facilitate an intensive selection of cows suited to produce bull calves, potential for AI use. It is calculated according to the formula:

$$I_6 = k_C[b_n(C-HA) + 0.1(HA-BA)]/BA*100 + k_S(I_S-100) + k_D(I_D-100) + 100$$

where, C is the average of the cow's adjusted lactations,

HA is the average of the cow's herdmates,

BA is the regional breed average,

b_n is the heritability of an average of n adjusted lactations,

0.1 is the heritability of herd yield differences,

I_S is the sire's index adjusted for genetic trend,

I_D is the dam's cow index,

k_C, k_S and k_D are partial regression coefficients.

The index combines information about the cow, her parents, herdmates and breed and may be used for selecting cows across herds.

2.5.7 USDA-DHIA Cow Index (I_5)

This index combines weighted information about a cow and her sire (Powell, *et al.*, 1976):

$$I_5 = 1/2[w(\text{cow's } \overline{\text{MCD}}') + (1-w)\text{sire's PD}]$$

where, cow's $\overline{\text{MCD}}'$ is the cow's modified mean contemporary deviations including genetic merit of sires of her contemporaries,

sire's PD is the sires predicted difference, and

w is the weighting factor for information about the cow.

The index, which expresses the cow's transmitting ability, offers a reliable and broader basis for cow selection.

2.5.8 Scottish Cow Index (I_7)

The Scottish Cow Index (Scottish Milk Marketing Board, 1976), which represents the cow's breeding value, is estimated as:

$$I_7 = b_1\overline{P}_C + b_2\overline{P}_M + b_3\overline{P}_{MHS} + b_4\overline{P}_{PHS} + b_5\overline{P}_D$$

where, b_1 to b_5 are partial regression coefficients,

$\overline{P}$ (the mean performance of an individual relative to its herdmates)

$= [w_1(y_1-\overline{Y}_1) + w_2(y_2-\overline{Y}_2) + \ldots + w_n(y_n-\overline{Y}_n)]/\Sigma w$,

$w = N_2/N_2+1$ and N_2 denotes the number of contemporary records,

y_1 to y_n are the first to the nth records of the animal in question, and

$\overline{Y}_1$ to $\overline{Y}_n$ the corresponding mean performance of the contemporaries.

The $\overline{P}$ values are computed in this manner for the cow (C) herself and for her maternal half-sisters (MHS), her dam (M) and her daughters (D). For paternal half-sisters (PHS), the sire's transmitting ability (contemporary comparison) rating is used.

The b coefficients are, in this case, derived by solving the following linear equations:

	Cow	Dam	MHS	PHS	Daughters		
Cow	$d_{11}b_1$	$+1/2h^2b_2$	$+1/4h^2b_3$	$+1/4h^2b_4$	$+1/2h^2b_5$	=	h^2
Dam	$1/2h^2b_1$	$+d_{22}b_2$	$+1/2h^2b_3+$	$(0)b_4$	$+1/4h^2b_5$	=	$1/2h^2$
MHS	$1/4h^2b_1$	$+1/2h^2b_2+$	$d_{33}b_3$ +	$(0)b_4$	$+1/8h^2b_5$	=	$1/4h^2$
PHS	$1/4h^2b_1+$	$(0)b_2$ +	$(0)b_3$ +	$d_{44}b_4$	$+1/8h^2b_5$	=	$1/4h^2$
Daughters	$1/2h^2b_1$	$+1/4h^2b_2$	$+1/8h^2b_3$	$+1/8h^2b_4+$	$d_{55}b_5$	=	$1/2h^2$

whereby the fractions are the additive relationships between the candidate cow and its relatives. Noteworthy also is that equations corresponding to missing sources of information are ignored.

The diagonal elements (d_{ii}) are obtained as follows:

$$d_{ii} = [[1+(n_i-1)r]/n_i + (P_i-1)a_{P_iP_i}h^2]/P_i$$

where, h^2 is the heritability for milk yield,

r is the repeatability for milk yield,

n_i is the number of records,

P_i is the number of animals in the group, e.g. the number of PHS, and

$a_{P_iP_i}$ is the additive component of relationship within the group, e.g. 1/4 in the case of half-sisters.

The inclusion of information from the five sources namely the cow herself and her dam, maternal half sisters, paternal half sisters and daughters greatly improve the accuracy of this index. But due to the long period of time that has to pass before a daughter record is available, it is not advisable to wait for such a record. Nevertheless, the index offers a reliable basis of cow selection across herds whether the daughter record is included or not.

2.5.9 Cow Genetic Index (I_8)

Cow genetic index (CGI) was jointly developed, by the Scottish Milk Marketing Board, Milk Marketing Board of England and Wales, British Friesian Cattle Society and the Department of Agriculture of Northern Ireland, for its universal use in the United Kingdom (Milk Marketing Board of England and Wales).

The index is only computable for pedigree cows since its computation requires the following sources of information:

1) The cow's own records: lactations 1 to 5.
2) The proof, i.e. Improved Contemporary Comparison (ICC) of her sire.
3) The index (CGI) of her dam.
4) The average genetic level of the herd at the time of indexing.

The inclusion of the genetic level of the herd (HGL) is necessary in order that cows and herds are ranked relative to a national base.

Individual cow indices can be calculated for yield of milk, fat and protein to give figures that are directly comparable with an ICC value of a bull. These figures are therefore thought of as cow ICCs.

