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GENETIC ANALYSIS OF MILK PRODUCTION AND FERTILITY TRAITS OF THE SAHIWAL CATTLE IN SEMI-ARID KENYA

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A thesis submitted to the Graduate School in partial fulfilment of the requirements for the Master of Science Degree in Animal Production (Animal Breeding) of Egerton University.

EGERTON UNIVERSITY

February 2007

DECLARATION AND APPROVAL

1. DECLARATION

This thesis is my own original work and has not been presented for the award of a degree or diploma in any other university.

Signed: _____

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2. APPROVAL

This thesis has been approved for final submission with our approval as University supervisors.

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Date: 05/02/2007

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Date: 5th February 2007

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DEDICATION

This work is dedicated to

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ABSTRACT

The Sahiwal breed serves as a model for determining the potential role of indigenous cattle in contributing to the economic and efficient milk and meat supply under the prevailing tropical conditions. Despite these, knowledge on extend of the additive genetic variance and estimate of genetic and phenotypic parameters for traits of economic importance based on appropriate models are lacking. The aim of this study was to genetically analyse milk production and reproductive traits of Sahiwal cattle in semi-arid Kenya using various conventional and test day animal models. Genetic and phenotypic parameters were estimated using conventional univariate, bivariate and trivariate and test day models (TDM) based on a derivative free restricted maximum likelihood (DFREML) procedure. Milk production traits considered were: lactation milk yield (LMY, kg), lactation length (LL, days) and test day milk yield (TMY, kg) while reproductive traits included: age at first calving (AFC, days), calving interval (CI, days) and number of services per conception (NSC). The mean estimates for milk production traits were 1,368 kg, 282 days, and 4.9 kg for LMY, LL and TMY, respectively. The reproductive traits were 468 days, 2.2 and 1,345 days for CI, NSC and AFC respectively. Heritability estimates from conventional univariate model were 0.16, 0.07, 0.03, 0.04 and 0.01 for LMY, LL, CI, AFC and NSC, respectively. The heritability estimates from trivariate analysis were higher for milk production traits than those from univariate analysis with ranges of 0.32 to 0.45 for LMY and 0.26 to 0.34 for LL. Genetic correlations were high and undesirable between milk production and fertility traits while phenotypic correlations were correspondingly low. Genetic trends were close to zero for all traits while environmental and phenotypic trends fluctuated over the study period. Heritability estimates for TMY ranged from 0.28 to 0.46, 0.38 to 0.52 and 0.33 to 0.52 in the first, second and third lactation, respectively. Genetic correlations among TMY ranged from 0.41 to 0.93, 0.50 to 0.83 and 0.43 to 86 in the first, second and third lactation, respectively. The phenotypic correlations were correspondingly lower. Genetic and phenotypic correlations between TMY and LMY in the first three lactations were high and positive. The corresponding phenotypic correlation estimates were also high and positive. This implies that TMY could be used in genetic evaluation in the Sahiwal cattle breeding programme. Results indicate opportunities for genetic improvement of milk yield by selection.

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LIST OF ABBREVIATIONS

12MWT	Weight at one year
27MWT	Weight at 27 months
305-d MY	305 day milk yield
AFC	Age at first calving
AI	Artificial insemination
AM	Animal model
AMM	Maternal animal model
ANOVA	Analysis of variance
ASALs	Arid and semi arid lands
BLUP	Best linear unbiased prediction
BW	Birth weight
CC	Contemporary comparison
CG	Contemporary group
CI	Calving interval
DFREML	Derivative free restricted maximum likelihood
DIM	Days in milk
DO	Days open
EBVs	Estimated breeding values
FAO	Food and Agricultural Organisation
ICC	Intra class correlation
KARI	Kenya Agricultural Research Institute
LL	Lactation length
LMY	Lactation milk yield
MAM	Multivariate Animal Model
MINQUE	Minimum norm quadratic estimation
MIVQUE	Minimum variance quadratic estimation
ML	Maximum likelihood
MW	Mature weight
MY	Milk yield
NSC	Number of services per conception
NSS	National Sahiwal Stud

ONBS	Open nucleus breeding scheme
PHS	Paternal half sib correlation
REML	Restricted maximum likelihood
RR	Random regression
SM	Sire model
TD	Test day
TDM	Test day model
TMY	Test day milk yield
UAM	Univariate animal model
WWT	Weaning weight

CHAPTER ONE

GENERAL INTRODUCTION

The Sahiwal is a dual-purpose breed that has been prioritised for development through genetic improvement and proper management for use in tropical and sub-tropical regions (FAO, 1992). Although the locally adapted *Bos indicus* breeds in developing countries commonly show low absolute production figures, the Sahiwal is known to have the greatest potential for milk and meat production in tropical environment (Trail and Gregory, 1981; Mwandotto, 1994; Singh and Nagarcenkar, 1997; Dahlin et al., 1998; Muhuyi et al., 1999). It is adapted to local conditions of poor nutrition, high disease challenges and ambient temperatures (Islam and Buiyan, 1997; Dahlin et al., 1998; Syrstad and Ruane, 1998; Khan et al., 1999;). The breed was introduced in Kenya from India and Pakistan in the late 1930s after attempts to improve the Small East African Zebu (SEAZ) through selection and breeding for milk production showed low genetic progress. The National Sahiwal Stud (NSS) was established and a breeding plan drawn for the genetic improvement of the breed (Meyn and Wilkins, 1974). The objective of the NSS is to produce a dual-purpose breed suitable for pure breeding in semi-arid environments and crossbreeding for dairy production.

The success of a Sahiwal cattle breeding programme depends on the genetic change that should be commensurate with breeding goal and management policies. Therefore, knowledge of environmental and genetic parameters for milk production and fertility traits is important in the development of sound and effective breed improvement programmes. Appropriate analytical models are needed to obtain accurate estimates of genetic and phenotypic parameters. These parameters are useful measures of genetic variation and knowledge of their estimates would be necessary to predict response to selection and genetic gain expected from a Sahiwal cattle improvement programme (Sorensen and Kennedy, 1984; Roman and Wilcox, 2000). In the estimation of these parameters, the emphasis should also be on making the best use of available data to enhance accuracy of estimation (Powell and Norman, 1998).

In many dairy cattle improvement programmes, an individual animal model is becoming a standard method for estimation of variance components using restricted maximum likelihood (REML) and as a basis for predicting breeding values (Kennedy et al., 1988). The approach has been to use conventional univariate repeatability and/or multiple trait animal models. A univariate repeatability model that assumes unity correlation among multiple lactation records has predominantly been used (e.g., Rege et al., 1992; Musani and Mayer,

1997; Dahlin et al., 1998; Ojango and Pollot, 2001). However, when selection is based on more than one trait, multiple trait models become the optimum methodology because they simultaneously account for genetic and phenotypic correlations among traits in evaluation of animals. With regard to the Sahiwal cattle in Kenya, no estimates of genetic parameters for milk production and fertility traits, on the basis of an animal model, are available. Relatively little is known about the relationship (genetic and phenotypic correlation) among milk production traits and between milk production and fertility traits of Sahiwal cattle under semi-arid conditions in Kenya. Understanding the nature of these relationships would enable the breeder to further genetic improvement of milk production without sacrificing performance on fertility traits

Traditionally, estimation of genetic and phenotypic parameters and subsequent evaluation of milk production traits in most dairy cattle selection programmes in Kenya has been based on standardised lactation yield. However, models based on standardised milk yield for estimating genetic parameters cannot account for effects associated with individual test day milk yield (TMY) (Jamrozik and Schaeffer, 1997; Swalve, 1998). Ptak and Schaeffer (1993) proposed the use of TMY data for estimation of genetic and phenotypic parameters and evaluation of dairy cattle. Statistical procedures based on TMY consider both genetic and environmental effects that are specific to a particular test-day (TD), which gradually but continuously change over the course of lactation, and therefore effectively account for these effects (Ptak and Schaeffer, 1993; van der Werf et al., 1998). The current trend should be to change the data used for genetic evaluation from standardised lactations yields to TD yield data where dairy sires and cows can be evaluated and ranked based on a single or a few yield records. However, information on genetic parameter estimates and subsequent genetic evaluation of *Bos indicus* cattle based on TMY is scarce in the literature

Genetic and environmental trends are crucial in designing appropriate breeding strategies aimed at maximising genetic gain, and also as indictors for amendments in the existing management policies whenever desirable (Wilson and Wilham, 1986). While favouable phenotypic trends for milk production and reproductive performance traits have been reported for temperate breeds in Kenya (Musani and Mayer, 1997; Ojango and Pollot, 2001), the last evaluation of the Sahiwal breed indicated declining phenotypic performance (Rege and Wakhungu, 1992). Impact of intervention measures suggested by these studies has to be determined to assess the progress so far achieved. As a result of changes in analytical procedures over time, changes in genetic parameter estimates are expected. However, improvement of the Sahiwal breed through use of unbiased estimates obtained using such

analytical methods has not been undertaken. Previous studies did not apply these methods and as such estimates were likely to be biased.

1.1. Objectives

The overall objective of this study was to genetically evaluate milk production and fertility traits of the Sahiwal cattle using conventional and TD models (TDM). The specific objectives were:-

1. To determine factors affecting performance of the Sahiwal cattle and obtain mean estimates for milk production and fertility traits using conventional and TDM.
2. To estimate genetic and phenotypic parameters for milk production and fertility traits using conventional and TDM.
3. To estimate genetic and environmental trends for milk production and fertility traits.

1.2. Hypotheses

H_O: Environmental factors are not the causes of observed variation in milk production and fertility traits in the Sahiwal cattle.

H_O: Genetic and phenotypic parameters estimated using the various models are comparable in the Sahiwal cattle.

H_O: No genetic improvement in milk production and fertility traits has occurred over the years in the Sahiwal cattle.

Reference

Dahlin, A., Khan, U. N., Zafar, A. H., Saleem, M., Chaundhry, M. A. and Philipsson, J., 1998. Genetic and environmental causes of variation in milk production traits of Sahiwal cattle in Pakistan. *Animal Science.* **66**: 307-318.

FAO. 1992. Animal genetic resource conservation and management report of the FAO/UNEP Technical consultation held in Rome, 1992. Food and Agriculture Organisation of the United Nations, Rome Italy.

Islam, S. S. and Bhuiyan, A. K. F. H., 1997. Performance of crossbred Sahiwal cattle at the Pabna milk shed area in Bangladesh. *Asian-Australian Journal of Animal Sciences.* **10**: 581-586.

Jamrozik, J., and Schaeffer, L. R. 1997. Estimation of genetic parameters for a test day model with random regression for yield traits of first lactation. *Journal of Dairy Science.* **80**: 762-770.

Kennedy, B. W., Schaeffer, L. R. and D. A. Sorensen 1988. Genetic properties of animal models. *Journal of Dairy Science.* **71**: 17-26.

Khan U. N., Dahlin A., Zafar A. H., Saleem M., Chaudhry M. A. and Philipsson J. 1999. Sahiwal cattle in Pakistan: genetic and environmental causes of variation in body weight and reproduction and their relationship to milk production *Animal Science.* **68:** 97-108.

Meyn, K. and Wilkins, J. V., 1974. Breeding for milk in Kenya, with particular reference to the Sahiwal stud. *World Animal Review.* **11**: 24-30.

Muhuyi, W. B., Lokwaleput, I. and Sinkeet, S. N., 1999. Conservation and utilisation of the Sahiwal cattle in Kenya. *FAO Animal Genetics Research Information.* **26**: 35-44.

Musani, S. K., and Mayer, M.. 1997. Genetic and environmental trends in a large commercial Jersey herd in the central rift valley, Kenya. *Tropical Animal Health and Production.* **29**: 108-116

Mwandotto, B. A. J. 1994. Phenotypic, genetic and environmental parameter estimates of weight, growth and maturing patterns in Sahiwal females. *Bulletin Animal Production* **42**: 61-67.

Ojango, J. M. K. and Pollot, K. 2001. Genetics of Milk yield and fertility traits in Holstein-Friesian cattle on large scale Kenyan farms. *Journal of Animal Science.* **79**: 1742-1750.

Powell, R. L., and Norman, H. D. 1998. Use of Multinational data to improve national evaluation of Holstein bulls. *Journal of Dairy Science.* **81**: 2257-2263.

Ptak, E., and. Schaeffer, L. R. 1993. Use of test day yields for genetic evaluation of dairy sire and cows. *Livestock Production Science.* **34**: 23-34.

Rege J. E. O., Lomole M. A. and Wakhungu, J. W. 1992. An evaluation of a long-term breeding programme in a closed Sahiwal herd in Kenya. I. Effects of non-genetic factors on performance and genetic parameter estimates. *Journal of Animal Breeding and Genetics.* **109:** 364-373.

Rege, J. E. O, and Wakhungu, J. W. 1992. An evaluation of a long term breeding programme in a closed Sahiwal herd in Kenya. Genetic and phenotypic trends and levels of inbreeding. *Journal of Animal Breeding and Genetics.* **109**: 374-384.

Roman, R. M. and Wilcox, C. J. 2000. Bivariate animal model estimates of genetic, phenotypic, and environmental correlations for production, reproduction, and somatic cells in Jerseys. *Journal of Dairy Science.* **83**: 829-835.

Singh, S. K. and Nagarcenkar, R. 1997. Factors affecting milk yield and lactation length in Sahiwal cows. *Indian Journal of Animal Sciences*. **67**: 989-992.

Sorensen, D. A. and Kennedy, B. W. 1984. Estimation of response to selection using least squares and mixed model methodology. *Journal of Animal Science*. **58**: 1097-1106.

Swalve, H. H. 1998. Use of test day records for genetic evaluation. *Sixth* (please make this change all through) *World Congress on Genetics Applied to Livestock Production*. **23**: 195-302.

Syrstad, O. and Ruane, J. 1998. Prospects and Strategies for genetic improvement of the dairy potential of tropical cattle by selection. *Tropical Animal Health and Production*. **30**: 257-268.

Trail, J. C. M and Gregory, K. E., 1981. Sahiwal cattle. An evaluation of their potential contribution to milk and beef production in Africa. *International Livestock Centre for Africa (ILCA) Monogram. No. 3.* ILCA, Addis Ababa, Ethiopia.

Van der Werf, J. H. J., Goddard, M. E. and Meyer, K., 1998. The use of covariance functions and random regression for genetic evaluation of milk production based on test day records. *Journal of Dairy Science*. **81**: 3300-3308.

Wilson, D. E. and Willharm, R. L 1986. Within herd phenotypic, genetic and environmental trends in lines for beef cattle breeders. *Journal of Animal Science*. **63**: 1087-1099.

CHAPTER TWO

LITERATURE REVIEW

Phenotypic expression of milk production and fertility traits is influenced by the genetic constitution of an animal and the environment under which it is performing. To improve milk production and reproductive efficiency, there is need to select animals of high genetic merit in the relevant traits to be parents of the next generation. Genetic merit cannot be measured directly but is estimated from the phenotypic performance of the animal. Therefore, phenotypic performance should be adjusted for the effects of non-genetic factors to ensure accuracy in genetic evaluation (Bebber et al., 1997). Adjustments are important in eliminating the environmental influences from performance records. The need to quantify the effect of these non-genetic factors on milk production and fertility traits of Sahiwal cattle is critical.

Precise and accurate knowledge of genetic and phenotypic parameters becomes critical in planning and developing appropriate breeding programmes (Choundhary et al., 2003; Kahi et al., 2004). Breed improvement programmes should undergo regular appraisal to identify optimum efficiency and predict possible rates of progress. Success of such breeding programme would depend on the genetic change that should be commensurate with breeding goal. Generally, in the livestock industry, there has been a marked improvement in genetic evaluation in the recent past. The dramatic improvement is attributed to development of sophisticated statistical methods to overcome biases inherent in earlier genetic evaluation procedures (Bourdon, 1998).

2.1 Importance of the Sahiwal cattle breed to milk and meat production

The Sahiwal cattle play a complimentary role to other livestock species in utilising feed resources in the vast ASALs where crop production is almost impracticable. Therefore, appropriate improvement programmes are necessary for sustainable increase in the productivity of the Sahiwal, and their derivatives in these areas so as to meet the demands of the human population. Development of improvement programmes requires a clear understanding of the different production systems and their associated constraints. Muhuyi (1997) classified these systems based on production methods, products and operational scale: (i) beef production system characterised by agro-pastoral, pastoral and commercial ranching, (ii) large scale dairy production system, (iii) dual purpose production system and (iv) small scale dairy production system in high to medium potential areas where Sahiwal crossbreds are utilised. These production systems are discussed next.

2.1.1. Beef production

This is practised by pastoralists and commercial ranchers in the rangelands where the Sahiwal breed and its derivatives with exotic breeds are kept in mixed herds with indigenous sheep, goats and camels. The Sahiwal breed is preferred to the *B. taurus* breeds by commercial ranchers due to its relative adaptability to the tropical production environment, which facilitate its greater ability to survive, grow and reproduce. These characteristics have been achieved following generations of natural and artificial selection in conditions of high ambient temperatures, poor feed quality and high pathogen incidences that typify the ASALs. Commercial production of beef is the objective of this system while the milk is meant for domestic consumption. Commercial beef production systems in Kenya include the Sahiwal herds at Elkarama ranch in Laikipia and Ilkerin Loita ranch in Narok. Cattle are extensively grazed on natural pastures and supplemented with minerals (Muhuyi, 1997). The off take rate is about 27%, which accounts for over 90% of the total income. These commercial ranchers play an important role in the supply of beef and breeding stock to the local and export markets. In the case of the pastoralists, animals are grazed on natural pasture in which case either transhumance or nomadism is practised. Revenues accrued from the system are lower due to the low input levels. The major constraints in this system include feeding during unfavourable seasons, breeding management, and competition from wildlife, marketing beef produced and occasional invasion into the ranches by pastoralists.