The index (CGI) takes the form:

$$I_8 = (b_1Cow1 + b_2Cow2 + b_3Sire + b_4Dam) + HGL$$

where, b_1 to b_4 are index weights,

Cow1 is the cow's 1st lactation deviation from heifer herdmates,

Cow2 is the cow's 2nd and later lactation average deviated from herdmate average,

Sire = Sire ICC - Average Sire ICC of herdmates,

Dam = Dam's Index - Average Dam Index of herdmates,

HGL = $1/2(\overline{X}_{Dam\ Index} + \overline{X}_{Sire\ ICC})$,

$\overline{X}_{Dam\ Index}$ is the average Dam Index in the herd, and

$\overline{X}_{Sire\ ICC}$ is the average Sire ICC in the herd.

This index can, however, be modified to take care of other comparable methods of sire evaluation by replacing the sire ICC with the transmitting ability of the sire obtained by the sire evaluation method in use.

2.5.10 Best Linear Unbiased Prediction (BLUP): The Animal Model

Use of the animal model (Henderson and Quass, 1976) is the most advanced procedure for evaluating sires and cows. And although it is demanding in terms of data structure and computation, it has desirable properties of the BLUP procedure. The reduced animal model (RAM) developed by Quass and Pollak (1980) gives identical solutions to the animal model and is less demanding computationally. The RAM separates parents from non-parents and, by absorbing equations for non-parents into parents, allows solving larger equations when supercomputers are not available. The primary advantage of the animal model applied to dairy cattle evaluation is that the inverse relationship matrix (A^{-1}) includes the relationships of all animals being evaluated. In addition to sires with progeny distributed across herds, A^{-1} includes relationships of daughters to female relatives in all herds. Merit of potential bull-dams is more accurately estimated in the animal model. Use of all relationships in the animal model can improve bull-dam evaluations because some cows have several sons by embryo transfers and their daughters are potential bull-dams. The animal model, with the addition of a permanent environment effect, can include multiple lactations for evaluating a single trait.

The obvious starting point is to write down a model of the data taking account of all the problems of relatedness, selection, the environment and its interaction with genotype. Rather than describing the animal's record in terms of, say, sire and dam effects, it may be described in terms of a genetic model, for example,

$$Y_{ijkl} = \mu+\beta_i+A_{jk}+C_j+E_{ijkl}$$

where, μ and β_i represent (fixed) environmental effects,

A_{jk} represents the breeding value of the animal,

C_j common environment effects of sibs, and

E_{ijkl} individual error.

This could obviously be extended to include dominance, epistasis, maternal genetic effects, common environmental effects of repeated records, and so on. The records on a group of individuals, whether of the same or of different generations, are then described jointly by the incidences (presence/absence) of the fixed effects and by the covariances of the random genetic and environmental components. The whole set of observations y can be described in matrix terms as:

$$\underline{y} = X\underline{\beta}+Z\underline{\mu}+\underline{e}$$

where, X represents the incidence matrix of the fixed effects β, and Z is the incidence matrix of the random effects μ. X and β can be divided into blocks representing, say, years, herds, etcetera, and also include any covariates fitted. Correspondingly, Z and μ can be divided into parts representing breeding values and common environment effects. The vector of random residual errors, e, is usually written separately but could be incorporated in μ. Commonly, elements of e are assumed to be independent for all observations.

If animals' genetic merit is the only random classification in the model, that is if there are no common environmental effects,

$$\text{Var}(y) = ZAZ'\sigma^2_A + \underline{I}\sigma^2_E$$

where A is the numerator relationship matrix between animals.

Following Henderson (1973), it can be shown, for this case, that

$$\begin{bmatrix} X'X & X'Z \\ Z'X & Z'Z+A^{-1}\sigma^2_E/\sigma^2_A \end{bmatrix} \begin{bmatrix} \hat{\underline{\beta}} \\ \hat{\underline{\mu}} \end{bmatrix} = \begin{bmatrix} X'\underline{y} \\ Z'\underline{y} \end{bmatrix}$$

These BLUP equations, often called the "mixed model equations", can be solved on a computer. It is, however, important to note that use of the animal model only became feasible when a quick direct method was developed to find A^{-1} which requires neither calculation nor inversion of A (Henderson, 1976). In the example given above, μ includes additive genetic and common environment effects. Assuming these are uncorrelated, the variance-covariance matrix of the observations is

$$Var(y) = Z \begin{bmatrix} \sigma^2_A A & 0 \\ 0 & \sigma^2_C C \end{bmatrix} Z' + \underline{I}\sigma^2_E$$

where Z now consists of two parts pertaining to the breeding values, A_{jk} and environmental effect, C_j, respectively.

The above literature on methods of cow evaluation gives an account of the developments in dairy cow evaluation. It shows how evaluation of dairy cows evolved from a very humble beginning to what it is at present and leaves no doubt in my mind that BLUP is the most accurate and therefore appropriate method of evaluating and ranking dairy cows according to their genetic merit. BLUP should therefore be adopted, where technically possible, as the method of evaluating dairy cows for selection.

3 MATERIALS AND METHODS

3.1 Source of the Data

The data for this study was in form of lactation records made by Friesian cows at Sasumua Estate Farm, located at the bottom of the Rift Valley, from 1966 to 1987. It was compiled by the Livestock Recording Centre in Naivasha from the cow files available at the Kenya Milk Records office in Nakuru.

The farm, where the data originated, is situated in a high potential area that receives an average annual rainfall of about 940 mm (Appendix 1). The annual rainfall totals, which spans a period of 22 years (1966 to 1987), was recorded at Njoro Plant Breeding Research Station which borders the data source farm. The rainfall exhibited a bimodal pattern over the period in that it had two peak periods separated by relatively dry periods. Average monthly rainfall ranged from about 30 mm (January) to about 150 mm (April) over the same period.

The cows were grazed on natural pastures *ad libitum*. Feed supplementation, largely with hay, was only done during the relatively dry period (January, February, June, July, August, September and December). Prophylactic (preventive medicine) practices, such as dipping and vaccinations, were carried out regularly particularly against tick-borne diseases.

The herd was mostly served by AI, with semen imported by the farm, and, to a lesser degree, natural service. Calving was all-the-year-round but with majority of the calves born during the relatively dry months according to the season-calving distribution (Table 7).

The cows were hand-milked twice (morning and evening) daily. The milk produced by each cow was recorded at each milking.

3.2 Data Format

Each cow lactation record contained the following information:

Field No.	Field Name
1	Farm code
2	Cow code
3	Breed code
4	Date of Birth (DD/MM/YY)
5	Number of Tests for Butter-fat
6	Calving interval (in days)
7	Cow Name
8	Cow's Sire Code
9	Cow's Sire Name
10	Lactation Number

11	Calving Date (DD/MM/YY)
12	Actual Milk Yield in kg
13	Days in milk
14	Butter-fat percent
15	Estimated 305-day MY

3.3 Data Editing and Preparation

All the records without a cow code, calving interval, sire code, lactation number, calving date, actual milk yield and/or days in milk were edited out. This was then followed by the removal of the farm and breed codes, date of birth, number of tests for butter-fat, cow and sire names and butter-fat percent from each of the remaining lactation records. Records of lactations shorter than 100 days (McDowell, 1972; Madalena, 1988) were also removed as well as those of lactations, other than parity 1, with a preceding calving interval of less than 298 days, beyond the tenth and from sires with less than five daughters. Out of an original of 3755 lactation records, 2865 remained after the editing.

The estimated 305-day milk yield (Est. 305-d MY) values were then recalculated by regressing the actual milk yield (AMY) on the lactation length, that is, days in milk (DIM) (Madalena, 1988), thus

Est. 305-d MY = (AMY/DIM) * 305

This was done on the assumption that all the cows involved in this analysis had the genetic potential of producing milk for at least 305 days. Besides, heritabilities and repeatabilities are relatively unaffected by lactation length and extension of records to 305 days (Abubakar *et al.*, 1986).

Season of calving was derived from the date of calving. There were three calving seasons defined according to Rege and Mosi (1989) as: Season 1: Long rains from March to May, Season 2: Short rains from October to November, and Season 3: Dry period represented by the rest of the year.

3.4 Statistical Analyses

Harvey's Mixed Model, Least-squares and Maximum Likelihood Computer Programme (Harvey, 1987) was used in the analysis using statistical models with parity, year and season of calving as the fixed effects. The programme also estimated heritability, repeatability, sire transmitting abilities as well as cow solutions. The F-values in the ANOVA table gave the level of significance of each of the fixed effects. The standard errors of the heritability and repeatability estimates were computed according to Becker (1967).

All the lactation records were corrected for each of the fixed effects using least-squares constants. To compute one of the cow indices namely the "adjusted least squares mean" for each cow, the corrected records were averaged over the parities of the cow.

Panacea (Pan Livestock Services Ltd., 1989) was used for computing the other three cow indices (Section 3.7), as well as rank correlations between and standard deviations within the four indices.

The following mixed statistical model (Model 1) was fitted to all the qualifying records:

$$Y_{ijklmn} = \mu + YR_i + SN_j + P_k + s_l + c_{lm} + e_{ijklmn}$$

where, Y_{ijklmn} is the n^th^ 305-day milk yield (kg) record of the m^th^ daughter (cow) of the l^th^ sire freshening her k^th^ parity in the j^th^ season of the i^th^ year,

μ is an underlying constant common to all records,

YR_i is a fixed effect due to year of calving,

SN_j is a fixed effect due to season of calving,

P_k is a fixed parity effect,

s_l is a random sire effect, common to all daughters of the l^th^ sire, with mean zero and variance σ^2_s ,

c_{lm} is a random effect, common to all records of the m^{th} daughter of the l^{th} sire, with mean zero and variance σ^2_c , and

e_{ijklm} is a random error effect, associated with each observation, with mean zero and variance σ^2_e.

3.4.1 Estimation of heritability and Non-genetic (fixed) effects

Model 1 was fitted to the data whose structure is set out in Table 3 as a mixed model with one set of cross-classified and another of nested non-interacting random effects (Harvey, 1987) to, among other things, give estimates of the heritability of 305-day milk yield and the fixed effects. A paternal half-sib method was used to compute the heritability estimate ($\hat{h}^2$) thus:

$$\hat{h}^2 = 4\hat{\sigma}^2_s/(\hat{\sigma}^2_s + \hat{\sigma}^2_c + \hat{\sigma}^2_e)$$

where, $\hat{\sigma}^2_s$ is the sire variance estimate,

$\hat{\sigma}^2_c$ is the cow variance estimate, and

$\hat{\sigma}^2_c$ is the error (environmental) variance estimate.

The standard error of the $\hat{h}^2$[S.E.($\hat{h}^2$)] was, on the other hand, computed according to Becker (1967) thus:

$$S.E.(\hat{h}^2) = 4\sqrt{\frac{2(n.-1)(1-t)^2[1+(k-1)t]^2}{k^2(n.-s)(s-1)}}$$

where, n. is the total number of daughters (cows),

s is the number of sires,

$t = 0.25\hat{h}^2$, that is, the intra-class correlation,

$k = (s-1)^{-1}[n.-(\Sigma n^2_i)/n.]$, and

n_i is the number of daughters of the i^{th} sire.