2.1.2. Large-scale dairy production system

Dairy ranching is practised in the highlands, sub-humid and semi-arid areas mainly in agro-ecological zones III and IV with relatively low annual rainfall of 600 to 800mm. The average farm size in this system is between 500 to 1000 hectares with a herd size of approximately 200 animals (Muhuyi et al., 1997). Sahiwal and its crossbreds with exotic breeds are mainly kept. Examples of large-scale dairy farms in Kenya are Deloraine Estate, Loldia Estate and Kilifi Plantations. Cattle are rotationally grazed on natural and improved pastures, and supplemented with dairy meal and minerals for milk and meat production. The contribution to the total income from milk sales is about 73% (Muhuyi, 1997).

2.1.3. Dual-purpose production systems

Dual-purpose production systems in Kenya include the purebred Sahiwal herds and their crosses with *B. taurus* breeds at Deloraine Estate, Oljorai, NSS and Mariakani Research Centre. Cattle are extensively grazed on natural pastures and supplemented with minerals for milk and meat production. Milk off-take accounts for approximately 69% whereas cattle off

take earns about 31% of the total revenue. Dual-purpose herds are raised to produce milk and meat and this system has been shown to be more efficient in utilising feed resources compared to a system where beef is the main product (Muhuyi, 1997).

2.1.4. Small-scale dairy production systems

This system is practised in the high rainfall and marginal areas. The Sahiwal cattle and the SEAZ and their crosses are the main breeds kept. These producers practice crop production therefore form the agro pastoral group (Muhuyi, 1997). Average farm size is small ranging from 1 to 5 hectares with an average herd size of 5 Sahiwal and or Sahiwal genotypes. Cows are grazed on natural pastures and supplemented with concentrates and mineral licks. The Sahiwal breed is mainly kept for milk while sales from excess stock meet domestic cash needs. Average milk yield of the Sahiwal cow on smallholder farms is about 2097 kg (Muhuyi. 1997). The main aim of production in these systems is based on survival and risk minimisation strategies rather than increased productivity. It is a low input system and thus low levels of output.

The Sahiwal crossbreds have found wide utilisation in the smallholder dairying sector, which contributes appreciably to the total national milk output (Bebe et al., 2003). The smallholder dairy sector is characterised by limited land and feed resources, and increased veterinary costs (Kahi et al., 2000a and b). It has been shown that the Sahiwal cattle and its crossbreds can be utilised profitably for milk production in different production systems characterised by specific environmental and management situations (Muhuyi, 1997; Kahi et al., 2000a and b).

2.2. Breeding plan at the National Sahiwal stud

The introduction of Sahiwal breed in Kenya in 1939 ended the fruitless attempts to select an improved indigenous Zebu for dairy and beef production. Following the recommendation of Mason (1965), a breeding programme with a major emphasis on milk production was designed. The main objective of this programme is to produce progeny tested bulls for the Central Artificial Insemination Station (CAIS), bulls and cows of high genetic merit for sale to pastoralists and ranchers in ASALs and to ensure continuous genetic improvement of the breed. Figure 1 shows the Sahiwal breeding plan at the NSS. Mwandotto (1985) has reported details of the selection process and therefore these will not be repeated here. However, it is worth mentioning the methodology used in the selection of sires. Sires are selected using a selection index that comprises of the breeding values of milk yield in the sire and dam and of weight at 2 years of age in the individual as follows:

$$I = b_1G_D + b_2G_s + b_3G_p \quad (1)$$

where b_1, b_2 and b_3 are the weighing factors, G_D and G_s are the estimated breeding values of lactation milk yield (LMY) in the dam and sire, respectively and G_p the estimated breeding value of weight at 2 years of age in the individual bull. The weighing factors are calculated as:

$$b_1 = b_2 = W_m h_n^2 \quad (2)$$

$$b_3 = W_w h_w^2 \quad (3)$$

where W_m and W_w are the gross margins of milk yield and live weight (KSh), respectively, and are calculated from the gross margin per additional unit of production estimated from performance data at the NSS, h_n is the heritability of milk yield for n lactations, h_w is the heritability of live weight at the age of 2 years of age. It is assumed that there is no genetic and phenotypic correlation between milk yield and weight. Heritability estimates for LMY and weight at 2 years is assumed to be equal to 0.3, while the repeatability estimate for LMY is assumed to be 0.6. The dam's average LMY is deviated from the year's group lactation mean as:

$$b_1G_D = 0.5W_m h_n^2 (D_m - H_m) \quad (4)$$

where 0.5 represent the selection path coefficient from dam to son, D_m the lifetime average milk yield per lactation of the bull's dam, and H_m the lifetime average LMY of the entire herd. The sire component of the index refers to the first LMY of the daughters and is calculated as:

$$b_2G_s = 0.5W_m G_s \quad (5)$$

where 0.5 represents the path coefficient from sire to son. Contemporary comparison among the heifers calving in the same month forms the basis of estimating the breeding values of the test sires. The effective number of daughters of the test sire for each month is given by:

$$n_m = \frac{n_1 n_2}{n_1 + n_2} \quad (6)$$

Where n_m is the effective number of daughters of the test sire, and n_1 and n_2 the number of daughters of a test sire calving in a particular month and number of contemporary heifers in the herd calving that month, respectively. The third component of the selection index covers the growth potential of the test sire. Live weight at 2 years of age is adjusted for the average age of their birth year's bull team and this is deviated from the team's years average. Therefore,

$$b_3G_p = h_m^2 W_m D_p \quad (7)$$

where D_p is the deviation of the bull's adjusted live weight in comparison to the team's year average.

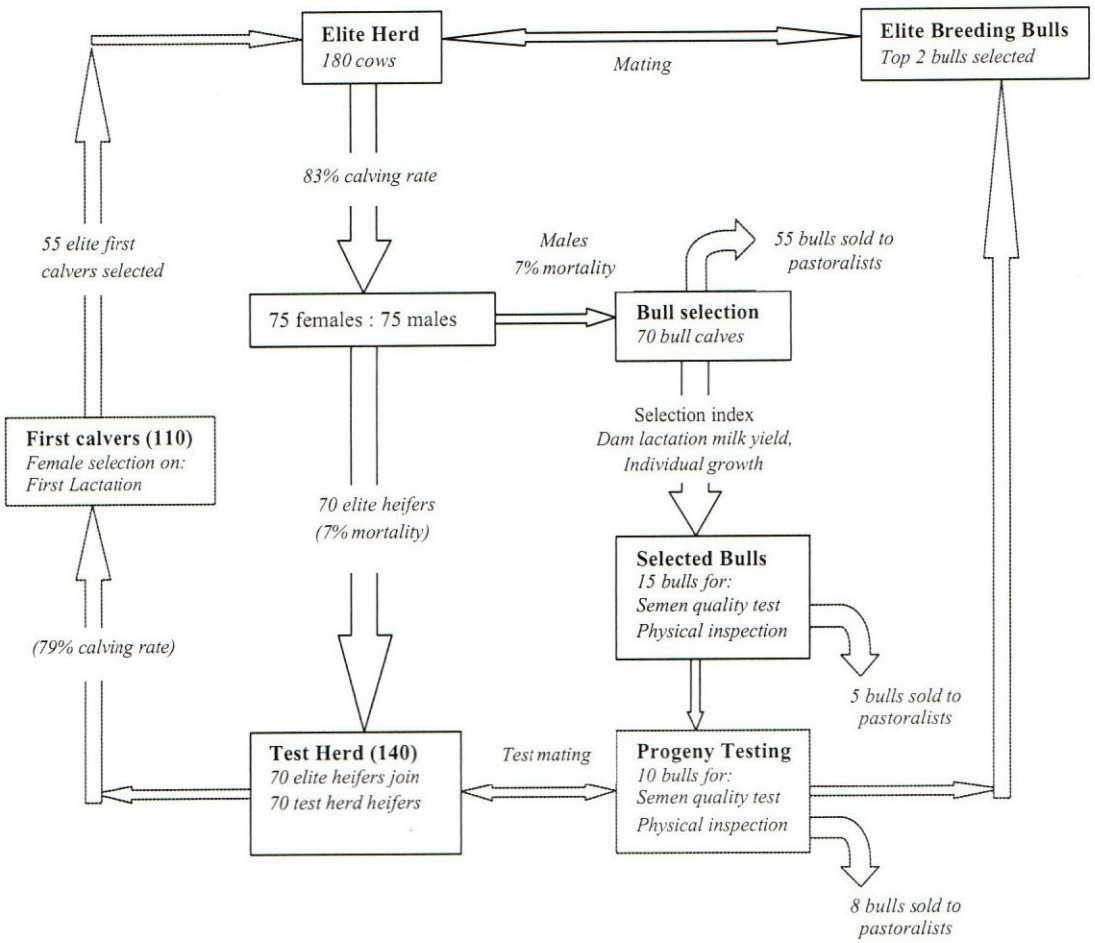


Figure 1. Sahiwal cattle breeding programme at the NSS

2.3. Traits of economic importance in Sahiwal cattle

Dairy producers are normally faced with the challenge of identifying traits that directly influence profitability, which collectively form the breeding goal (Kahi and Nitter, 2004). Knowledge of the traits would help producers improve on the production efficiency of their dairy herds (Abdallah and McDaniel, 2000; Tekerli et al., 2000). These traits can broadly be classified as production (e.g., milk yield and growth) and functional traits (e.g., fertility and adaptability). Although the locally adapted *B. indicus* breeds in developing countries commonly show low absolute production figures, the Sahiwal is known to have the greatest potential for milk and meat production, and efficient reproductive performance in tropical

environment (Rege et al., 1992; Mwandotto, 1994; Singh and Nagarcenkar, 1997; Dahlin et al., 1998; Khan et al., 1999).

2.3.1. Production traits

Production traits influence various aspects of production ranging from maintenance requirements to culling decisions and therefore directly influence profitability of dairy and beef production enterprises. In any dairy enterprise, improvement in milk production traits is very important. Some of these traits include LMY, butterfat and protein content. More recently, somatic cell score and persistence of lactation have been included in the selection criteria in developed countries (Tekerli et al., 2000). Roman and Wilcox (2000) have shown that single trait selection for milk yield results in correlated increase in constituent yields with slight decrease in percentage composition of constituents and somatic cell counts. In Kenya, the main breeding goal for dairy cattle production is increased genetic merit for total lactation milk yield (Kahi and Nitter, 2004; Kahi et al., 2004). This has resulted in increased average genetic merit among *B taurus* breeds for volume of milk (Njubi et al., 1992; Musani and Mayer, 1997; Ojango and Pollot, 2001). However, genetic improvement for milk production traits has been reported to be negative for the Sahiwal breed in the tropics (Rege and Wakhungu, 1992; Dahlin et al., 1998).

Growth traits include birth weight (BWT), weaning weight (WWT), pre-weaning and post-weaning growth rates. The expression of these traits is dependent on the animal's inherent growth ability and production environment (Mackinnon et al., 1991). Growth traits fit well in dual-purpose selection programmes because they are easily measured and are expressed early in life (Mwandotto, 1985).

2.3.2. Functional traits

Most dairy and beef producers endeavour to adopt a selection principle that results in productive, robust and efficient cattle. To be able to achieve this goal, more attention has to paid to functional traits such as fertility, disease resistance and herd life (Vukasinovic et al., 1997 and 2001;Weigel et al., 1998). Fertility traits are considered important in dairy and beef cattle because they affect the profitability of these enterprises and the rate of genetic progress (Pryce et al., 1997). Indices such as regularity of oestrus cycles, conception rate, age at first calving, days to first service, number of services per conception, days open and calving interval have been used to evaluate reproductive performances of dairy breeds in the tropics (Rege, 1991; Musani and Mayer, 1997; Dahlin et al., 1998; Khan et al., 1999; Ojango and Pollot, 2001). These traits determine the overall number of calves born per year in the herd

and how many will be availed for replacement or sale. Nevertheless, most current breeding programmes put more weight on milk yield and type traits than functional traits (Darwash et al., 1997). The low heritability (less than 0.09) for fertility traits makes discrimination of more fertile genotypes difficult and has consequently hampered selection for fertility (Hayes et al., 1992; Campos et al., 1994; Marti and Funk, 1994; Darwash et al., 1997; Ojango and Pollot, 2001).

Genetic selection for increased herd life is expected to result in improved general health, production and reproduction, which can increase dairy and beef profitability by allowing rearing costs to be spread over a longer period and by increasing the number of cows producing at mature level (Vukasinovic et al., 1997). Herd life is a measure of the animal's adaptability to a particular production environment and is usually described as survival rates at various developmental stages measured in terms of tolerance to pathogenic parasites and mortality (Vukasinovic et al., 1997; Burrow, 2001). High survival rates are important in cattle production systems in order to ensure regular supply of replacement heifers and to provide males for sale as breeding stock. High disease incidences result in mortality, which leads to the loss of good combination of desirable genes and reduction in intensities of selection and consequently reduced annual genetic turnover.

2.3.4. Relationship between milk yield and fertility

Milk production depends on reproductive performance of a herd (Mrode and Akinokun, 1986). However, most breeding programmes weight milk yield traits more than fertility traits, a practice that has resulted in substantial genetic progress for yield at the expense of reproductive performance, given the negative genetic and phenotypic correlation between fertility and yield traits (Berger et al. 1981; Hansen et al., 1983; Raheja et al., 1989; Oltenacu et al., 1991; Dematawewa and Berger, 1998; Khan et al., 1999). In the early stages of lactation, cows experience a slow increase in dry matter intake with a rapid increase in daily milk yield, and increased mobilisation of body nutrients (Butler and smith, 1989; Nebel and McGilliard, 1993; Veerkamp et al., 2001). This results in a negative energy balance because the energy requirements for milk production cannot be offset by the diet (Butler and smith, 1989; Nebel and McGilliard, 1993). Reproductive performance, particularly the probability of conception, of cows may be associated negatively with the magnitude and severity of negative energy balance in early lactation (Butler and Smith, 1989; Nebel and McGilliard, 1993). Laben et al. (1982) and Castillo-Juarez et al. (2000) showed that phenotypic antagonism between milk yield and reproductive efficiency is inversely related to the environmental trends. Therefore, long term selection for milk yield and poor management

policies may adversely affect reproductive performance of the herd. It is important to understand the relationship between milk production and reproductive performance, as well as genetic and environmental factors that affect performance of individuals for these traits to enhance genetic improvement.

2.4 Performance of the Sahiwal and some *B. indicus* dual-purpose breeds in the tropics

2.4.1 Production traits

The main selection emphasis in dual-purpose breeds has been laid on milk production efficiency and growth rate. The mean performance for some of these production traits for Sahiwal and other *B. indicus* cattle reported in the tropics are summarised in Table 1. There are differences in mean performances of the Sahiwal and other indigenous cattle breeds in the tropics. The mean milk yield of the Sahiwal cattle in Kenya (Rege et al., 1992; Muhuyi, 1997) is lower than reported for the same breed in India (Pundir and Raheja, 1994; Singh and Nagarcenkar, 1997). However, the mean LMY reported for some Sahiwal herds in Pakistan (Dahlin et al., 1998) is lower than reported in Kenya, although some Sahiwal herds in Pakistan showed a comparable mean LMY (Bajwa et al., 2002). On average, the mean LMY for the Sahiwal is higher than for the Hariana, Tharpakar and Boran breeds. In Kenya, various authors have reported differences in LMY (e.g., Kimenye, 1978: Rege et al., 1992: Muhuyi, 1997). This is as a result of standardisation of LMY, exclusion of shorter LL from the analysis, classification of fixed effects and different herd management policies over the years. Exclusion of shorter LL reduces the genetic variance for milk yield (Madalena, 1988).

There are variations in the mean LL of *B. indicus* breeds with a high tendency towards short lactations (Yadav et al., 1995; Singh and Nagarcenkar, 1997; Dahlin et al., 1998; Demeke et al., 2004a). The mean LL of Sahiwal cattle in Pakistan is comparable to that of Tharpakar breed in India (Yadav et al., 1995; Dahlin et al., 1998). Longer LL have been reported in some Sahiwal and Hariana herds in India (Pundir and Raheja, 1994; Yadav et al., 1995; Singh and Nagarcenkar, 1997). Short lactations are partly due to the inability of the cattle to let down milk in the absence of a calf and also because of low genetic potential of *B. indicus* breeds to produce milk for longer periods (Maule, 1990).