Table 3: Data structure for analysis with Model 1

		Average per subclass	
		Cows	Lactation Records
Total lactation records	2865		
No. of cows (daughters)	922		3.1
No. of sires	41	22.5	69.9
Years	22	41.9	130.2
Seasons	3	307.3	955.0
Parities	1-10		

3.4.2 Estimation of Repeatability

The repeatability estimate ($\hat{r}$) was obtained by fitting the following mixed model (Model 2), to the data whose structure is set out in Table 4. The model had one set of cross-classified non-interacting random effects:

$$Y_{ijkl} = \mu + YR_i + SN_j + c_k + e_{ijkl}$$

where, Y_{ijkl} is the l^{th} 305-day milk yield (kg) record of the k^{th} cow calving in the j^{th} season of the i^{th} year,

μ, YR_i and SN_j are as described in Model 1,

c_k is a random effect, common to all records of the k^{th} cow, with mean zero and variance σ^2_b, and

e_{ijkl} is a random error effect, associated with each observation, with mean zero and variance σ^2_w.

The repeatability computation was in accordance with the formula (Miller et al., 1966):

$$\hat{r} = \hat{\sigma}^2_b/(\hat{\sigma}^2_b + \hat{\sigma}^2_w)$$

where, $\hat{r}$ is the repeatability estimate,

$\hat{\sigma}^2_b$ is the between cow variance estimate, and

$\hat{\sigma}^2_w$ is the within cow variance estimate.

On the other hand, the standard error of the repeatability estimate [S.E.($\hat{r}$)] was computed according to Becker (1967):

$$S.E.(\hat{r}) = \sqrt{\frac{\{2(m.-1)(1-\hat{r})^2\{1+(k_1-1)\hat{r}\}^2\}}{k^2_1(m.-c)(c-1)}}$$

where, S.E.($\hat{r}$) and $\hat{r}$ are as explained above,

m. is the total number of observations,

c is the number of cows, and

$k_1 = (c-1)^{-1}[m.-(\Sigma m^2_i)/m.]$

Table 4: Data structure for analysis with Model 2

		Average per subclass	
		Cows	Lactation Records
Total lactation records	2865		
No. of cows (daughters)	956		3
Years	22	41.9	130.2
Seasons	3	307.3	955.0

3.5 Sire and Cow Evaluation

The best linear unbiased prediction (BLUP) procedure (Harvey, 1987) was used for evaluating the bulls as well as their daughters by fitting Model 1 which, in matrix notation, can be written as:

$$\underline{y} = X\underline{\beta} + Z\underline{\mu} + \underline{e}$$

where, $\underline{y}$ is a vector of known dependent variables,

X is the incidence matrix for fixed effects,

Z is the incidence matrix for random effects due to sires and cows,

$\underline{\beta}$ is an unknown vector of fixed effects,

$\underline{\mu}$ is an unknown vector of random effects due to sires and cows, and

$\underline{e}$ is a vector of the random error effects

On the other hand, the expectation (E) and variance (Var) of the observations (Jansen *et al.*, 1987) are, respectively,

$$E\begin{bmatrix}\underline{y}\\ \underline{\mu}\\ \underline{e}\end{bmatrix} = \begin{bmatrix}X\underline{\beta}\\ \underline{0}\\ \underline{0}\end{bmatrix}, \text{ and}$$

$$\mathrm{Var}\begin{bmatrix}\underline{y}\\ \underline{\mu}\\ \underline{e}\end{bmatrix} = \begin{bmatrix}ZGZ'+R & GZ' & R\\ GZ' & G & 0\\ R & 0 & R\end{bmatrix}$$

where, G is the variance-covariance matrix of random effects (sire and cow), and R is the variance-covariance matrix of the residual effects, that is Var $(\underline{e})$.

With two random factors namely cows and sires whereby cows are nested within sires, Z and $\underline{\mu}$ were partitioned thus:

$$Z = (Z_1, Z_2)$$

$$\underline{\mu} = (\underline{\mu}_1, \underline{\mu}_2)$$

where, Z_1 and Z_2 are the incidence matrices of random sire and cow effects respectively while $\underline{\mu}_1$ and $\underline{\mu}_2$ are unknown vectors of random sire and cow effects respectively.

The variance-covariance matrices (for the random and residual effects) were, under the assumptions of the model, defined as:

$$G = \begin{bmatrix} \underline{I}\sigma^2_s & 0 \\ 0 & \underline{I}\sigma^2_c \end{bmatrix}, \quad \text{and} \quad R = \underline{I}\sigma^2_e$$

where, σ^2_s is the sire variance component,

σ^2_c is the cow variance component, and

σ^2_e is the error variance component.

In other words, all the relationships in the pedigree, except sire-daughter relationships, were ignored.

The mixed model equations (in a matrix form) which were solved for the best linear unbiased estimates and the best linear unbiased predictions (BLUPs), which are solutions of the fixed and random effects respectively, are:

$$\begin{bmatrix} X'X & X'Z_1 & X'Z_2 \\ Z'_1 X & Z'_1 Z_1 + \underline{I}k_1 & Z'_1 Z_2 \\ Z'_2 X & Z'_2 Z_1 & Z'_2 Z_2 + \underline{I}k_2 \end{bmatrix} \begin{bmatrix} \beta \\ u_1 \\ u_2 \end{bmatrix} = \begin{bmatrix} X'\underline{Y} \\ Z'_1 \underline{Y} \\ Z'_2 \underline{Y} \end{bmatrix}$$

where, $k_1 = \sigma^2_e/\sigma^2_s$ and $k_2 = \sigma^2_e/\sigma^2_c$ or $[4(1-r)]/h^2$ and $(1-r)/(r-1/4h^2)$ respectively (Appendix 3).

The values of k_1 and k_2 as well as the corresponding heritability and repeatability values used in their calculation are set out in Table 5.

But due to the large sizes of Z_1 and Z_2, it was neither possible to store the left hand side matrix in-core nor invert it. Sire and cow equations were therefore absorbed into the fixed effects while the required information for back solution was stored in separate files.