Table 1. Production trai ts of the Sahiwal and other *B. indicus* dual-purpose breeds in the tropics

Trait[a]	Breed	Mean	Country	Fixed effects fitted	Reference
LMY (kg)	Sahiwal	1395	Pakistan	Herd, year, season and age at calving	Dahlin et al. (1998)
	"	1544	Kenya	Parity, year-season of calving	Muhuyi (1997)
	"	1710	"	Year- season of calving	Yadav et al. (1995)
	"	1530	"	"	Dhaka et al. (2002)
	"	1540	"	"	Pundir and Raheja (1994)
	"	1475	Pakistan	Year-season of calving, age	Bajwa et al. (2002)
	Tharpakar	1405	India	Period, season of calving, breed	Yadav et al. (1995)
	Boran	614	Ethiopia	Parity, year	Demeke et al. (2004a)
	Hariana	1429	India	Period, season of calving, breed	Yadav et al. (1995)
305-d MY (kg)	Sahiwal	1455	Kenya	Year -season of calving, parity	Kimenye (1978)
	"	1663	"	Parity, year-season of calving	Rege et al. (1992)
	"	1363	Pakistan	Herd, year, season, and age calving	Dahlin et al. (1998)
	"	1760	India	Herd-year-season and age at calving	Singh and Nagarcenkar (1997)
	"	1436	"	Year-season	Pundir and Raheja (1994)
LL (days)	"	252	Pakistan	Herd, year ,season and age at calving	Dahlin et al. (1998)
	"	288	India	Herd-year-season and age at calving	Singh and Nagarcenkar (1997)
	"	279	"	Year-season of calving	Yadav et al. (1995)
	"	295	"	"	Dhaka et al. (2002)
	"	336	"	"	Pundir and Raheja (1994)
	Hariana	270	"	Period, season of calving, breed	Yadav et al. (1995)
	Boran	193	Ethiopia	Parity, year of calving	Demeke et al. (2004a)
	Tharpakar	258	India	Period, season of calving, breed	Yadav et al. (1995)
BWT (kg)	Sahiwal	22.9	Kenya	Year-season of birth, sex, parity	Mwandotto (1985)
	Boran	30	"	Parity, sex	Indetie et al. (2000)
	Sahiwal	22.7	"	Year-season of birth, sex, parity	Rege et al. (1992)
	Boran	25.0	Ethiopia	Herd-year-season, sex, dam parity	Demeke et al. (2003)
	Boran	24	"	Year-season of birth	Haile-Mariam and Kassa-Mersha (1994)
Age55 (days)	Sahiwal	98	Kenya	Year-season of birth, sex, parity	Rege et al. (1992)
AWN (days)	Boran	180	"	Parity, sex	Indetie et al. (2000)
WWT (kg)	"	98	Ethiopia	Herd-year-season of birth, sex, dam parity	Demeke et al. (2003)
	"	169	"	Year-season of birth, sex	Haile-Mariam and Kassa-Mersha (1994)
	Sahiwal	170	Kenya	Year-season of birth, sex, dam parity, breed	Trail and Gregory (1981)
	Boran	170	"	Year-season of birth, sex, dam parity, breed	"
	"	155	"	Parity, sex	Indetie et al. (2000)

[a]LL, lactation length; LMY, lactation milk yield; 305-d MY, 305-day lactation milk yield; BWT, birth weight; AWN, age at weaning; Age55, age at 55 kg body weight.

An evaluation of growth performance of Sahiwal and Boran breeds in Kenya revealed that both breeds weaned their calves at an average weight of 170 kg although Borans were heavier at 22 months (Trail and Gregory, 1981). The difference could be due to the higher individual additive genetic influence on the growth of Boran cattle than Sahiwal. The WWT of Boran breed is variable. This could be a reflection of the calf rearing systems and environmental conditions of the herds where the data were obtained. Calves that are allowed to suckle their dams have high growth rates and are heavier at weaning than their bucket fed counterparts (Haile-Mariam and Kassa-Mersha, 1994; Demeke et al., 2003). Information on WWT of Sahiwal calves at the NSS is scarce in the literature due to the existing management policy of weaning the young stock at a specific weight of 55 kg.

The differences between countries in productive traits is expected because of the inherent differences that exist in production circumstances, climatic conditions and management practices, including quantity and quality of nutrient resources available (Rege et al., 1992; Haile-Mariam and Kassa-Mersha, 1994; Yadav et al., 1995; Dahlin et al., 1998; Demeke et al., 2004a). The differences mainly result through nutrition, disease incidences and management practices both within herds and across countries. The observed variation in mean performances on most of the production traits is due to great interannual variation in climate, resulting in poor pasture quality and availability, lack of supplimentary feeding and high disease incidence, which is typical of most tropical countries. Acceptable levels of management tend to increase performance on production traits. Any improvement strategy targeted towards these areas should therefore be able to realise substantial improvement

Table 2. Functional traits of the Sahiwal and some *B. indicus* dual-purpose breeds in the tropics

Trait[a]	Breed	Mean	Country	Significant effects fitted	Reference
CI (days)	Sahiwal	465	Pakistan	Herd, year,season and age at calving	Khan et al. (1999)
	"	426	Kenya	Parity, year-season of calving	Rege et al. (1992)
	"	544	India	Year, season of calving	Dhaka et al. (2002)
	"	446	Kenya	Parity, year-season of calving	Muhuyi (1997)
	"	493	India	Year- season of calving	Yadav et al. (1995)
	Hariana	415	"	Period, season of calving, breed	Yadav et al. (1995)
	"	486	"	Year, season of calving	Dhaka et al. (2002)
	Tharpakar	486	"	Year, season of calving	"
	"	431	"	Period, season of calving, breed	Yadav et al. (1995)
	Boran	473	Ethiopia	Parity, year of birth	Demeke et. (2004b)
	"	442	"	Year-season of calving	Haile-Mariam and Kassa-Mersha (1994)
NSC	Sahiwal	2.1	Kenya	Year-season of calving, parity	Rege et al. (1992)
	"	2.0	India	Year, season of calving	Dhaka et al. (2002)
	Tharpakar	1.9	"	"	Dhaka et al. (2002)
	Hariana	2.0	"	"	"
	Boran	1.7	Ethiopia	"	Demeke et. (2004b)
AFC (days)	Sahiwal	1323	Pakistan	Herd-year-season of birth	Khan et al. (1999)
	"	1230	Kenya	Year-season of calving	Rege et al. (1992)
	"	1388	India	Year, season of birth	Dhaka et al. (2002)
	"	1236	Kenya	Year-season of calving	Muhuyi (1997)
	Nandi Zebu	1290	"	-	Rege et al. (2001)
	Sahiwal	1467	India	Year-season of calving, inbreeding coefficient	Nandagawali et al. (1997)
	Hariana	1455	"	Year, season of birth	Dhaka et al. (2002)
	Tharpakar	1426	"	"	"
	Boran	1275	Ethiopia	Year, season of birth, parity	Demeke et al. (2004b)
	"	1271	"	Year-season of birth	Haile-Mariam and Kassa-Mersha (1994)
	Rathi	1388	India	Period-season of birth	Singh et al. (1997)

[a]CI, calving interval; NSC, number of services per conception; AFC, age at first calving.

2.4.2. Fertility traits

Mean performance estimates for some fertility traits for the Sahiwal and other *B. indicus* cattle reported in the tropics are summarised in Table 2. This may indicate a failure to maintain a uniform reproductive management in the herds. Prolonged CI is undesirable particularly in production systems in which there is high demand for pregnant or lactation heifers and feed resources are scarce (Rege, 1991; Musani and Mayer, 1997; Khan et al., 1999). Therefore, improvement of this trait can be achieved through management interventions, which include proper feeding, accurate heat detection and timely insemination and control of reproductive disorders.

The Sahiwal cattle in Kenya are being served and calve down for the first time at an earlier age than the Rathi cattle in India (Singh et al., 1997) and the Sahiwal cattle in Pakistan (Khan et al., 1999). The mean AFC of the Boran cattle in Ethiopia (Haile-Mariam and Kassa-Mersha, 1994; Demeke et al., 2004b) is comparable to that reported for the Sahiwal in Kenya (Rege et al., 1992) but lower than that reported in Pakistan (Khan et al., 1999). Differences in mean AFC may be due to different management between herds and countries. For example, in studies of the Sahiwal cattle in Kenya the management policy requires that heifers be served at a specific weight, which affected the age at first service.

2.4.3. Non-genetic factors influencing production and functional traits

Various factors influence productive and reproductive performances of dairy and beef cattle. These factors are usually included in the analysis to account for environmental sources of variation in the animals' performance, as main factors or interactions either as fixed effects or as continuous effects (Bebber et al., 1997). Fixed effects are defined into classes comprising of all the possible levels of interest and they include, herd, year, season, sex, breed and parity. Continuous effects are sources of variation usually not defined into class levels and have a continuous influence on the observation and are usually fitted as covariates. Such effects include age related effects like age of the calf at weaning and age of the cow at birth or calving. Results from the literature (Table 1 and 2) indicate that these effects influence productive and reproductive performances of *B. indicus* cattle in the tropics. Season effects cause variation in milk production due to differences in climate and management practices and thus the performance level of most *B. indicus* cattle tends to reflect seasonal variation. In the tropics, seasonality in performance is primarily a manifestation of fluctuations in feed quality and quantity, in which case the significance of seasons depends on the sensitivity of the trait to these. Herd management practices, for instance supplementation during dry

seasons should be able to smoother out seasonal differences as a result of differential nutrition. Cows on low nutrition require more inseminations to conceive. This is because nutrition is responsible for the cows body condition during service, conception and successful parturition (Nebel and McGilliard, 1993). During the dry season, cows are usually underfed and tend to exhibit silent heat. As a result, insemination and conception are delayed, leading to prolonged days open and calving intervals. Furthermore, there are diseases that are prevalent during certain seasons, which without properly defined disease control programmes, are likely to affect performance adversely.

Interannual climatic variation is one of the important causes of the year of calving/birth effect by its major influence on pasture quality and availability, and hence affects herd management practices. Therefore its effect on performance of *B. indicus* cattle in the tropics is important (Rege et al., 1992; Muhuyi, 1997; Dahlin et al., 1998; Khan et al., 1999; Demeke et al., 2004a). Cows calving during unfavourable years exhibit depressed performances especially in cases where the management policy does not put emphasis on proper feeding and diseases control practices during such times (Rege et al., 1992; Muhuyi, 1997; Dahlin et al., 1998; Khan et al., 1999). Similarly calves born during such periods will exhibit slow growth rates and attain maturity at later stages (Trail and Gregory, 1981; Haile-Mariam and Kassa-Mersha, 1994; Demeke et al., 2003).

Significant herd effects imply differences in management between herds when performance data is drawn from different herds which is an indicator of the differences in management levels between the herds therefore an important source of variation in animal performance. (Singh and Nagarcenkar, 1997; Dahlin et al., 1998; Khan et al., 1999). Sex is an important source of variation in the analysis involving growth traits (Table 1). This is attributed to the differences in physiological changes in maturing characteristics between the sexes resulting in sexual dimorphism in growth performance (Trail and Gregory 1981). In most studies involving *B. indicus* cattle in the tropics, male cattle were heavier than their female counterparts at all ages (Trail and Gregory, 1981; Mwandotto, 1985; Rege et al., 1992; Indetie et al., 2000; Demeke et al., 2003)

Milk yield and reproductive performances have been reported to significantly influenced by the age or parity of the cow (Rege et al., 1992; Yadav et al., 1995; Dahlin et al., 1998; Singh and Nagarcenkar, 1997; Demeke et al., 2004a). Age at first calving is an important factor affecting the productive performance of dairy cows in first and later lactations (Singh and Nagarcenkar, 1997; Dahlin et al., 1998). Early breeding of the Sahiwal cows in Pakistan had negative consequences of low first lactation milk production, but milk

yield increased with age at calving in subsequent lactations (Dahlin et al., 1998). Mature cows are characterised by complete udder development hence capable of producing more milk than first calvers (Akers, 2000). However, this will depend on nutritional management and selection for early maturity. Age is an important variable in dairy cattle performance and therefore has to be taken into account when analysing performance records to eliminate bias and make comparison feasible.

The inclusion of fixed effects in the analysis of production and fertility traits should be able to cater for the variation in performance. Accurate description of the environment from which the data was obtained and the suitability of the model fitted are critical for the correction of non-genetic effects in the analysis of performance data and genetic evaluation (Bebber et al., 1997; Khan et al., 1997; Powell and Norman, 1998).

2.5. Genetic and phenotypic parameters

Genetic and phenotypic parameters are useful measures of variation and knowledge of their estimates is necessary to predict response to selection and genetic gain expected from selection programmes, select between various breeding strategies and evaluate livestock improvement programmes (Sorenson and Kennedy, 1984; Roman and Wilcox, 2000). Although it would be desirable to have enormous well balanced data sets to obtain better estimates of genetic and phenotypic parameters (Henderson, 1984), animal breeding data sets are often unbalanced and therefore true parameters are never known. With recent developments in quantitative genetics and the resultant tendency to apply more efficient breeding plans, accurate estimates of genetic and phenotypic parameters by fitting models that best describe the observation are required. Genetic and phenotypic parameters of importance in most selection programmes are discussed below.

2.5.1. Heritability

This refers to that part of the phenotypic variance that is attributable to heredity. It is the extent to which additive genes influence phenotypic observation of a particular trait. Heritability determines the degree of resemblance between related individuals by expressing the proportion of total variance that is due to differences in breeding values. Heritability is a property of the character, the population from which the data is accrued and the environmental circumstances to which the population is subjected (van Vleck, 1993; Falconer and Mackay, 1996). This implies that heritability estimates may vary depending on the gene frequency, previous selection and the environment. Traits with high heritability can be improved through selection, with response to selection and genetic gain expected to be great.

2.5.2. Repeatability

Repeatability is a measure of the extent to which the repeated records are correlated. It is that fraction of variance attributable to the permanent differences, both genetic and environmental. It is measured as the intra-class correlation (ICC) among repeated records within individuals and is estimated as a ratio of the variance due to effect of individuals and variance among repeated measures within individuals (Meyer and Hill, 1997). The practical application of repeatability measure is to predict a future record on the basis of other records, producing abilities of individuals and the change that can result from culling poor producers from the population. Repeatability estimates will vary depending on the character, genetic properties of the population and the environmental circumstances surrounding the individuals.

2.5.3. Correlations

Any automatic response in the unselected trait occurring simultaneously with the response in the trait under selection is defined as the correlated response. Phenotypic correlations among traits are gross correlations that include both the environment and genetic portions of the covariance. Genetic correlations among traits indicate how two traits are affected by similar genes regulating physiological processes, i.e. the correlation between additive genetic value of the two traits, environmental deviation and non additive genetic deviations (Falconer and Mackay, 1996; Roman and Wilcox, 2000). They directly influence the size of selection differential when several traits are included in a selection index, especially with high correlation among traits (Lasley, 1987). It is therefore important to estimate this parameter for design of efficient selection plans and for prediction of possible correlated changes in traits when selection for other traits has been applied.

2.5.4. Some estimates of genetic and phenotypic parameters for production and functional traits

Heritability and repeatability

Heritability and repeatability estimates of some production and fertility traits are summarised in Table 3 and 4. There are differences in estimates of heritability and repeatability of *B. indicus* cattle in the tropics. These differences arise mainly from the amount of data used, models fitted in estimating genetic parameters, and definition of the various effects in the model. Some studies were based predominantly on small data sets (e.g., Pundir and Raheja, 1994; Bajwa et al., 2002; Choundhary et al., 2003), which indicate that the parameter estimates may be biased to some extent due to sampling errors.

Table 3. Heritability and repeatability estimates of milk production and fertility traits of the Sahiwal and other *B. indicus* dual purpose breeds in the tropics

Trait[a]	Heritability				Repeatability	Breed	Model[b]	Reference
	Lactation							
	1	2	3	Pooled				
LMY	0.15	0.12	0.17	0.17	0.42	Sahiwal	UAM	Dahlin et al. (1998)
	0.18					"	MAM	Choudhary et al. (2003)
				0.15	0.46	"	UAM	Bajwa et al. (2002)
	0.27			0.34	0.60	"	PHS	Singh and Nagarcenkar (1997)
	0.17	0.15	0.20			"	MAM	Dahlin et al. (1998)
	0.28					"	SM	Pundir and Raheja (1994)
	0.37					Tharpakar	PHS	Basu et al. (1982)
				0.38		"	PHS	Bhatnagar et al. (1982)
				0.39		Hariana	PHS	Misra et al. (1980)
305-d MY	0.14	0.11	0.15	0.17	0.42	Sahiwal	UAM	Dahlin et al. (1998)
	0.16	0.14	0.22			"	MAM	Dahlin et al. (1998)
				0.36	0.38	"	SM	Rege et al. (1992)
	0.35	0.47	0.31			"	PHS	Kimenye (1978)
LL	0.17	0.09	0.11	0.15	0.31	"	UAM	Dahlin et al. (1998)
	0.14	0.14	0.17			"	MAM	"
	0.13					"	MAM	Choudhary, et al. (2003)
	0.25			0.27		"	PHS	Singh and Nagarcenkar (1997)
				0.16		"	PHS	Kimenye (1978)
				0.32		"	SM	Pundir and Raheja (1994)
CI	0.08			0.15	0.39	"	SM	Rege et al. (1992)
	0.07	0.04	0.05			"	UAM	Khan et al. (1999)
	0.06	0.05	0.03			"	MAM	"
					0.34	"	ICC	Gandhi and Gurmani (1992)
	0.26			0.28		White Fulani	SM	Mrode and Akinokun (1986)
AFC	0.12					Sahiwal	MAM	Khan et al. (1999)
	0.24					Sahiwal	SM	Pundir and Raheja (1994)
	0.29					Sahiwal	SM	Rege et al. (1992)
	0.40					Hariana	PHS	Misra et al. (1980)
	0.24					Tharpakar	PHS	Basu et al. (1982)
	0.06					Boran	AM	Haile-Mariam and Kassa-Mersha (1994)
	0.26					White Fulani	SM	Mrode and Akinokun (1986)
NSC	0.02					Sahiwal	SM	Rege et al. (1992)

[a]LMY, lactation milk yield; LL, lactation length; 305-d MY, 305 day milk yield; CI, calving interval; AFC, age at first calving; NSC, number of services per conception.
[b]UAM, univariate animal model; MAM, multivariate animal model; PHS, paternal half-sib correlation; SM, sire model; ICC, intra-class correlation.