Table 5: Values of k_1 and k_2, heritability and repeatability used

Character	h^2	r	k_1	k_2
305-day milk yield	0.20	0.43	7.5	1
305-day milk yield	0.25	0.45	6.2	1

3.6 Construction of the cow indices

Four genetic indices were computed for each cow as described here below.

3.6.1 Adjusted Least Squares Mean (ALSM)

All the qualifying lactation records were first corrected additively for the year of calving ($\hat{YR}_i$), season of calving ($\hat{SN}_j$) and parity ($\hat{P}_k$) using the constant estimates in Appendix 2 (Parekh and Singh, 1987):

$$\hat{Y}_{kmo} = Y_{ijklmo} - \hat{YR}_i - \hat{SN}_j - \hat{P}_k$$

where Y_{ijklmo}, $\hat{YR}_i$, $\hat{SN}_j$ and $\hat{P}_k$ are as described above while

Y_{kmo} is the corrected 305-day milk yield.

This was then followed by averaging the corrected milk records over the parities of the cow to give her ALSM that may now be used for within-herd selection. But when two or more herds are involved and the records are also adjusted for herd, ALSM may also be used for selecting cows across herds.

And although ALSM is a very simple and less accurate cow index compared to others, especially those found in developed countries, it can nevertheless be very useful in developing countries, such as Kenya, where the computation of sophisticated cow indices is technically not possible.

3.6.2 Expected Real Producing Ability (ERPA)

The ERPA (Parekh, 1987; Parekh and Singh, 1987) of each cow was computed according to the formula:

$$\text{ERPA} = \bar{P} + \{nr/[1+(n-1)r]\}\{\bar{X}_n-\bar{P}\}$$

where, ERPA is as defined above,

$\bar{P}$ is the 305-day milk yield population mean or herd average

n is the number of lactation records of cow X,

r is the repeatability of 305-day milk yield, and

$\bar{X}_n$ is the cow's ALSM.

That is, the deviation of each cow's ALSM from the 305-day milk yield population mean or herd average ($\bar{P}$) was weighted by repeatability (r) and then added to $\bar{P}$ to give the cow's ERPA.

ERPA, which gives the expected real performance of the evaluated animal, may be used for selecting cows across herds provided that the effect due to herd is corrected for when computing each cow's ALSM.

3.6.3 Expected Breeding Value (EBV)

The EBV (Parekh, 1987; Parekh and Singh, 1987) for each cow was again computed according to a formula thus:

$$EBV = \bar{P} + \{nh^2/[1+(n-1)r]\}\{\bar{X}_n-\bar{P}\}$$

where, $\bar{P}$, n, r and $\bar{X}_n$ are as described above while

h^2 is the 305-day milk yield heritability.

EBV, which reflects a cow's breeding value, may be used for cow selection even across herds. It differs from ERPA above in that the deviation of the cow's ALSM (that is $\bar{X}_n$) from $\bar{P}$ is weighted by heritability other than by repeatability. EBV could therefore be said to be a better cow index than ERPA.

3.6.4 Predicted Breeding Value (PBV)

The PBV of each cow was calculated as the sum of her sire's estimated transmitting ability (ETA), which equals the sire's solution, and the fraction of the cow solution that is genetic. That is,

$$PBV = Sire\ ETA + (3k_2/k_1 * Cow\ Solution)$$

where, PBV is as described above, while Sire ETA and Cow Solution are the sire and cow BLUPs respectively.

The fraction of the cow variance that is genetic is $0.75h^2/[r-0.25h^2]$ (Henderson, 1973), where h^2 and r are the heritability and repeatability of 305-day milk yield respectively. This fraction was simplified to $3k_2/k_1$ (Appendix 3) and used in this study.

PBV, which predicts the breeding value of a cow, may be used for both intra- and inter-herd cow selection.

3.7 Rank Correlations

The evaluated cows were ranked, in a descending order, depending on their respective ALSM, ERPA, EBV and PBV. A rank correlation test was then carried out, with the view to determining whether the said indices ranked cows differently, according to Snedecor and Cochran (1967) as:

$$r = 1 - 6\Sigma d^2/[n(n^2-1)]$$

where, r is the rank correlation coefficient,

d^2 is the squared rank difference, and

n is the total number of the ranked cows.

3.8 Relative Efficiency of Index

The relative efficiencies of the EBV and PBV as cow genetic indices were derived as correlations using the formula of Falconer (1981), thus:

$$r_{IA} = \sigma_I/\sigma_A$$

where, r_{IA} is the relative efficiency of the index (I) expressed as a correlation between it and the true breeding value (A) of an animal,

σ_I is the standard deviation of the index in the population, and

σ_A is the additive genetic standard deviation in the population.

Since the additive genetic standard deviation in the population is the same for either index, the magnitude of the sample standard deviations of the indices (s_I) - which are good estimators of their respective σ_I values - were considered to be indicative of their relative efficiencies. In other words, as the index deviation increases, the correlation between the index and the true breeding value of the animal approaches unity. And since the closer to unity the correlation is the more accurate the index, then the index with a larger standard deviation is said to be more accurate.

The relative efficiencies of the other two indices, namely ALSM and ERPA, were on the other hand deduced on the basis of their degree of similarity (in ranking the cows) with EBV as given by their respective rank correlations.

4 RESULTS

4.1 Estimates of Non-Genetic Effects

The results of least-squares ANOVA (Model 1) to estimate the effects of parity as well as year and season of calving on 305-day milk yield are given in Table 6.

Table 7 on the other hand gives the least-squares means (Model 1) showing how 305-day milk yield varied by parities as well as years and seasons of calving.

According to Table 6, year of calving and parity significantly (P<0.001) affected 305-day milk yield while season of calving was not a significant (P>0.05) source of variation for 305-day milk yield.

Milk yield increased with parity up to the fifth parity, when it peaked, before exhibiting a decline in subsequent lactations.

The dry season (Season 3) calvers (Table 7) produced the most milk followed by those calving in Season 1 (long rains) and Season 2 (short rains) in that order. This was thought to have been due to the fact that the dry season calvers took advantage of the succeeding rainy season, whereas the dry season effect was managed through feed supplementation.

Table 6: Least-squares analysis of variance of 305-day milk yield

SOURCE	D.F.	MEAN SQUARES	F
SIRE	40	5930322.104	3.719^{***}
COW:SIRE	921	1594391.031	1.997^{***}
PARITY	9	42031133.119	52.638^{***}
SEASON OF CALVING	2	1475360.009	1.848^{NS}
YEAR OF CALVING	21	13185806.186	16.513^{***}
REMAINDER	1871	798487.603	

***Significant ($P<0.001$)

^{NS}Non-significant ($P>0.05$)

Table 7: Least-squares means of milk yield by parity, season and year of calving

	NO. OF OBSERVATIONS	LEAST-SQUARES MEAN	STANDARD ERROR OF LS MEAN
PAR 1	878	3499	287
PAR 2	614	4192	245
PAR 3	446	4674	209
PAR 4	333	5206	180
PAR 5	267	5485	163
PAR 6	137	5368	172
PAR 7	87	5053	194
PAR 8	54	4821	241
PAR 9	29	4961	304
PAR 10	20	4453	357
SOC 1	744	4751	158
SOC 2	461	4733	161
SOC 3	1660	4829	155
YOC 66	3	6023	812
YOC 67	23	5759	562
YOC 68	80	5898	487
YOC 69	100	5651	431
YOC 70	120	5025	383
YOC 71	176	4152	333
YOC 72	167	4302	293
YOC 73	172	4653	253
YOC 74	173	4977	218
YOC 75	189	4853	192
YOC 76	219	4286	174
YOC 77	256	4159	171
YOC 78	227	4234	188
YOC 79	214	4127	216
YOC 80	230	4429	253
YOC 81	135	5036	298
YOC 82	93	4766	343
YOC 83	84	4314	386
YOC 84	91	4579	427
YOC 85	48	4715	489
YOC 86	58	4801	540
YOC 87	7	4226	682

PAR = Parity
SOC = Season of calving
YOC = Year of calving

4.2 Heritability and Repeatability Estimates

The estimates of heritability and repeatability, for 305-day milk yield, obtained in this study were 0.20±0.07 and 0.43±0.02 respectively. The rather large standard error for the heritability estimate, which gives a 95% range of 0.06 to 0.34, attaches a low accuracy to the estimate. That for the repeatability estimate is small, which gives a 95% range of 0.39 to 0.47, and therefore the estimate's accuracy is high.

4.3 Rank correlations

The correlations between the cow rankings by the four evaluation methods, with h^2=0.20 and r=0.43, used in this study are given in Table 8.

ALSM had the same rank correlation of 0.99 separately between ERPA and EBV while ERPA and EBV had, as expected, a rank correlation of 1.00. On the other hand, PBV had a rank correlation of 0.74 between each of ALSM, ERPA and EBV.

Table 8: Correlations between cow rankings by the indices ALSM, ERPA, EBV and PBV computed using the parameter estimates of this study

INDEX	ERPA	EBV	PBV
ALSM	0.99	0.99	0.74
ERPA		1.00	0.74
EBV			0.74

The above results parallels those obtained when the average values of heritability (0.25) and repeatability (0.45) were used in the computation of the indices prior to carrying out a rank correlation test. The results in Table 9 attest to this.

Indeed, these results appear better in that the higher rank correlation of 0.80 between PBV and ALSM, ERPA or EBV shows an increased similarity in cow ranking by the four indices.

Table 9: Correlations between cow rankings by the indices ALSM, ERPA, EBV and PBV computed using the average parameter estimates

INDEX	ERPA	EBV	PBV
ALSM	0.99	0.99	0.80
ERPA		1.00	0.80
EBV			0.80

4.4 Relative Efficiency of Index

The standard deviations of the Expected and Predicted Breeding Values in the sample studied were 235.16±7.81 and 331.23±11.00 (for $h^2=0.20$ and $r=0.43$) and 287.23±9.54 and 357.93±11.89 (for $h^2=0.25$ and $r=0.45$) respectively. This means that the correlation between the actual breeding value (A) and PBV is larger than that between EBV thereby implying that the relative efficiency of PBV as a cow genetic index is higher than that of EBV.

And using the rank correlations reported in Section 4.3, it can be deduced that ERPA is as efficient as EBV while ALSM is about 1% less efficient.

5 DISCUSSION

5.1 Effects of Non-Genetic Factors

Non-Genetic factors such as year and season of calving, parity and/or age normally have considerable influence on lactation yields. Their respective effects should therefore be estimated and corrected for in any genetic evaluation of dairy cows and development of acceptable selection schemes.

5.1.1 Year of Calving

The fact that year of calving was a significant source of variation for 305-day milk yield was consistent with other findings in the country (Rege and Mosi, 1989). The significant effect of herd-year-season of calving reported by Lindstrom and Solbu (1978) and Mosi (1984) does, indirectly though, also support the said result of this study.

These findings suggests that year-to-year climatic and managerial flactuations are so considerable as to give rise to significantly different lactation yields. Each lactation yield should therefore be adjusted for the year of calving prior to carrying out any cow evaluation procedure. This adjustment removes the bias due to the year of calving and is therefore important in avoiding over-estimating or under-estimating the true genetic potential of the candidate cows.