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In general, milk production traits have medium to high heritability (Rege et al., 1992; Dahlin et al., 1998; Bajwa et al., 2002; Choundhary et al., 2003). The moderate values of heritability for LMY imply that the additive genetic variance for milk production in *B. indicus* cattle is rather high, which offers an opportunity to improve this trait through selection. Repeatability estimates for milk yield and LL are relatively high (Table 3), indicating that variation in these traits could be attributed to differences among individuals. Therefore, poor producers can be culled based on records in early lactation with some reasonable degree of accuracy. Differences in herd management and other environmental factors influence most reproductive traits, resulting in rather low heritability estimates (Rege et al., 1992; Khan et al., 1999; Dhaka et al., 2002). Nonetheless, significant genetic variation exists for certain traits indicating the possibility to improve reproductive performance in the Sahiwal cattle selection programmes in the tropics.

Table 4. Heritability estimates of growth traits of the Sahiwal and other *B. indicus* cattle in the tropics

Trait[a]	Breed	Country	Model[b]	Parameter[c]		Reference
				h^2	m^2	
BW	Sahiwal	Kenya	SM	0.35		Rege et al. (1992)
	Boran	Ethiopia	AM	0.26		Haile-Mariam and Kassa-Mersha (1994)
WWT	"	"	AMM	0.07	0.03	Demeke et al. (2003)
MW	Sahiwal	Kenya	PHS	0.15		Mwandotto (1994)
Age55	"	"	SM	0.35		Rege et al. (1992)
27MWT	"	"	PHS	0.31		Mwandotto (1994)
12MWT	Boran	Ethiopia	AM	0.41		Demeke et al. (2003)

[a]BW, birth weight; WWT, weaning weight; MW= mature weight; Age55, age at 55 kg; 27MWT, weight at 27 months; 12MWT, weight at one year.
[b]PHS, paternal half sib correlation; SM, sire model; AM, animal model; AMM, maternal animal model.
[c]h^2, direct heritability; m^2, maternal heritability.

Available heritability estimates for AFC are variable and range from 0.06 to 0.40 (Table 3). The wide range of heritability seems to suggest variation in environmental and other management factors. However, in herds where heritability for AFC is medium to high then selection pressure on this trait can yield fruitful results (e.g., Misra et al., 1980; Basu et al., 1982; Mrode and Akinokun, 1986; Pundir and Raheja, 1994). Heritability estimates for NSC as a measure of reproductive performance are scarce in the literature. The few estimates available show that the trait has low heritability (Rege et al., 1992). In *B. taurus* breeds, low heritability estimates for NSC have been reported (Berger et al., 1981; Hansen et al., 1983; Musani and Mayer, 1997; Dematawewa and Berger, 1998). The rather low heritability for NSC suggests that selection to alter this trait could be ineffective. Management would probably be more effective in improving the trait.

Estimates of heritability for CI range from low to medium (Table 3). In the Sahiwal cattle in Pakistan (Khan et al., 1999) and Kenya (Rege et al., 1992), the estimated values were low. However, Mrode and Akinokun (1986) reported a higher heritability for CI in white Fulani cattle, which suggest a considerable variation among animals for the trait in the breed. The low heritability reported for the Sahiwal cattle in the tropics imply that CI responds to the choice of better management practices and that direct selection for the trait would not result in substantial improvement.

There are differences in heritability estimates of various growth traits in *B. indicus* in the tropics (Table 4). These differences may be attributed to differences in the population structure of the herds, the model fitted for in the estimation of genetic parameters, the breed and the environment where the data was obtained. However, there is large additive genetic variance for growth traits in *B. indicus* cattle breeds in the topics which offers an opportunity to improve growth and maturing characteristics through selection.

Correlations

Table 5 shows estimates of genetic and phenotypic correlations between various production and functional traits in the Sahiwal cattle. Genetic and phenotypic correlations between milk yield and LL is favourable (Dahlin et al., 1998; Choundary et al., 2003). Increased selection for milk yield would result in a correlated response in LL. The high genetic correlation between LMY and LL imply that the latter accounts for most of the variation in lactation yield. Lactation length would therefore be used in selection for increased milk yield in tropical cattle breeds where milk recording is remote (Syrstad, 1993; Dahlin et al., 1998). Unfavourable relationship exist between milk production and fertility (Khan et al., 1999), which imply that long term selection for increased milk production is likely to result in loss of reproductive efficiency. Cows with high LMY also exhibit longer service periods, which result in extended days open and CI (Lee et al., 1997). High yield during early lactation increase the current days open (DO) and CI, possibly because of a biological antagonism between energy balance and reproductive cycling (Nebel and McGilliard, 1993; Veerkamp et al., 2001). Estimates of genetic and phenotypic correlations between growth and milk production and between growth and reproductive traits in *B. indicus* are scarce in the literature.

Table 5. Genetic and phenotypic correlations between production and fertility traits of the Sahiwal

	Traits[a]	Genetic	Phenotypic	Reference
LMY	LL	0.46	0.67	Choundhary et al. (2003)
"	LL	0.86	0.77	Dahlin et al. (1998)
"	CI	0.68	0.19	Khan et al. (1999)
"	AFC	-0.12	0.03	"
"	"	-0.12	0.06	Rege et al. (1992)
"	"	-0.12	0.06	Choundhary et al. (2003)
"	NSC	-	0.06	Rege et al. (1992)
LL	CI	0.90	0.37	Khan et al. (1999)
"	AFC	0.27	0.03	Khan et al. (1999)
AFC	CI	0.02	0.07	"

[a]LL, lactation length; CI= calving interval; AFC, age at first calving; NSC, number of services per conception.

2.6. Methods of estimating genetic parameters

2.6.1. Least squares techniques

Traditionally, phenotypic covariances between relatives have been estimated using analysis of variance (ANOVA). This requires that individuals be assigned to groups with the same degree of relationship for all the members, with family structures such as paternal half sib. However, data arising from animal breeding is often unbalanced and therefore assumptions made in using ANOVA are often violated. To overcome this problem, Henderson (1953) described three methods of analyses of unbalanced designs in animal breeding data, i.e., Henderson's method I, II and III. Henderson's method III which is the most complex and accurate of the three has found extensive use for handling unbalanced data and fitting both fixed and random effects in a model. This method replaces the sum of squares in the balanced ANOVA by quadratic forms involving the least square solutions of effects for which variances are to be estimated. Moreover, selection is often a genetic improvement strategy in most livestock breeding programmes and therefore performance data may not be a random sample of the population contrary to assumptions in ANOVA, resulting in biased predictors (Henderson, 1984). Selection results in reduced variances of breeding values, and correlation between breeding values and errors become evident (Henderson, 1984).

2.6.2. Maximum likelihood procedures

Their desirable statistical properties and availability of computer algorithms to solve various equations propelled general interest in maximum likelihood (ML) estimators of variance components (Hill and Meyer, 1988). Of particular interest is their great deal of flexibility, allowing for any structure of genetic relationship, design and accounts for selection in the population, which cannot be accommodated for by ANOVA type of estimators. In the

estimation of variance components by ML, data is generally assumed to have a multivariate normal distribution. However, this is bound to lead to biased estimates since the loss of degrees of freedom when estimating the fixed effects part of the model is not accounted for (Meyer, 1989). Modification of the ML into a restricted maximum likelihood (REML) resulted in the adjustment of the observation by accounting for the loss of degrees of freedom when fitting fixed effects. This method maximises only that part of the likelihood, which is independent of the fixed effects unlike ML, and therefore estimates that are less biased. It is also robust against some kind of selection and non-random mating, which would otherwise lead to bias when using earlier approaches (Meyer, 1991).

2.6.3. Other methods

A variety of other methods of estimating variance components exist. These include non-iterative procedures of minimum variance (MIVQUE) and norm (MINQUE) quadratic unbiased estimation and Bayesian approaches to estimation of genetic parameters (Gianola and Fernado, 1986). Gibbs sampling, based on Bayesian methods, has been used to estimate variance components (Wang et al., 1994; Van Tassel and Van Vleck, 1996). Use of Gibbs sampling allows not only point estimates but also confidence intervals for posterior distribution of the variance components without approximations or normality assumption (van Tassell and van Vleck, 1996). However, some of these methods do not account for selection in field data and therefore biased compared to REML procedures (Ouweltjes et al., 1988). Approximation to the REML procedures, which are computationally simple such as pseudo REML and the REML inverse of the coefficient matrix have also been used to estimate variance and covariance components (Wright et al., 1987).

2.7. Genetic evaluation of dairy cattle

The main goal in dairy cattle selection programmes is to maximise genetic progress and profitability of production. It is therefore desirable to select animals of high genetic merit to accelerate genetic gain. In most cases, this amounts to finding animals with the best additive genetic effects (breeding values) to serve as parents for future generations (Kelm et al., 1997). The most effective method for evaluating breeding values for these animals would be to determine their genotypes directly. In practice, however, this is not possible, but instead assess merit of the genotype by indirect methods with knowledge of the phenotype (Alberro, 1974). This phenotypic assessment is based on the type-conformation, performance of the individual and his/her relatives, while removing variations that arise due to systematic environmental effects (Kennedy et al., 1988; Bebber et al., 1997; Powell and Norman, 1998;

Togashi et al., 2004). In dairy cattle, because milk production is a sex-limited trait, a combination of this information determines the value of a male as a parent. With dramatic improvement and development of sophisticated statistical methods in genetic evaluation, current methods should be adopted to be able to predict genetic merit more accurately using the available information (Bourdon, 1998).

2.7.1. Methods of genetic evaluation

Contemporary comparison

This is a method of sire evaluation where records of a particular sire are compared with their contemporaries. Contemporaries are cows within that herd subjected to the same management regime as the daughters of that sire and should have lactated almost at the same time (Lasley, 1987). This method is based on the assumption that all herdsmates are drawn randomly from one genetically homogeneous population, that there's no genetic trend in this population, and that the bull's daughters and their herdsmates are subjected to the same severity of culling for milk yield (Dickinson, 1974). Contemporary comparison has been biased by incorrect adjustment for age at freshening, genetic trend, genetic differences between sire sampling programmes, non-random distribution of AI sires among herds and non-random sampling of mates within a herd (Everett, 1974). This method does not utilise a lot of available information in computing breeding values and ignores the dam's influence on performance of its progeny. Contemporary comparison has been the method of choice for calculating breeding values for sires at the NSS (Mwandotto, 1985).

Modified contemporary comparison

Modified contemporary comparison differs markedly from contemporary comparison (CC) in that all available lactation records are used. Daughter-herdsmates are weighted so that those of similar parity receive greater emphasis than those of different parities, hence modified contemporary comparison (Dickinson, 1974). In this method, two contemporary groupings are used. One group includes the daughter's first lactation compared with their contemporaries in the same lactation. The second group includes records on at least second lactation for the daughter of a sire with contemporary average, encompassing records initiated during a five-month interval (Lasley, 1987). In this method, the dam is only represented by her sire, which imply that maternal half sibs and dams' own performance is not considered (Cassell, 1988).

Best linear unbiased prediction (BLUP)

This is the current method of choice for genetic evaluation of continuously distributed traits in most selection programmes. Breeding values are Best Linear Unbiased Predictions, and the procedure of using linear models in genetic evaluation is therefore called BLUP (van Vleck, 1993). Best means the procedure maximises the correlation between true and predicted breeding values (minimises prediction error variance); Linear implies that the predictors are linear additive functions of the observation; Unbiased because the predicted breeding value is equal to the expected value of the true breeding value; and prediction comes from the fact that the procedure is dealing with a random variable to predict an outcome. When using BLUP, genetic and environmental effects, and the mean are simultaneously estimated which guarantees unbiased estimates (Henderson, 1975). Pedigree merit calculated by BLUP has been shown to be more accurate in the evaluation of AI sires than a pedigree index from modified contemporary comparison (Samuelson and Pearson, 1995). There are various models that can be used within the BLUP framework. The sire and animal model, which are commonly used, are discussed below.

Sire model

When the genetic effect involved in a record is a sire effect, then the model of evaluation is a sire model (Togashi et al., 2004). The general model fitted can be written as;

$$y = Xb + Zs + e \qquad (8)$$

where y is a vector of observations, b a vector of fixed effects, X and Z incidence matrices associated with vectors b and s, respectively, s a vector of random sire genetic effects, and e the random residual.

$$E \begin{matrix} s \\ e \end{matrix} = \begin{matrix} 0 \\ 0 \end{matrix} \text{ and } \text{var}\begin{bmatrix} s \\ e \end{bmatrix} = \begin{bmatrix} A\delta_s^2 & 0 \\ 0 & I\sigma_e^2 \end{bmatrix}$$

where A is the numerator relationship matrix among the sire and I the identity matrix. The random component corresponds to the sire for which the breeding value is to be estimated (Togashi et al., 2004). The sire model assumes that there is no relationship among the dams and that sires are randomly mated to the dams (Meyer, 1987; Cassell, 1988). However, these assumptions do not hold in most dairy cattle breeding programmes because sires are usually assigned to particular dams, which in essence introduces bias in sire evaluation (Meyer, 1987; Cassell, 1988). Quaas (1979) proposed the sire maternal grandsire model to account for the effect of the maternal grandsires of the cows.

Animal model

This is perhaps the most sophisticated model and predominantly widely used for estimation of breeding values (Meyer, 1991; Harris and Johnson, 1998; Israel and Weller, 2000; Togashi et al., 2004). The genetic effect involved in the observations is the animal. The breeding value of each animal is modelled as a random component of the model with each record providing information about the additive genetic merit of the animal (Kennedy et al., 1988; Mrode, 1996). The general model could be written as;

$$y = Xb + Za + e \quad (9)$$

where y, X, b, e are as defined in equation 8, a the vector of random animal's genetic effects and Z is the incident matrix associated with vector a.

$$\text{var}\begin{bmatrix} y \\ a \\ e \end{bmatrix} = \begin{bmatrix} v & ZA'\sigma_a^2 & R \\ AZ'\sigma_a^2 & g & 0 \\ R & 0 & R \end{bmatrix}$$

$R = I\sigma_a^2$ and $V = ZGZ' + R$

Animal model increases the accuracy of estimating breeding values by utilising performance of an individual and information from relatives and accounting for non-random mating and changes in genetic trends involving multiple generations (Meyer, 1991; Israel and Weller, 2000; Togashi et al., 2004). Milk production and reproductive performance data can be analysed under the animal model in various ways. This could be based on conventional univariate and multivariate animal models, or extension of these models into TDMs for analysis of milk production traits.

2.8. Models for the genetic evaluation of cattle

2.8.1. Conventional models

Univariate animal model

When fitting this model, all records are assumed to be measurements of the same trait (Pollak and Quaas, 1983; Reents, 1995; Meyer and Hill, 1997). It implies that all genetic variances and covariances are of the same magnitude. All phenotypic variances are considered identical, and phenotypic correlations and covariances among all measurements are assumed to be the same (Meyer and Hill, 1997). This is a model that has been predominantly used to estimate genetic parameters and predict breeding values of dairy cattle in the tropics (Musani and Mayer, 1997; Dahlin et al., 1998; Ojango and Pollot, 2001; Demeke et al., 2004a). The main reason of fitting univariate models would be reduced computational demands and

accounting for individual permanent environmental effects due to repeated measures on the same animal.

Multivariate animal model

The multivariate animal model takes into consideration all interrelationships among traits and utilises the covariance structure among traits (Pollak and Quaas, 1983; Meyer and Hill, 1997). The multiple trait model is the optimum methodology when selection is based on two or more traits, because it accounts for the actual phenotypic and genetic correlation between traits in simultaneously evaluation of animals. Unlike in the univariate models, the effect of selection on variance is accounted for, and environmental factors are better adjusted for. However, a multivariate model in which many traits are analysed would result in a highly overparametrised analysis, which would impose unnecessary computational demands and yield estimates with greatly increased sampling errors (Meyer and Hill, 1997). Therefore, models that fit the least number of traits while adequately describing the data need to considered.