For instance, the true genetic potential of cows calving during favourable and adverse weather conditions will respectively be over-estimated and under-estimated if their lactation yields are not adjusted for the year of calving prior to the evaluation exercise. Favourable weather conditions result in lactation yields that are over and above the genetic potential of the cows involved. Conversely, adverse weather conditions give rise to lactation yields that are lower than the cow's capacity because her genetic potential is depressed.

5.1.2 Season of Calving

Season of calving was, on the other hand, a non-significant (P>0.05) source of variation for 305-day milk yield. And although this was consistent with other findings in the country (Kiwuwa, 1974; Kimenye, 1978; Mosi, 1984; Mwandotto, 1985; Wakhungu, 1988; Rege and Mosi, 1989), it was nevertheless surprising because season classes were based on expected rainfall amounts and hence pasture availability. However, this observation is thought to have been due to the fact that the lactating cows were provided with supplementary feeds during the dry period thereby reducing the between-season differences, in as far as feed availability is concerned, thus making seasonal effects insignificant. In other words, the feed supplementation when grass was scarce gave rise to more or less uniform seasons and therefore this source of variation need not be adjusted for under the circumstances. But where feed supplementation is not practised, the effect due to season of calving may be significant thereby necessitating the adjustment of the laction records in order to increase the accuracy of the evaluation.

Ideally, season classification should aim at minimising within-season and maximising between-season differences. But the practice so far adopted of classifying seasons in to long rain, short rain and dry periods does not achieve this important goal. This is so because climatic flactuations do not allow the same months year after year to have the same climatic conditions.

5.1.3 Parity

Parity significantly influenced milk yield in that it increased with parity up to the fifth parity as it did in the studies of Syrstad (1965), Kiwuwa (1973), Mosi (1984), and Rege and Mosi (1989). This was however slightly earlier and later than the sixth and fourth parities reported by Lindstrom and Solbu (1978) and Wakhungu (1988) respectively.

In view of this finding and the fact that the genetic correlation between production of first and later lactations differs significantly from unity (Maijala and Hanna, 1974), the various lactations should be considered as different traits (Philipsson *et al.*, 1978). Adjustment for parity should therefore be done in order to render the various lactation yields devoid of the parity effect.

5.2 Parameter Estimates

It is sometimes necessary to estimate such parameters as heritability and repeatability from the data at hand instead of using the available estimates. In this study, it was necessary to estimate and use these two parameters in order to determine whether the results obtained notably differed from those obtained when their average values were used instead.

5.2.1 Heritability

The 305-day milk yield heritability estimate (0.20±0.07) obtained in this study is consistent with other available estimates (Mosi, 1984; Rege and Mosi, 1989) for the Kenyan Friesian population. This heritability estimate is lower than 0.25, which is generally applied worldwide, thereby suggesting that different dairy breeds may be having varying heritability values for 305-day milk yield. As a result, it may be always necessary to obtain heritability estimates for each breed to facilitate accurate within-breed cow evaluation.

Generally speaking, the heritability of individual milk records increase with the herd level (Averdunk and Alps, 1971; Maijala and Hanna, 1974; Danell, 1982; Hill *et al.*, 1983). Index variation does also increase with the herd level as the indices are more accurately estimated with the same amount of information for corresponding higher heritability. And since high yielding cows are often found in high yielding herds, it may be questioned whether the generally applied heritability value is appropriate for exceptionally productive cows. This is due to the fact that the heritability may have a curvilinear trend with the level of production meaning that the most productive cows are influenced by a greater proportion of all positive environmental factors than is the case at intermediate levels of production. Besides, very high yielding cows may also be thought to result from maximum non-additive genetic effects that are generally of no great importance in milk production.

5.2.2 Repeatability

The repeatability estimate of 0.43 obtained by this study is also consistent with local estimates available in literature (Kimenye, 1978; Wakhungu, 1988; Rege and Mosi, 1989). Other studies (Maijala and Hanna, 1974; Mosi, 1984) have also estimated high genetic correlations among lactations. The use of all the available records will, as these findings suggest, increase the accuracy of breeding value estimates by increasing the number of records per candidate animal.

5.3 Rank Correlations

The rank correlation of 0.99 between ALSM and ERPA or EBV, which totally agrees with previous studies (Parekh, 1987; Parekh and Singh, 1987), confirms that the cow ranking by ALSM was convincingly similar to that by ERPA or EBV and also that roughly the same cows would have separately been selected by the three methods. Indeed, the correlation could have been 1.00 were it not for the fact that the candidate cows had varying number of records.

The rank correlation of 1.00 between ERPA and EBV shows, as expected since they are functionally dependent, that the two evaluation methods ranked the cows similarly and can therefore be said to be equally efficient in selection.

Finally, the rank correlation of 0.74, or 0.80 for that matter, between PBV and ALSM, ERPA or EBV does on the other hand show that the cow ranking by PBV was significantly different from that by any of the other three methods.

5.4 Relative Efficiency of Index

The efficiency of an index is measured by the correlation, r_{IA}, between the index (I) and the actual breeding value (A). The index that makes the best use of the information available is said to have maximised r_{IA}. Consequently, the higher the correlation the better is the index as a predictor of the actual breeding value. Besides, the index that combines the most sources of information is theoretically expected to be the most efficient.

The fact that PBV resulted in the highest efficiency (See Section 4.4) shows that PBV is the most appropriate index, of the four indices studied, for comparing and selecting dairy cows. This is the case because PBV not only incorporates information on the cow but also on the sire while the other three indices are based on the cow's phenotype only. PBV is therefore expected to be the most efficient of the four cow indices studied for it combines two sources of information as opposed to only one in the case of the other three. The method used by the Bull Purchasing Committee (BPC) when choosing bull-dams for the Contract

Mating Scheme, for instance, should consequently be replaced by adopting PBV as the dairy cow selection index. This is because PBV is a genetic index while the said BPC method is based on phenotypic parameters such as milk yield, calving interval and conformation. That is, PBV gives the genetic potential of the dairy cow, in as far as milk production is concerned, and hence is a far much better basis, than any of the other three, for selecting bull-dams.