2.8.2. Test day models

Milk production traits are measured repeatedly over time. These repeated observations on the same animal could be described by a function of time, where milk yield at a particular time can be considered as a distinct trait (Meyer and Hill, 1997). In the tropics breeding programmes concerning milk production have always been evaluated based on the analysis of standardised lactations yields generated from sets of TMY made throughout the lactation period (e.g., Rege et al., 1992; Musani and Mayer, 1997; Dahlin et al., 1998; Ojango and Pollot, 2001). However, conventional models based on standardised milk yields for estimating genetic parameters cannot account for effects associated with individual TMY, as contemporary groups are formed on the basis of year season of calving (Jamrozik and Schaeffer, 1997; Swalve, 1998). The current trend is therefore to change the data used for genetic evaluation from standardised lactation yields to TMY where dairy sires and cows can be evaluated and ranked based on a single or a few yield records (Ptak and Schaeffer, 1993).

Statistical procedures based on TMY consider both genetic and environmental effects that are specific to a particular TD, which gradually but continuously change over the course of lactation (Ptak and Schaeffer, 1993; van der Werf et al., 1998). This gives a more precise definition of the contemporary groups, and allows more accurate description of the changing effects due to disease, medical treatment, pregnancy status and stage of lactation, which would be difficult to model with conventional models (Meyer et al., 1989; Ptak and Schaeffer,

1993; Vischer and Goddard, 1995; Schaeffer et al., 2000; Kettunen et al., 2000). The cost of dairy cattle performance recording could be reduced by allowing flexible recording schemes where any information on TMY can be used (Schaeffer et al., 2000; Swalve, 2000).

While conventional models used for analysis of standardised and total lactation yields are relatively simple and require few parameters, TDMs are much more complex and would require more parameters, which is computationally expensive (Misztal et al., 2000; Jensen, 2001). Despite this, the advantages of TDM far much outweigh the short-term disadvantages. Two types of TDMs have been developed for evaluation of dairy herds; fixed regression and random regression TDMs.

Fixed regression TDMs

These models have been derived from conventional univariate and multivariate models. A single trait TDM is an extension of the univariate repeatability model under which the TMY within a lactation are taken as repeated measurements (Ptak and Schaeffer, 1993; Reents et al., 1995). The curvilinear pattern of production is accounted for by fixed regressions of days in milk in the model (Ptak and Schaeffer, 1993; Swalve, 2000; Jensen, 2001). A simplified scalar version of the fixed regression TDM for yield records in a single lactation could be written as;

$$y = F + \sum b_1 x_1 + a + p + e \qquad (10)$$

where y is the TMY, F is the fixed effect which could include herd-year season of sampling a TMY or herd-test date, a the random additive genetic affect, p is the permanent environmental effect associated with each cow, e the random residual. The lactation curve is accounted for by several coefficients of a fixed regression of yield on days in milk, $\sum b_1 x_1$.

Considering the random effects, the model assumes a constant additive genetic and permanent environmental variance throughout the lactation. The genetic and permanent environmental correlations between yields at different days in milk are assumed to be unity, irrespective of the distance between TDs. This model has been extended to a multiple trait TDM under which TD records within a lactation are considered as separate traits (Pander et al., 1992; Vargas et al., 1998; Kettunen et al., 2000; Machado et al., 1998). It assumes a covariance structure among the TDs with genetic correlations not equal to one. The multiple trait TDM has also been extended to a repeatability multiple trait TDM in which TD records within a lactation are considered as repeated records and the lactations treated as separate traits (Reents et al., 1995; Rekaya et al., 1999; Serrano et al., 2001).

Random regression TDM

This is an extension of the fixed regression models. The random regression (RR) TDM assumes that a lactation curve is influenced by random genetic and permanent environmental effects (Schaeffer and Dekkers, 1994; Jamrozik et al., 1997; Jamrozik and Schaeffer, 1997; Swalve, 2000; Schaeffer et al., 2000). In this model, the genetic and permanent environmental variances during the lactation can be accommodated (Schaeffer and Dekkers, 1994; Jamrozik and Schaeffer, 1997; Mistzal et al., 2000; Schaeffer et al., 2000). Schaeffer and Dekkers (1994) suggested the concept of using RR in the genetic evaluation of dairy cattle. In a simplified scalar form, the RR model could be written as;

$$y = F + \sum b_i x_i + \sum a_j x_j + \sum p_k x_k + e \qquad (11)$$

where y is as defined in equation 10, a the additive genetic effect corresponding to regression coefficient j, x_j and x_k the corresponding covariates for the additive and permanent environmental effects, respectively. Covariates x_i are usually parameters of the Wilmink functions (Wilmink, 1987) or functions of legendre polynomials (van der Werf et al., 1998; Kettunen et al., 2000).

Random regression TDMs contains linear functions and random coefficients and a set of covariates to describe the shapes of lactation curves for individual or groups of cows (Schaeffer and Dekkers, 1994; Jamrozik et al., 1997). These makes it possible to predict persistence for future cows or daughters of a particular sire, and provide for a more biological description of a cow's performance across the lactation period (Schaeffer and Dekkers, 1994; Jamrozik and Schaeffer, 1997; Swalve, 1998; Schaeffer et al., 2000). Reduced rank random regression models have been proposed because of the reduced dimension of TDMs, which reduces computation time (Wiggarns and Goddard, 1997; van der Werf et al., 1998; Lidauer et al., 2003).

2.9 Genetic, environmental and phenotypic trends

It is important for any cattle breeding programme to have some knowledge regarding the rate of change occurring in a particular herd. Thus, bifurcation of the phenotypic trend into genetic and environmental trends will enable the breeder in assessing the effectiveness of the selection programme and management conditions over time (Musani and Meyer, 1997; Dahlin et al., 1998; Khan et al., 1999; Ojango and Pollot, 2001). Such efforts help in designing more appropriate genetic improvement and management strategies. The Sahiwal cattle improvement programme has basically emphasised improvement of milk production (Rege et

al., 1992; Muhuyi, 1997; Singh and Nagarcenkar, 1997; Dahlin et al., 1998). It is therefore expected to show positive phenotypic trend for this trait due to high selection emphasis on it.

Positive and desirable genetic and environmental trends for milk production have been reported for some Sahiwal herds in India (Singh and Nagarcenkar, 1997). However, the direction of change has been somewhat slow or even negative in the Sahiwal populations in Kenya and Pakistan (Rege and Wakhungu, 1992; Dahlin et al., 1998; Khan et al., 1999). The magnitude and direction of the change reflect the failure of the existing selection and management goals in the two countries (Rege and Wakhungu, 1992; Dahlin et al., 1998; Khan et al., 1999). These suggest that proven sires may not have been selected and utilised effectively and the effect of inimical environmental under which the herds were performing was not smothered out through proper managemental interventions. Decline in milk and reproductive performance of Sahiwal cattle in the tropics is of great concern (Rege and Wakhungu, 1992; Dahlin et al., 1998; Khan et al., 1999). This apparent decline is associated with lack of proper genetic improvement and managemental strategies. Better evaluation methods and sound herd management practices should be able to give opportunity to cow and sires of high genetic merit to be utilised in these herds.

2.10. Conclusions

Genetic evaluation has improved dramatically over the past few decades from the contemporary comparisons to the recent mixed model BLUP methodology. Statistical models for estimating genetic and phenotypic parameters have also progressed from the sire model to the animal model, and from univariate to multiple trait models. Genetic evaluation of dairy sires and cows based on TMY is replacing the conventional evaluation based on total lactation or standardised lactation milk yields. Much of these improvements could be attributed to the development of more appropriate statistical methods that overcome inherent biases in genetic evaluation using field data. These methods when combined with modern computing facilities allow the use of more information to evaluate dairy cattle breeding programmes with greater accuracy than before. Because of the statistical properties of the animal model, it was used in this study for the estimating genetic and phenotypic parameters of the Sahiwal cattle in Kenya.

References

Abdallah, J. M. and McDaniel, B. T. 2000. Genetic change in milk, fat, days open, and body weight after calving based on three methods of sire selection. *Journal of Dairy Science.* **83**: 1359-1363.

Akers, R. M. 2000. Selection for milk production from a lactation biology view point. *Journal of Dairy Science.* **83**: 1151-1158.

Alberro, M. 1974. Progeny testing in dairy cattle and the selection of bull and calves to raise for breeding stock. *First World Congress on Genetics Applied to Livestock Production.* **1:** 119-128.

Bajwa, I. R., Khan M. S., Ahmad Z. and Gondal, K. Z. 2002. Genetic parameters of lactation milk yield as affected by lactation length adjustment procedures. Seventh *World Congress on Genetics Applied to Livestock Production.* CD-ROM communication N° 01-56.

Basu, S. B., Bhatnagar, D. S. and Taneja, V. K. 1982. Estimates of genetic parameters for first lactation performance in Tharpakar cattle. *Indian Journal of Animal Science.* **52**: 279-283.

Bebber, J., Reinsch, N., Junge, W. and Kalm, E. 1997. Accounting for herd, year and season effects in genetic evaluation of dairy cattle. A review. *Livestock Production Science.* **51**: 191-203.

Bebe, B. O. 2003. Herd Dynamics of Smallholder Dairy in the Kenya Highlands. Ph.D thesis, Wageningen Agricultural University, Wageningen, The Netherlands.

Berger, P. J. Shanks, R. D. Freeman, A. E. and R. C. Laben. 1981. Genetic aspects of milk yield and reproductive performance. *Journal of Dairy Science.* **64:** 114-122.

Bhatnagar, S. D., Taneja, V. K. and Basu, S. B. 1982. Effects of genetic and environmental sources of variation on total lactation yield in Tharpakar cattle. *Indian Journal of Animal Science.* **51:** 1-3.

Bourdon, R. M. 1998. Shortcomings of current genetic evaluation systems. *Journal of Animal Science.* **76**: 2308-2323.

Burrow, H. M. 2001. Variance and covariance between productive and adaptive traits and temperament in a composite breed of tropical beef cattle. *Livestock Production Science.* **70:** 213- 233.

Butler, W. R. and R. D. Smith. 1989. Interrelationship between energy balance and postpartum reproductive function in dairy cattle. *Journal of Dairy Science.* **72**: 767-783.

Campos, M. S., Wilcox, C. J., Becerril, C. M. and A. Diz. 1994. Genetic parameters for yield and reproductive traits of Holstein and Jersey cattle in Florida. *Journal of Dairy Science*. **77**: 867-873.

Cassell, B. G. 1988. What extension workers need to tell dairy farmers. *Journal of Dairy Science*. **71**: 85-90.

Castillo-Juarez, H., Oltenacu, P. A., Blake., W., Mcculloch, C. E. and Cienfuegos, E. G. 2000. Effect of Herd management on the genetic and phenotypic relationships among milk yield, conception rate, and somatic cell score in Holstein Cattle. *Journal of Dairy Science*. **83**: 807-814

Choundhary, V., Kotherkar, M. D., Raheja, K. L., Kasturiwale, N. N., Khire, D. W. and Kumar, P. 2003. Genetic parameters of first lactation traits in Sahiwal cattle using restricted maximum likelihood technique. *Asian-Australian Journal of Animal Sciences*. **16**: 639-643.

Dahlin, A., Khan, U. N., Zafar, A. H., Saleem, M., Chaundhry, M. A. and Philipsson, J., 1998. Genetic and environmental causes of variation in milk production traits of Sahiwal cattle in Pakistan. *Animal Science*. **66**: 307-318.

Darwash, A. O., Lamming, G. E. and Woolliams, J. A. 1997. Estimation of genetic variation in the interval from calving to postpartum ovulation of dairy cows. *Journal of Dairy Science*. **80**:1227-1234.

Dematawewa, C. M. B. and Berger, P. J. 1998. Genetic and phenotypic parameters for 305-day yield, fertility, and survival in Holsteins. *Journal of Dairy Science*. **81**: 2700-2709.

Demeke S., Neser F. W. C. and Schoeman S. J. 2004a. Estimation of genetic parameters for Boran, Friesian and crosses of Friesian and Jersey with Boran cattle in the tropical highlands of Ethiopia: milk production traits and cow weight. *Journal of Animal Breeding and Genetics*. **121**:163-175.

Demeke S., Neser F. W. C. and Schoeman S. J., 2004b. Estimation of genetic parameters for Boran, Friesian and crosses of Friesian and Jersey with Boran cattle in the tropical highlands of Ethiopia: reproductive traits. *Journal of Animal Breeding and Genetics* **121**: 57-65.

Demeke, S., Neser, F. W. C. and Schoeman, S. J. 2003. Variance components and genetic parameters for early growth traits in a mixed population of purebred *Bos indicus* and crossbred cattle. *Livestock Production Science*. **84**: 11- 21.

Dhaka, S. S., Chaundhary, S. R., Pander, B. L., Yadav, A. S. and Singh, S. 2002. Genetic divergence on performance traits among indigenous breeds of cattle. *Seventh World Congress on Genetics Applied to Livestock Production*. CD-ROM communication No. 25-34.

Dickinson, F. N. 1974. The evaluation of dairy sires progeny test by the United States department of Agriculture. *First World Congress on Genetics Applied to Livestock Production.* **1**: 111-118.

Everett, R. W. 1974. Problems in evaluating dairy sires. *First* World *Congress on genetics Applied to Livestock Production*: **1**; 99-103.

Falconer, D. S. and Mackay, T. F. C. 1996. Introduction to Quantitative Genetics, 4th Edition Longman Group, London.

Gandhi, R. S. and Gurnani, M. 1992. Repeatability estimates of some economic traits of Sahiwal cattle over different farms. *Indian Journal of Animal Sciences.* **62**: 571-573.

Gianola, D. and Fernado, R. L. 1986. Bayesian methods in animal breeding. *Journal of Animal Science.* **63**: 217-244.

Haile-Mariam, M. and Kassa-Marsha, H., 1994. Genetic and environmental effects on age at first calving and calving interval of naturally bred Boran (Zebu) cows in Ethiopia. *Animal Production*. 58: 329- 334.

Hansen. L. B., Freeman, A. E. and Berger P. J. 1983. Yield and fertility relationship in dairy cattle. *Journal of Dairy Science.* **66**: 293-305.

Harris, B. and Johnson, D .1998. Approximate reliability under an animal model. *Journal of Dairy Science.* **81** 2723-2728.

Hayes, J. F., Cue, R. I. and H. G. Monardes. 1992. Estimation of repeatability of reproductive measures in Canadian Holsteins. *Journal of Dairy Science.* **75**: 1701-1706.

Henderson, C. R. 1953. Estimation of variance and covariance components. *Biometrics.* **9**: 226-252.

Henderson, C. R. 1975. Best linear unbiased estimation and prediction under selection model. *Biometrics.* **31**: 423-447.

Henderson, C. R. 1984. Estimation of variances and covariances under multiple trait models. *Journal of Animal Science.* **63**: 208-216.

Hill, W. G. and Meyer, K. 1988. Developments in methods for breeding value and parameter estimation in Livestock. *British Society of Animal Production.* **12:** 81-95.

Indetie, D., Kinyua, J. M. and Gachanja, P. M. 2000. Environmental factor contributing to pre-weaning performance of beef cattle in Kenya. Proceedings of the 7th biennial KARI conference. PP 39- 43.

Israel, C. and Weller, J. I. 2000. Effect of misidentification on genetic gain and estimation of breeding values in dairy cattle populations. *Journal of Dairy Science.* **83**: 181-187.

Jamrozik, J., and Schaeffer, L. R. 1997. Estimation of genetic parameters for a test day model with random regression for yield traits of first lactation. *Journal of Dairy Science.* **80**: 762-770.

Jamrozik, J., Schaeffer, L. R. and Dekkers, J. C. M., 1997. Genetic evaluation of dairy cattle using test day yields and random model. *Journal of Dairy Science.* **80:** 1217-1226.

Jensen, J. 2001. Genetic evaluation of dairy cattle using test day models. *Journal of Dairy Science.* **84:** 2803-2812.

Kahi, A. K. and Nitter, G. 2004. Developing breeding schemes for pasture based dairy production systems in Kenya. I. Derivation of economic values using profit functions. *Livestock Production Science.* **88**: 161-177.

Kahi, A. K., Nitter, G. and Gall, C. F., 2004. Developing breeding schemes for pasture based dairy production systems in Kenya. II. Evaluation of alternative objectives and schemes using a two-tier open nucleus and the young bull system. *Livestock Production Science.* **88:** 179-192.

Kahi, A. K., Thorpe, W., Nitter, G. and Baker, R. L., 2000a. Crossbreeding for Dairy production in the Lowland tropics of Kenya. I. Estimation of individual crossbreeding effects on milk production and reproductive traits and cow live weight. *Livestock Production Science.* **63**: 39-54.

Kahi, A. K., Thorpe, W., Nitter, G. and Baker, R. L., 2000b. Crossbreeding for Dairy production in the Lowland tropics of Kenya. II. Prediction of performance of alternative crossbreeding strategies. *Livestock Production Science.* **63**: 55-63.

Kelm, S. C., Freeman, A. E. and D. H. Kelly. 1997. Realized versus expected gains in milk production and fat production of Holstein cattle, considering the effect of days open. *Journal of Dairy Science.* **80**: 1786-1794.

Kennedy, B. W., Schaeffer, L. R. and D. A. Sorensen 1988. Genetic properties of animal models. *Journal of Dairy Science.* **71**: 17-26.

Kettunen, A., Mäntyaari, E. A. and Pösö, J. 2000. Estimation of genetic parameters for daily milk yield of primiparous Ayrshire cows by random regressions test-day models. *Livestock Production Science.* **66**: 251-261.

Khan U. N., Dahlin A., Zafar A. H., Saleem M., Chaudhry M. A. and Philipsson J. 1999. Sahiwal cattle in Pakistan: genetic and environmental causes of variation in body weight and reproduction and their relationship to milk production *Animal Science.* **68:** 97-108.

Khan, M. S., Ali, A., Ali, S. and Saleem, M. 1997. Seasonal grouping in year-season animal model evaluation of Sahiwal cattle. *Asian-Australian Journal of Animal Sciences.* **10**: 75-78.

Kimenye, D., 1978. A Genetic Study of the Kenyan Sahiwal Breed. Ph.D. Thesis, University of Nairobi, Kenya.

Laben, R. L., Shanks, R. D., Berger, P. J. and Freeman, A. E. 1982. Factors affecting milk yield and reproductive performance. *Journal of Dairy Science.* **65**: 1004-1015.

Lasley, F. J. 1987. Genetics of Livestock Improvement. 3rd Edition. Prentice Hall, Inc., Englewood Cliffs, New Jersey.

Lee, J. K., VanRaden, P. M., Norman, H. D., Wiggarns, G. R. and Meinert, T. R. 1997. Relationship of yield during early lactation and days open during current lactation with 305-day yield. Journal of Dairy Science. **80**: 771-776.

Lidauer, M., Mantysaari, E. A. and Stranden, I., 2002. Comparison of test day models for genetic evaluation of productive traits in dairy cattle. *Livestock Production. Science.* **79**: 73-86.

Machado S. G., Freitas M. A. R. and Gadini, C. H. 1998. Genetic parameters of test day milk yield of Holstein cows. *Sixth World Congress on Genetics Applied to Livestock Production.* **23**:427-430.

Mackinnon, M. J., Meyer, K. and Hetzel, D. J. S. 1991. Genetic variation and covariation for growth, parasite resistance and heat tolerance in tropical cattle. *Livestock Production Science.* **27**: 105- 122.

Madalena, F. E. 1988. A note on the effect of variation of lactation length on the efficiency of tropical cattle selection for milk yield. *Theoretical and Applied Genetics.* **76**: 830-834.

Marti, C. F. and Funk, D. A. 1994. Relationship between production and days open at different levels of herd production. *Journal of Dairy Science.* **77**: 1682-1690.

Mason, I. L., 1965. Report to the Government of Kenya on the National Sahiwal Stud.

Maule, J. P. 1990. The Cattle of the Tropics. University of Edinburgh Centre for Tropical Veterinary Medicine, Edinburgh, UK.

Meyer, K. 1987. Estimates of Variances due to sire x herd interactions and environmental covariances between paternal half-sibs for first lactation dairy production. *Livestock Production Science*. **17**: 95-115.

Meyer, K. 1989. Approximate accuracy of genetic evaluation under an animal model. *Livestock Production Science*. **21**: 87-100.

Meyer, K. 1991. Estimating variances and covariances for multivariate animal models by restricted maximum likelihood. *Genetics, Selection and Evolution*. **23**: 67-83.

Meyer, K. and Hill, W. G 1997. Estimation of genetic and phenotypic covariance functions for longitudinal or 'repeated' records by restricted maximum likelihood. *Livestock Production Science*. **47**: 184-200.

Meyer, K., Grasser, H. U., and Hammond, K. 1989. Estimation of genetic parameters for first lactation test day production of Australian black and white cows. *Livestock Production Science*. **21**: 177-199.

Misra, A. K., Singh, B. and Singh, B. P. 1980. Genetic studies on the economic characters of Hariana cattle. *Indian Veterinary Journal*. **57**: 569-572.

Misztal, I., Strabel, T., Jamrozik, J., Mantysaari, E. A. and Meuwissen, T. H. E. 2000. Strategies for estimating the parameters needed for different test day models. *Journal of Dairy Science*. **83**: 1125-1134.

Mrode, R. A and Akinokun J. O., 1986. Genetic parameters and factors affecting reproductive performance in white Fulani cattle in Southern Nigeria. *Tropical Animal Health and Production* **18**: 81-85.

Mrode, R. A. 1996. Linear Models for the Prediction of Animal Breeding Values. CAB International, Wallinford, UK.

Muhuyi, W. B., 1997. A Comparison of the Productivity of Kenya Sahiwal and Their Crosses in Large Scale Dairy Dual Purpose and Beef Production Systems. Ph.D. thesis, University of Nairobi, Kenya.

Muhuyi, W. B., Lokwaleput, I. and Sinkeet, S. N., 1999. Conservation and utilisation of the Sahiwal cattle in Kenya. *FAO Animal Genetics Research Information*. **26**: 35-44.

Musani S. K. and Mayer, M. 1997. Genetic and environmental trends in a large commercial Jersey herd in the central Rift Valley, Kenya. *Tropical Animal Health and Production.* **29:** 108-116.

Mwandotto, B. A. J. 1985. Weight, Growth and Maturing Characteristic of Kenya Sahiwal Cattle. Ph.D. thesis, Texas A &M University, U.S.A.

Mwandotto, B. A. J. 1994. Phenotypic, genetic and environmental parameter estimates of weight, growth and maturing patterns in Sahiwal females. *Bulletin of Animal Production.* **42**: 61-67.

Nandagawali, S. B., Kothekar, M. D., and Gore, A. K. 1997. Effect of level of inbreeding on some economic traits in Sahiwal cattle. *Indian Journal of Dairy Science.* **50**: 28-31.

Nebel, R. L. and McGilliard 1993. Interaction of high milk yield and reproductive performance in dairy cows. *Journal of Dairy Science.* **76**: 3257-3268.

Njubi, D. M., Rege, J. E. O., Thorpe, W., Lusweti, E. C. and Nyambaka, R. 1992. Genetic and environmental variation in reproductive and lactational performance of Jersey cattle in the Coastal Sub-humid tropics. *Tropical Animal Health and Production.* **24**: 231-237.

Ojango, J. M. K. and Pollot, K. 2001. Genetics of Milk yield and fertility traits in Holstein-Friesian cattle on large scale Kenyan farms. *Journal of Animal Science.* **79**: 1742-1750.

Oltenacu, P. A., Frick, A., and Lindhe, B.. 1991. Relationship of fertility to milk yield in Swedish cattle. *Journal of Dairy Science.* **74**: 264-268.

Ouweltjes, W., Schaeffer, L. R. and Kennedy, B. W. 1988. Sensitivity of methods of variance component to culling type selection. *Journal of Dairy Science.* **71**: 773-779.

Pander, B. L., Hill, W. G. and Thompson, R. 1992. Genetic parameters of test day records of British Holstein-Friesian heifers. *Animal Science.* **55**: 11-21.

Pollak, E. J. and Quaas, R. L. 1983. Definition of group effects in sire evaluation models. *Journal of Dairy Science.* **66**: 1503-1509.

Powell, R. L. and Norman, H. D. 1998. Use of multinational data to improve national evaluations of Holstein bulls. *Journal of Dairy Science.* **81**: 2257-2263.

Pryce, J. E., Veerkamp, R. F., Thompson, R, Hill, W. G. and Simm, G. 1997. Genetic aspects of common health disorders and measures of fertility in Holstein-Friesian dairy cattle. *Animal Science.* **65**: 353-360.

Ptak, E., and Schaeffer, L. R. 1993. Use of test day yields for genetic evaluation of dairy sire and cows. *Livestock Production Science.* **34**: 23-34.

Pundir, R. K. and Raheja, K. L. 1994. Relationship between sire's estimated breeding value for first lactation and lifetime traits in Sahiwal and Hariana cattle. *Indian Journal of Animal Sciences.* **64**: 1219-1225.

Quaas, R. L., Everett, E. W. and McClintock A. C. 1979. Maternal grandsire model dairy sire evaluation. *Journal of Dairy Science.* **62**: 1648-1654.

Raheja, K. L. Burnside, E. B. and Schaeffer, L. R. 1989. Relationship between fertility and production in Holstein dairy cattle in different lactations. *Journal of Dairy Science.* **72**: 2670-2678.

Reents, R., Dicers, J. C. M. and Schaeffer, L. R. 1995. Genetic evaluation for somatic cell score with a test day model for multiple lactations. *Journal of Dairy Science.* **78**: 2858-2870.

Rege, J. E. O. and Wakhungu. J. W. 1992. An evaluation of a long term breeding programme in a closed Sahiwal herd in Kenya. Genetic and phenotypic trends and levels of inbreeding. *Journal of Animal Breeding and Genetics.* **109**: 374-384.

Rege, J. E. O., 1991. Genetic analysis of reproductive performance of Friesian cattle in Kenya 1. Genetic and phenotypic parameters. *Journal of Animal Breeding and Genetics.* **108**: 412-419.

Rege, J. E. O., Kahi, A. K., Okomo-Adhiambo, M. O., Mwacharo, J. and Hanotte, O., 2001. Zebu cattle of Kenya: Uses, performance, farmer preference, measures of genetic diversity and options for improved use. *Animal Genetic Resources Research 1. ILRI (International Livestock Research Institute), Nairobi, Kenya.*

Rege, J. E. O., Lomole, M. A. and Wakhungu, J. W., 1992. An evaluation of a long-term breeding programme in a closed Sahiwal herd in Kenya. I. Effects of non-genetic factors on performance and genetic parameter estimates. *Journal of Animal Breeding and Genetics.* **109**: 364-373.

Rekaya, R., Carabano, M. J. and Toro. 1999. Use of test day yields for genetic evaluation of production traits of Holstein-Friesian cattle. *Livestock Production Science.* **57:** 203-217.

Roman, R. M. and Wilcox, C. J. 2000. Bivariate animal model estimates of genetic, phenotypic, and environmental correlations for production, reproduction, and somatic cells in Jerseys. *Journal of Dairy Science.* **83**: 829-835.

Samuelson, D. J., and Pearson, R. E. 1995. Accuracy of predicting genetic merit from pedigree information for bulls entering stud sampling programs. *Journal of Dairy Science.* **78**: 2057-2064.

Schaeffer L. R., Jamrozik J., Kistemaker G. J. and Doormaal. B. J. 2000. Experience with a test day model. *Journal of Dairy Science.* **83**: 1135-1144.

Schaeffer. L. R., and Dekker, J. C. M. 1994. Random regression in animal models for test-day production in dairy cattle. *Fifth World Congress on Genetics Applied to Livestock Production.* **18**: 443-446.

Serrano M., Ugarte E., Jurado J. J., Perez-Guzman M. D. and Legarra, A. 2000. Test day models and genetic parameters in Latxa and Manchenga dairy ewes. *Livestock Production Science.* **67**: 253-264.

Singh, B., Gahlot, G. C. and Gahlot, R. S. 1997. Lifetime performance of Rathi cows in closed herd. *Indian Journal of Dairy Sciences.* **50**: 439-442.

Singh, S. K. and Nagarcenkar, R. 1997. Factors affecting milk yield and lactation length in Sahiwal cows. *Indian Journal of Animal Sciences.* **67**: 989-992.

Sorenson, D. A. and Kennedy, B. W. 1984. Estimation of response to selection using least squares and mixed model methodology. *Journal of Animal Science.* **58**: 1097-1106.

Swalve, H. H. 1998. Use of test day records for genetic evaluation. *Sixth World Congress on Genetics Applied to Livestock Production.* **23**: 295-302.

Swalve, H. H. 2000. Theoretical basis and computation methods for different test day genetic evaluation methods. *Journal of Dairy Science.* **83**: 1115-1124.

Syrstad, O. 1993. Milk yield and lactation length in tropical cattle. *World Animal Review.* **77**: 56-69.

Tekerli, M., Akinci, Z., Dogan, I. and Akcan, A. 2000. Factors affecting the shape of lactation curves of Holstein cows from the Balikesir province of Turkey. *Journal of Dairy Science.* **83**: 1381-1386.

Togashi, K., Lin, C. Y. and Yokouchi, K. 2004. Overview of genetic evaluation in dairy cattle. *Animal Science Journal.* **75:** 275-284.

Trail, J. C. M. and Gregory, K. E. 1981. Characterisation of the Boran and Sahiwal breeds of cattle for economic characters. *Journal of Animal Science.***52**: 1286- 1293.

Van der Werf, J. H. J., Goddard, M. E. and Meyer, K. 1998. The use of covariance functions and random regression for genetic evaluation of milk production based on test day records. *Journal of Dairy Science.* **81**: 3300-3308.

Van Tassell, C. P. and Van Vleck, L. D. 1996. Multiple trait gibbs sampler for animal models. Flexible programmes for bayesian and likelihood-based (Co)variance component inference. *Journal of Animal Science.* **74**:2586-2597.

Van Vleck, L. D. 1993. Selection index and introduction to mixed model methods CRC Press. Inc.

Vargas, B., Perez E., Van Arendonk J. A. M. 1998. Analysis of test day yield data of Costa Rican dairy cattle. *Journal of. Dairy Science.* **81:** 255-263.

Veerkamp, R. F., Koenen, E. P. and. De Jong,G. 2001. Genetic correlation among body condition score, yield, and fertility in first parity cows estimated by random regression models. *Journal of Dairy Science*. **84**: 2327-2335.

Visscher, P. M. and Goddard, M. E. 1995. Genetic parameters for milk yield, Survival, workability and type traits for Australian Dairy cattle. *Journal of Dairy Science*. **78**: 205-220.

Vukasinovic, N., Moll, J. and Casanova, L. 2001. Implementation of a routine genetic evaluation for longevity based on survival analysis techniques in dairy cattle populations in Switzerland. *Journal of Dairy Science*. **84**: 2073-2080.

Vukasinovic, N., Moll, J. and Künzi, N. 1997. Analysis of productive life in Swiss Brown cattle. *Journal of Dairy Science*. **80**: 2372-2579.

Wang, C. S., Rutledge, J. and Gianola, D. 1994. Bayesian analysis of mixed linear models via Gibbs sampling with application to litter size in Iberian pigs. *Genetics, Selection and Evolution*. **26**: 91-115.

Weigel, K. A., Lawlor, T. J., Vanraden, P. M. and Wiggarns, G. R. 1998. Use of linear type and production data to supplement early predicted transmitting abilities for productive life. *Journal of Dairy Science*. **81**: 2040-2044.

Wiggarns, G. R. and Goddard, M. E., 1997. Computationally feasible test day models for genetic evaluation of yield traits in the United States. *Journal of Dairy Science*. **80**; 1795-1800.

Wilmink, J. B. M. 1987. Adjustment of test day milk, fat and protein yield for age, season and stage of lactation. *Livestock Production Science*. **16**: 335-348.

Wright, H. B., Pollak, E. J. and Quaas, R. L. 1987. Estimation of variance and covariance component to determine heritability and repeatability of weaning weight in American Simmental cattle. *Journal of Dairy Science*. **65**: 975-981.

Yadav, A. S., Rathi, S. S., Arora, D. N. and Balbir Singh. 1995. Reproductive and production traits in indigenous cattle. *Indian Journal of Animal Sciences*. **65**: 542-547.

CHAPTER THREE

MILK PRODUCTION AND REPRODUCTIVE PERFORMANCE OF THE SAHIWAL CATTLE

3.1. Introduction

Among the *B. indicus* breeds, the Sahiwal is known to have the greatest potential for milk production and growth, and efficient reproductive performance under tropical and subtropical environments (Meyn and Wilkins, 1974; Dahlin et al., 1998; Ahmad and Sivarajasigam, 1998; Khan et al., 1999; Muhuyi et al., 1999). Milk production and reproductive efficiency are of utmost importance in any dairy cattle enterprise. They are influenced by both genetic and non-genetic factors. Most non-genetic factors relate to the environment under which the animals are performing. Knowledge of the non-genetic factors influencing productive and reproductive performance is important in developing sound and effective breed improvement strategies. Sources of variation in milk production and reproductive traits of the Sahiwal cattle need to be quantified in order to determine appropriate managemental interventions aimed at improving performance of the these cattle under semi arid conditions in Kenya. The objective of this chapter was to determine factors affecting milk production and reproductive traits in the Sahiwal cattle and obtain mean estimates for these traits under semi arid conditions in Kenya.

3.2. Materials and Methods

3.2.1. Environment and herd management

Records of milk production and reproductive traits were obtained from NSS, which is maintained by the National Animal Husbandry Research Centre, KARI, Naivasha. The NSS is located approximately 70 km North west of Nairobi city at an altitude of 1,829 - 2,330 metres above sea level in agro-ecological zone IV, classified as semi arid (Muhuyi, 1997). The vegetation consists mainly of Kikuyu grass (*Pennisetum clandestinum*) with scattered trees of *Acacia* species. The average annual rainfall is 680mm. Rainfall distribution is bimodal with a peak in April and November. Rainfall distribution over the study period is shown in Figure 2. The temperature ranges from 8 to 26°C and the relative humidity varies from 60 to 75% (NAHRC, 2000).