6 CONCLUSIONS

A number of conclusions were drawn from the results of this study. These are:

1) The average heritability (0.25) and repeatability (0.45) estimates for 305-day milk yield do not alter the results reported in this study and could therefore be used in any such analysis under the same conditions (as of this study) without compromising the credibility of the results.
2) ERPA and EBV are completely similar in cow ranking and therefore selection.
3) That ranking by ALSM is convincingly similar to that by ERPA or EBV.
4) ALSM is, by and large, easier to compute than ERPA or EBV in that its computation involves less cumbersome calculations.
5) PBV is the best method, of the four studied, of cow evaluation and should therefore be used for both bull-dam and dam-dam selection especially by the bull purchasing committee and commercial dairy farms.
6) Improving the efficiency of ALSM by correcting for all the known factors, and their interactions thereof, that systematically influence milk yield could perhaps provide the simplest, but nonetheless reliable, method of dam evaluation for selection.

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8 APPENDICES

Appendix 1 : Annual rainfall totals for Njoro Plant Breeding Research Station

YEAR	RAINFALL TOTAL (mm)
1966	950.9
1967	685.2
1968	1162.4
1969	833.4
1970	1200.5
1971	918.2
1972	830.8
1973	741.3
1974	1076.3
1975	1188.9
1976	710.8
1977	1169.2
1978	1268.5
1979	911.8
1980	780.2
1981	940.2
1982	956.6
1983	950.6
1984	588.4
1985	1031.8
1986	979.9
1987	739.3

Source: Meteorological Department Headquarters, Nairobi

Appendix 2: Estimates of the fixed effects

	CONSTANT ESTIMATE	STANDARD ERROR OF CONSTANT
PAR 1	-1272	247
PAR 2	-579	196
PAR 3	-97	148
PAR 4	434	103
PAR 5	714	69
PAR 6	597	85
PAR 7	282	121
PAR 8	50	184
PAR 9	190	257
PAR 10	-318	313
SOC 1	-20	42
SOC 2	-39	46
SOC 3	58	30
YOC 66	1252	783
YOC 67	988	540
YOC 68	1127	463
YOC 69	879	404
YOC 70	254	354
YOC 71	-619	299
YOC 72	-469	253
YOC 73	-118	206
YOC 74	206	161
YOC 75	82	124
YOC 76	-485	94
YOC 77	-612	89
YOC 78	-537	118
YOC 79	-644	160
YOC 80	-342	207
YOC 81	265	260
YOC 82	-6	310
YOC 83	-457	357
YOC 84	-193	401
YOC 85	-56	465
YOC 86	29	520
YOC 87	-545	659

PAR = Parity
SOC = Season of calving
YOC = Year of calving

Appendix 3: Algebraic simplification of the genetic fraction of a cow solution

The following is a stepwise algebraic simplification of the genetic fraction ($0.75h^2/(r-0.25h^2)$) of a cow solution to $3k_2/k_1$.

When cows are nested within sires, as in this study, the expectations of the variance components estimates ($\hat{\sigma}^2$) are as follows:

$$E(\hat{\sigma}^2_s) = 1/4\sigma^2_A \text{ -----> } 4\sigma^2_s = \sigma^2_A,$$
$$E(\hat{\sigma}^2_c) = \sigma^2_G + \sigma^2_{PE} - \sigma^2_s, \text{ and}$$
$$E(\hat{\sigma}^2_e) = \sigma^2_{TE}$$

where subscripts A, G, PE and TE refer to additive genetic, total genetic, permanent environment and temporary environment respectively.

We also know that,

$$h^2 = \sigma^2_A/\sigma^2_P = 4\sigma^2_s/\sigma^2_P \text{ ----> } \sigma^2_s = 1/4h^2\sigma^2_P,$$
$$r = (\sigma^2_G + \sigma^2_{PE})/\sigma^2_P,$$
$$1-r = \sigma^2_e/\sigma^2_P, \text{ and}$$
$$\sigma^2_c/\sigma^2_P = (\sigma^2_G + \sigma^2_{PE})/\sigma^2_P - \sigma^2_s/\sigma^2_P$$
$$= r-1/4h^2 \text{ ----> } \sigma^2_c = (r-1/4h^2)/\sigma^2_P.$$

----> "implying that"

Expressed in terms of h^2 and r,

$$k_1 = \sigma^2_c/\sigma^2_a$$

$$= \frac{(1-r)\sigma^2_p}{1/4h^2\sigma^2_p} = \frac{(1-r)}{1/4h^2} = \frac{4(1-r)}{h^2} .$$

and, $k_2 = \sigma^2_e/\sigma^2_c$

$$= \frac{(1-r)\sigma^2_p}{(r-1/4h^2)\sigma^2_p} = \frac{(1-r)}{r-1/4h^2} .$$

Therefore,

$$\frac{k_2}{k_1} = \frac{(1-r)h^2}{(r-1/4h^2)[4(1-r)]} = \frac{h^2}{4(r-1/4h^2)} .$$

Multiplying k_2/k_1 by 3, we get

$$\frac{3k_2}{k_1} = \frac{3h^2}{4(r-1/4h^2} = 3(r-1/4h^2)/4h^2$$

which is equivalent to $0.75h^2/(r-0.25h^2)$.

Consequently,

$$0.75h^2/(r-0.25h^2) = 3k_2/k_1.$$