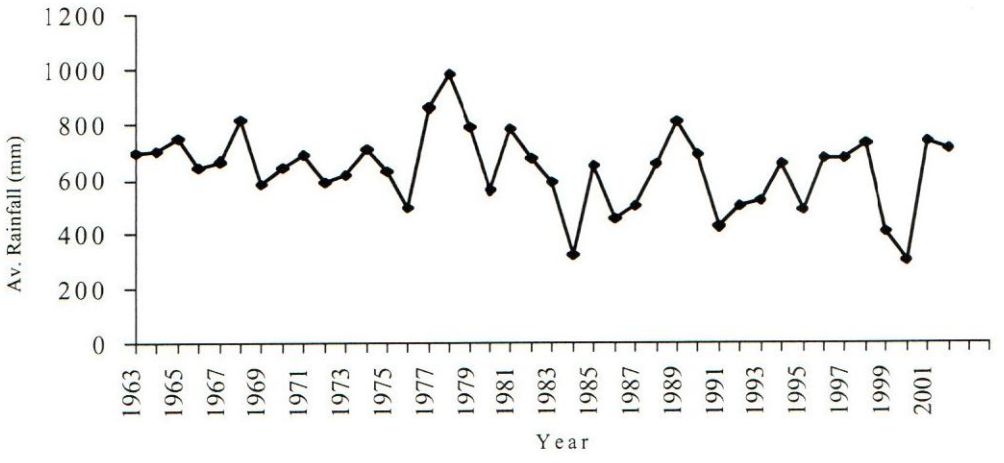


Figure 2. Annual rainfall pattern at the NSS from the years 1963 to 2002

Generally, the management practice is that calves are immediately removed from their dams at birth, weighed and ear tagged. They are bucket fed, receiving colostrum in the first 4 days, and whole milk for about 9 weeks in which period they are gradually weaned onto concentrates. Subsequent weighing is done weekly up to when they attain a body weight of about 55 kg and thereafter twice monthly until at an average weight of 125kg. Bulls and heifers are separated and managed in different herds. They are grazed on natural pastures with no supplementation. Bulls are weighed monthly while heifers at about 27 months and 270kg body weight (expected service age). Bulls are selected at two to three years of age either for progeny testing or for natural service in the pastoralist areas. All heifers and cows are weighed immediately after calving. Lactating cows are grazed on the best pastures and milked twice daily in mobile milking parlours. Water is provided *ad libitum* to all groups. Mineral licks are provided when available. All animals are treated for endo-parasites and dipped at least once a week to control ectoparasites. Routine vaccination is done against Foot and Mouth, Rinderpest, Black-quarter, Anthrax, Rift Valley Fever and Brucellosis.

3.2.2. Data and traits

Data on milk production and reproductive performance were collected from 1963 to 2003. Only records of animals with complete lactation information were picked. A lactation

record was considered normal if a cow had produced milk for at least 60 days and terminated with voluntary drying-off. A lactation record was deleted if the cow died during her lactation, or if the lactation was interrupted due to selling for dairy purposes, or due to bad temper and difficult milking. Lactations initiated as a result of abortions were also eliminated.

The LMY were not pre-adjusted to 305-day during the analysis. In tropical breeds, large variations exist in LL and Zebu cattle breeds show a high frequency of short lactations. The practice in previous studies on the Sahiwal cattle in Kenya has been to discard short lactations (e.g. Kimenye, 1978; Mwandotto, 1985; Rege et al., 1992). Exclusion of short lactations reduces the genetic variance for milk yield (Madalena, 1988). Short lactations are in part due to the inability of the cattle to let down milk in the absence of a calf or low genetic potential of a cow to produce milk for longer periods (Maule, 1990). However, use of statistical models that effectively account for various fixed effects should be able to remove differences in management groups. Syrstad (1993) pointed out that short lactations should not be eliminated not unless they have been warranted by death or sale of the cow while in lactation.

Two data sets were distinguished. Records for the first data set were obtained from the first four lactations and traits studied included LMY, LL, CI, NSC and AFC. In the second data set, TD records from the first three lactations of cows calving for the first time between 1978 to 2002 were obtained from the available milk sheets. First TD was sampled between day 2 and 15 post-partum, while the second TD was sampled between day 16 and 31. Time interval between successive TD was approximately 30 days, allowing for a maximum of eight TD. Test day milk yield was defined as the total sum of milk recorded in the morning and evening. After all the edits, the first data set consisted of 6,365 lactation records of 2,568 cows calving between 1965 to 2003 while the second data set consisted of 19,385 TMY records of 1,618 cows calving between 1978 to 2002.

3.2.3. Statistical analyses

Least square analyses of variance were conducted for different traits in order to assess the environmental effects on performance. The mixed model procedures were used for the analysis of variance (SAS, 1998). Two types of analyses were conducted. In the first analysis, a general model was used for the analysis of traits in the first data set. The mixed model may be written as follows:

$$y_{ijkl} = \mu + s_i + y_j + age_k + a_l + sy_{ij} + e_{ijkl} \qquad (12)$$

where y_{ijkl} is the record in animal l calving in season i of year j, s_i the effect of season of calving i (4 classes), y_j the effect of year of calving j (40 classes), age_k the effect of age class k (8 classes), a_l the additive genetic effect of animal l, sy_{ij} the effect of the interaction between season and year of calving and e_{ijkl} the residual term assumed to be normally distributed with mean zero and variance σ_e^2. The year of calving were from 1963 to 2002 each with four seasons: January to March for the first dry season; April to June for the main wet season; July to September and October to December as the secondary dry and wet seasons, respectively. Age at calving was grouped as; 30-39 months, 40- 49 months, 50-59 months, 60- 69 months, 70-79 months, 80-89 months, 90-99 months and >100 months. Age at calving was fitted as a fixed effect instead of parity because a preliminary analysis showed that fitting age class instead of parity improved the coefficient of determination (R^2) from 0.37 to 0.42. In the analysis of AFC, year and season of birth was fitted instead of year and season of calving and age at calving was removed from the model. In the second analysis, a model including eight TMY in the second data set was used to assess the environmental effects on TMY. The model fitted was similar to that fitted in the first analysis but the season and year of sampling a TD were fitted instead of the year and season of calving. In addition, TD was fitted as a fixed effect and TMY adjusted for the days in lactation by fitting days in milk (DIM) as both linear and quadratic covariates.

3.3. Results and discussion

Table 6 shows the analysis of variance for factors affecting milking production and reproductive traits. Lactation milk yield, LL and TMY were significantly ($P<0.05$) influenced by all effects fitted. Calving interval and NSC were significantly ($P<0.05$) influenced by the effects of year of calving, year-season of calving interaction and age at calving but the effect of season of calving was not significant ($P>0.05$) for both traits. The AFC was significantly ($P<0.001$) influenced by all the fixed effects fitted.

The least squares means of milk production and reproductive traits by seasons and age class are presented in Table 7. Figure 3 shows the trend in least squares means grouped by year of calving in milk production and reproductive traits. The overall mean LMY was 1368 kg. The Sahiwal cows produced more milk during the first dry and main wet seasons than during the secondary dry and wet seasons. There was no significant difference in LMY between the first dry and main wet seasons and also between the secondary dry and wet seasons. Lactation milk yield increased with age at calving. It was lowest in the first age class (30-39 months) and highest in the seventh age class (90-99 months) but the difference in

LMY in the last three age classes (80-89, 90-99 and >100 months) was not significant. Large fluctuations were observed in mean LMY across the years (Figure 3). Generally, mean LMY declined across the study period with sharp declines observed between 1973 and 1975, 1983 and 1985 and 1999 and 2001. However, increase in mean LMY was observed in the early years of the breeding programme until 1972.

Table 6. Analysis of variance for factors affecting milk pr oduction and reproductive traits

Traits[a]	Source of variation	df	Mean squares	F value
LMY (kg)				
	Season of Calving	3	783,874.8	3.7^{**}
	Year of calving	39	18,557,917.9	88.2^{***}
	Year-season	154	808,293.4	3.8^{***}
	Age class	7	9,885,639.5	47.0^{***}
LL (days)				
	Season of Calving	3	13,560.8	5.6^{***}
	Year of calving	39	47,294.8	19.4^{***}
	Year x season	154	5,880.6	2.4^{***}
	Age at calving	7	1,632.4	1.7^{*}
CI (days)				
	Season of Calving	3	6072.4	0.4^{ns}
	Year of calving	38	163667.4	10.7^{***}
	Year-season interaction	129	20924.9	1.4^{**}
	Age at calving	7	33682.7	2.3^{*}
NSC				
	Season of Calving	3	4.1	1.4^{ns}
	Year of calving	39	22.2	7.4^{***}
	Year- season interaction	156	6.9	2.3^{***}
	Age at calving	7	44.8	15.1^{***}
AFC (days)				
	Season of birth	3	212236.4	8.6^{***}
	Year of birth	37	2575527.0	104.4^{***}
	Year-season interaction	158	51391.4	2.1^{***}
TMY (kg)				
	Test day	7	442.3	110.2^{***}
	Season of sampling	3	383.1	95.5^{***}
	Year of sampling	24	229.9	57.3^{***}
	Year-season interaction	98	558.0	139.1^{***}
	Age at calving	7	66.5	16.6^{***}
	DIM	1	25.1	6.8^{***}
	DIM^2	1	52.5	13.07^{***}

[a]LMY, lactation milk yield; LL, lactation length; CI, calving interval; NSC, number of services per conception; AFC, age at first calving; TMY, test day milk yield.
$^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$, ns, not significant.

Table 7. Least squares means (LSM) (±s.e.) of milk production and reproductive traits[a] by season, age at calving and test day

	LMY		LL		CI		NSC		AFC		TMY	
	n	LSM	n	LSM	n	LSM	n	LSM	N	LSM	n	LSM
Overall LSM	6,365	1,368±18	6324	282±1.9	4441	468	7211	2.2±0.03	2894	1345±11	19,376	4.9±0.1
Season[b]												
First dry	1,386	1,387±21[a]	1,386	276±2.3[a]	955	470±5.5[a]	1,564	2.5±0.05[a]	671	1,396±12[a]	4,608	4.5±0.1[a]
Main wet	1,837	1,399±20[a]	1,836	275±2.2[a]	1287	471±5.0[a]	2,089	2.4±0.05[a]	774	1,394±14[a]	4,812	5.1±0.1[b]
Secondary dry	1,581	1,330±20[b]	1,581	272±2.2[a]	1130	474±5.5[a]	1,821	2.4±0.04[a]	765	1,382±14[a]	5,010	4.9±0.1[b]
Secondary wet	1,596	1,326±19[b]	1,521	274±2.2[a]	1069	472±5.5[a]	1,737	2.2±0.05[a]	684	1,370±13[a]	4,946	4.8±0.1[b]
Age at calving (months)												
30-39	880	1025±23[a]	880	273±2.5[a]	729	478±6.0[a]	1017	2.3±0.07[a]			1,282	4.0±0.1[a]
40-49	1,043	1129±22[b]	1,043	274±2.4[a]	808	468±5.5[a]	1197	2.1±0.06[a]			3,608	4.2±0.1[b]
50-59	1,374	1321±21[c]	1,374	274±2.2[a]	1148	473±5.0[a]	1537	2.1±0.06[a]			5,133	4.8±0.1[c]
60-69	1,051	1398±22[d]	1,051	274±2.4[a]	891	458±5.4[b]	1193	2.2±0.07[a]			3,655	5.0±0.1[d]
70-79	818	1421±23[d]	818	272±2.5[a]	485	469±6.7[a]	927	2.4±0.07[ab]			2,899	5.2±0.1[e]
80-89	604	1480±26[e]	604	275±2.7[a]	230	477±9.0[a]	690	2.5±0.08[b]			1,631	5.2±0.1[e]
90-99	313	1499±32[e]	313	278±3.4[a]	96	480±13.8[a]	351	2.6±0.10[b]			857	5.4±0.2[e]
>100	282	1462±36[e]	241	278±3.8[a]	54	469±21.0[a]	299	3.2±0.12[b]			311	5.6±0.2[f]
Test day (days)												
2-15											3,260	5.8±0.1[a]
16-31											2,678	6.1±0.1[b]
32-61											2,330	5.4±0.1[c]
62-91											2,330	4.8±0.1[d]
92-121											2,397	4.3±0.2[d]
122-151											2,194	4.0±0.2[de]
152-181											2,016	4.0±0.2[de]
182-215											2,171	3.9±0.3[e]

[a]LMY, lactation milk yield; LL, lactation length; CI, calving interval; NSC, number of services per conception; AFC, age at first calving; TMY, test day milk yield.
[b]Season of calving for LMY, LL, CI and NSC, season of sampling for TMY and season of birth for AFC. See text for classification of seasons.
Within effects, means followed by the same superscripts do not differ significantly ($P< 0.05$).

The mean LL was 282 days (Table 7). Least squares means across season were not significantly different ($P < 0.05$). Likewise the differences in LL across age classes were not significant but there was a general increase in LL across age classes with old animals having longer LL than young animals. Large variations were observed across years in the mean LL (Figure 1). The general trend indicated that LL was decreasing since the establishment of NSS. However, cows calving in earlier years (1965 to 1973) were milked for longer periods than those calving in later years.

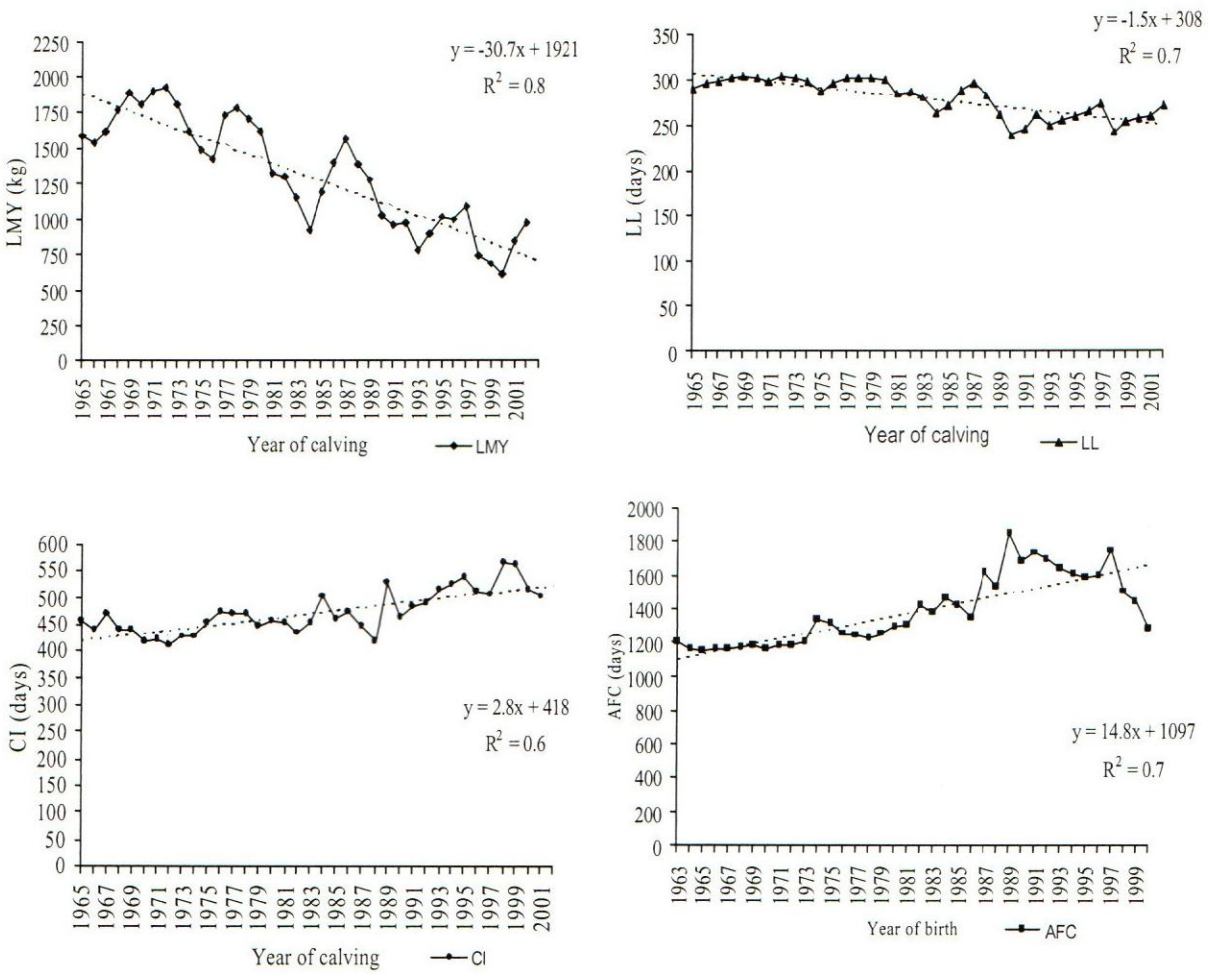


Figure 3. Trends in least squares means for milk production and reproductive traits (LMY, lactation milk yield; LL, lactation length; CI, calving interval; AFC, age at first calving)

The mean CI was 468 days (Table 7). There were no significant differences in the CI in the different seasons. The trend in mean CI across age classes was not uniform. The longest CI was observed in cows calving at an age of between 90-99 months while the shortest CI was

observed in cows calving at an age of between 70-79 months and over 100 months. The trend in mean CI was not steady across years (Figure 3), resulting in fluctuations across the study period, although the general trend showed that it was increasing.

The mean NSC was 2.2 (Table 7). No significant differences were observed in the mean NSC across seasons. Significant differences were observed ($P < 0.05$) in the mean NSC across age classes with a tendency to increase with age at calving. The mean AFC was 1345 days. Cows born in the first dry and main wet seasons were younger at first calving than those born during the secondary dry and wet seasons although the difference were not significant. The general trend indicated that AFC has increased since the inception of the breeding programme (Figure 3).

The mean TMY was 4.7 kg. The TMY in the first dry season was the lowest and significantly different to that in the other seasons. The TMY increased with age at calving. The TMY reached a peak of 6.1 kg between day 16 and 31 after calving and thereafter declined gradually to the end of lactation.

Effect of year-season of calving has been reported to significantly cause variation in LMY (Rege et al., 1992; Musani and Mayer, 1997; Singh and Nagarcenkar, 1997; Ojango and Pollot, 2001; Demeke et al., 2004a). The significant age effect on LMY was expected because cows in the first parity are still growing and therefore available nutrients are partitioned to meet all the body requirements. For the heifers, the nutrients are partitioned so as to be available for growth, maintenance and production. Furthermore, young cows have incomplete udder development implying that maximum production will be attained as age progresses. An increase in LMY with age has been reported in some Sahiwal herds in India (Singh and Nagarcenkar, 1997).

The mean LMY reported in the present study was lower than that reported in the Sahiwal populations in India (Pundir and Raheja, 1994; Singh and Nagarcenkar, 1997). However, recently a comparable mean LMY of 1,395 kg was reported for the Sahiwal populations in Pakistan (Dahlin et al., 1998). Using a subset of the current data, higher LMY were reported (Kimenye, 1978; Rege et al., 1992; Muhuyi, 1997). The differences in mean LMY estimates was due to standardisation of LMY and exclusion of shorter LL, and differences in herd management policies over the years. Higher mean LMY has been reported for the Tharpakar and Hariana breeds in India (Yadav et al., 1995). Lower mean LMY than reported in this study have been reported for the Boran in Ethiopia (Demeke et al., 2004a). As commonly noted for grazing animals under tropical conditions (Muhuyi, 1997; Negussie et al., 1998; Demeke et al., 2004a), large inter-annual variations in mean LMY over the years

were observed. There was an increase in mean LMY from the start of the breeding programme to 1972 and thereafter a decrease was observed. The favourable performance reported in the early stages of the programme was partly attributed to favourable climatic conditions with good pastures and supplementary feeding during unfavourable period. In addition, the foundation stock was composed of good yielders that had been collected from livestock improvement centres across the country to form the NSS. Depressed performance in the years 1973 to 1975, 1983 to 1985, 1992 to 1994 and 1998 to 2000 coincided with severe droughts in 1974, 1984, 1994 and the year 2000 that affected availability of pastures.

Significant changes in LL for year and season of calving are consistent with the literature reports (Musani and Mayer, 1997; Dahlin et al., 1998; Ojango and Pollot, 2001; Muasya et al., 2004). The mean LL was comparable to estimates reported for the Sahiwal cattle in India (Yadav et al., 1995; Gaur and Raheja, 1996; Singh and Nagarcenkar, 1997) and Friesian-Boran crossbreds in Ethiopia (Goshu and Hedge, 2003), but higher than reported for the Sahiwal cattle in Pakistan (Ahmad and Sivarajasingam, 1998; Dahlin et al., 1998), Holstein-Friesian cattle in Kenya (Ojango and Pollot, 2001), Boran cattle in Ethiopia (Demeke et al., 2004a) and Hariana and Tharpakar cattle in India (Yadav et al., 1995). The LL was fairly stable in the first 15 years (Figure 2). However, variations were observed from 1980, with distinct decline observed in the years 1983 to 1985, 1989 to 1991 and 1998 to 2000 as a result of severe drought during these periods. Inter-annual variations in LL as result of adverse climatic conditions has been reported in the Boran and Friesian-Boran crosses in Ethiopia (Demeke et al., 2004a).

The non-significant effect of seasons of calving on CI in this study is consistent with the literature for the Friesian-Boran crosses (Goshu and Hedge, 2003). The significance of the year effect in the inter-calving period could have been related to changes in the climatic conditions and availability of pastures over the years. Significant effects of year and season of calving and age at calving on CI have been reported in populations of exotic dairy breeds in Kenya (Musani and Mayer, 1997), Boran and Friesian-Boran crosses in Ethiopia (Demeke et al., 2004b) and Tharpakar and Hariana (Yadav et al., 1995). The mean CI was higher than reported earlier using a subset of the current data (Rege et al., 1992). This indicates an undesirable trend in mean CI over the years. This mean is comparable to estimates reported in some Sahiwal herds in Pakistan (Khan et al., 1999) and in Boran herds in Ethiopia (Demeke et al., 2004b) but higher than for Friesian-Boran crossbreds in Ethiopia (Goshu and Hedge, 2003; Demeke et al., 2004b). Under tropical conditions, mean CI reported for exotic breeds was lower than reported in the present study (Musani and Mayer, 1997; Ojango and Pollot,

2001; Demeke et al., 2004b). Inter-annual variations in mean CI (Figure 3) may indicate a failure to maintain a uniform reproductive management over the years. The high CI in some years may be due to deterioration in feeding management and untimely mating of in-heat cows. Generally, inter-annual means showed that CI was increasing over the years. Prolonged CI are undesirable particularly in production systems in which there is high demand for pregnant or lactation heifers and feed resources are scarce and their availability is variable, as is the case in Kenya (Kahi et al., 2004). Inadequate feed resources during drought leads to a negative energy balance that would result in delayed onset of oestrus. Therefore, improvement of this trait can be achieved through managemental interventions which include proper feeding, accurate heat detection and timely insemination and control of reproductive disorders.

The significant year and season effect on NSC in this study is in agreement with what has been reported in *Bos taurus* breeds (Musani and Mayer, 1997; Muasya et al., 2004). Inter-annual variations in NSC have also been reported in various Friesian-Boran crossbreds in Ethiopia (Demeke et al., 2004b). The mean NSC reported in this study is consistent with the literature reports (Rege et al., 1992; Musani and Mayer, 1997; Muasya et al., 2004), but lower than that reported for Boran cattle in Ethiopia (Demeke et al., 2004b).

This study indicates that the Sahiwal cattle in Kenya are being served and calve down for the first time at comparable ages to the Sahiwal cattle in Pakistan (Khan et al., 1999). Lower estimates of AFC have been reported for exotic breeds in Kenya (Ojango and Pollot, 2001; Muasya et al., 2004). The mean AFC reported earlier based on a subset of the current data was lower than reported in the present study, indicating that cows are lately served than in previous years (Muhuyi, 1997; Rege et al., 1992). Inter-annual trends in mean AFC indicated that AFC was increasing since the inception of the breeding programme (Figure 4). The notable increase in AFC was observed in cows born from 1983 to 1989. However, due to existing management policy of supplementary feeding during adverse conditions, mean AFC was fairly stable for cows born in earlier years (1963 to 1973). The current management requires that heifers be mated at 260 to 270 kg live weight. The general increase in mean AFC observed in this study imply that heifers were not able to attain these required weights possibly due to fluctuation in the climatic pattern over the years that resulted in inadequate feed for optimal growth consequently delayed puberty.

The environmental fixed effects fitted for TMY were concerned with the actual circumstances of the herd on the day of test. The significant ($P < 0.001$) effect of DIM on TMY was consistent with what has been reported in dairy cattle (Ptak and Schaeffer, 1992).

Usually, DIM accurately reflects the effect of lactation stage at the time of testing on milk yield. Significant variations were observed in mean TMY across the four sampling seasons. The mean TMY was higher when sampled in the wet season than in the dry season. Usually in the wet season, there is availability of quality pastures, which have an overall effect on the amount of milk produced per day. The mean TMY varied significantly with age at calving groups. Yield increased significantly from the first age class (30 – 39 months) up to the last age class (> 100 months). Significant increase in mean daily milk yield with increase in parity has been reported in various Friesian-Boran crosses in Ethiopia (Goshu and Hedge, 2003). The overall mean TMY found in this study is higher than reported for Boran cattle but lower than reported for Friesian-Boran crossbreds (Goshu and Hedge, 2003; Demeke et al., 2004a).

3.4. Conclusions

The influence of environmental factors on milk production and reproductive traits is apparent. The annual differences in these traits was due to non-systematic inter annual fluctuations in climatic conditions, which results in variability in feed availability both in quantity and quality. Frequent droughts and lack of proper feeding during such situations resulted in depressed performance over the years. The performance level of the Sahiwal cattle in semi arid environment in Kenya is comparable to some Sahiwal herds in Pakistan but lower than that reported in India. The NSS has remained a closed nucleus, sourcing breeding stocks from within. This would result in high risks of inbreeding and low selection intensities, hence depressed performance. There is potential to increase milk production and reproductive efficiency if satisfactory management and genetic improvement strategies are implemented at NSS.

References

Ahmad, M. and Sivarajasingam, S. 1998. Analysis on the production and reproductive traits in Sahiwal cows. *Sixth World Congress on Genetics Applied to Livestock Production.* **25**: 399-402.

Dahlin, A., Khan, U. N., Zafar, A. H., Saleem, M., Chaundhry, M. A. and Philipsson, J. 1998. Genetic and environmental causes of variation in milk production traits of Sahiwal cattle in Pakistan. *Animal Science.* **66**: 307-318.

Demeke, S., Neser, F. W. C. and Schoeman, S. J. 2004a. Estimation of genetic parameters for Boran, Friesian and crosses of Friesian and Jersey with Boran cattle in the tropical highlands of Ethiopia: milk production traits and cow weight. *Journal of Animal Breeding and Genetics.* **121**: 163-175.

Demeke, S., Neser, F. W. C. and Schoeman, S. J.2004b. Estimation of genetic parameters for Boran, Friesian and crosses of Friesian and Jersey with Boran cattle in the tropical highlands of Ethiopia: reproductive traits. *Journal of Animal Breeding and Genetic.* **121**: 57-65.

Gaur, G. K. and Raheja, K. L. 1996. Best linear unbiased estimates of different environmental effects for production and reproduction traits in Sahiwal. *Indian Journal of Animal Sciences.* **66**: 603-606.

Goshu, G and Hedge, B. P. 2003. Age at first calving, calving interval and milk yield performance of Friesian-Boran crossbred cattle at Cheffa state farm, Wollo, Ethiopia. *Bulletin of Animal of Production and Health in Africa.* **51**: 190-197.

Kahi, A. K., Nitter G. and Gall, C. F. 2004. Developing breeding schemes for pasture based dairy production systems in Kenya. II. Evaluation of alternative objectives and schemes using a two-tier open nucleus and young bull system. *Livestock Production Science.* **88**: 179-192.

Khan, U. N., Dahlin, A., Zafar, A. H., Saleem, M., Chaudhry, M. A. and Philipsson J. 1999. Sahiwal cattle in Pakistan: genetic and environmental causes of variation in body weight and reproduction and their relationship to milk production *Animal Science.* **68:** 97-108.

Kimenye, D. 1978. A Genetic Study of the Kenyan Sahiwal Breed. Ph.D. Thesis, University of Nairobi, Kenya.

Madalena, F. E. 1988. A note on the effect of variation of lactation length on the efficiency of tropical cattle selection for milk yield. *Theoretical and Applied Genetics.* **76**:830-834.

Maule, J. P. 1990. The Cattle of the Tropics. University of Edinburgh Centre for Tropical Veterinary Medicine, Edinburgh, UK.

Meyn, K. and Wilkins, J. V., 1974. Breeding for milk in Kenya, with particular reference to the Sahiwal stud. *World Animal Review.* (FAO) **11:** 24-30.

Muasya, T. K., Mosi, R. O., Wakhungu, J. W. and Okeyo, A. M. 2004. A study of the reproductive performance of the dairy herd at the University of Nairobi veterinary farm, Kanyariri. *The Kenya Veterinarian.* **27**: 106-108.

Muhuyi, W. B. 1997. A Comparison of the Productivity of Kenya Sahiwal and their Crosses in Large Scale Dairy Dual Purpose and Beef Production Systems. Ph.D. thesis, University of Nairobi, Kenya.

Muhuyi, W. B., Lokwaleput, I. and Sinkeet, S. N. 1999. Conservation and utilisation of the Sahiwal cattle in Kenya. *FAO Animal Genetics Research Information.* **26:** 35-44.

Musani, S. K. and Mayer, M. 1997. Genetic and environmental trends in a large commercial Jersey herd in the central Rift Valley, Kenya. *Tropical Animal Health and Production.* **29:** 108-116.

Mwandotto, B. N. 1985. Weight, Growth and Maturing Characteristics of Kenya Sahiwal Cattle. Ph.D. thesis, Texas A &M University, U.S.A.

NAHRC. 2000. National Animal Husbandry Research Centre, Annual Report, NAHRC, Naivasha, Kenya.

Negussie, E., Brännäng, E., Banjaw, K. and Rottmann, O. J. 1998. Reproductive performance of dairy cattle at Asella livestock farm, Arsi, Ethiopia. I. Indigenous cows versus their F_1 crosses. *Journal of Animal Breeding and Genetics.* **115**: 267-280.

Ojango, J. M. K. and Pollot, G. E. 2001. Genetics of milk yield and fertility traits in Holstein-Friesian cattle on large scale Kenyan farms. *Journal of Animal Science.* **79**: 1742-1750.

Ptak, E. and Schaeffer, L. R. 1993. Use of test day yields for genetic evaluation of dairy sire and cows. *Livestock Production Science.* **34**: 23-34.

Pundir, R. K. and Raheja, K. L. 1994. Relationship between sire's estimated breeding value for first lactation and lifetime traits in Sahiwal and Hariana cattle. *Indian Journal of Animal Sciences.* **64**: 1219-1225.

Rege, J. E. O., Lomole, M. A., Wakhungu, J. W. 1992. An evaluation of a long-term breeding programme in a closed Sahiwal herd in Kenya. I. Effects of non-genetic factors on performance and genetic parameter estimates. *Journal of Anima Breeding and Genetics.* **109:** 364-373.

Singh, S. K. and Nagarcenkar, R. 1997. Factors affecting milk yield and lactation length in Sahiwal cows. *Indian Journal of Animal Sciences.* **67**: 989-992.

Statistical Analysis System. 1998. SAS Language Guide for Personal Computers, SAS Institute Inc.

Syrstad O. 1993. Milk yield and lactation length in tropical cattle breeds. *World Animal Review.* **74**: 68-72.

Yadav, A. S., Rathi, S. S., Arora, D. N. and Singh, B. 1995. Reproductive and production traits in indigenous cattle. *Indian Journal of Animal Sciences.* **65**: 542-547.

CHAPTER FOUR

ESTIMATES OF GENETIC AND PHENOTYPIC PARAMETERS USING CONVENTIONAL MODELS

4.1. Introduction

The primary emphasis of the long-term Sahiwal cattle breeding programme is to increase milk yield, growth and reproductive efficiency (Mwandotto, 1985; Rege and Wakhungu, 1992; Muhuyi, 1997; Muhuyi et al., 1999). Genetic improvement of milk production and growth traits depends on the fertility traits. It is therefore important to have knowledge on the extent of additive genetic variance and the relationship among these traits in order to develop sound improvement strategies. In the Sahiwal cattle in Pakistan, heritability estimates for production and fertility traits and their relationships have been estimated (Dahlin et al., 1998; Khan et al., 1999). Genetic and phenotypic parameter estimates normally apply directly to the specific population and environment from which the data were collected. Consequently, it is not recommended to take estimates made in one population for application in another. In the Sahiwal cattle in Kenya, very little is known about the genetic variation of milk production and fertility traits and their genetic relationships. Furthermore, genetic and phenotypic parameter estimates for the Sahiwal cattle based on multivariate animal model are scarce. It is therefore important to estimate these parameters to enable design of efficient breeding plans and for prediction of possible correlated changes in fertility traits when selection for milk yield is intensified. This chapter presents the estimates of genetic and phenotypic parameters for milk production and fertility traits using various conventional models. Genetic, environmental and phenotypic trends in these traits are also presented.

4.2. Materials and methods

4.2.2 Description of traits and data characteristics

The data set analysed consisted of 7,211 lactation records from 257 sires and 2894 cows born between 1963 and 2000. These animals calved down between 1965 and 2003. Details of the data source, climate and herd management have been described in Chapter 3. Milk production and fertility traits considered were those analysed in the first data set in Chapter 3. These included LMY, LL, CI, NSC and AFC. In addition, LMY, LL, CI and NSC in the first three lactations were also considered as separate traits. Table 8 shows the data structure and means for various milk production and fertility traits.

Table 8. Data structure, means and effects fitted in the mixed model for various milk production and fertility traits

Item	Traits[a]				
	LMY (kg)	LL (days)	CI (days)	NSC	AFC (days)
Data structure					
Number of records	6365	6324	4441	7211	2894
Number of sires	319	319	297	334	331
Sires with progeny	257	257	248	262	260
Average progeny per sire	10.0	10.0	8.2	11.0	11.0
Number of dams	1857	1836	1509	2013	2112
Dams with progeny	1435	1434	1221	1563	1562
Average progeny per dam	1.8	1.8	1.7	1.8	1.9
Mean	1363	282	468	2.1	1345
S.D.	379	71	124	1.7	150
CV (%)	28	25	27	81	11
Effects[b]					
Year-Season of calving	154	154	156	160	152
Age at calving	8	8	8	8	-

[a]LMY, lactation milk yield; LL, lactation length; CI, calving interval; NSC, number of services per conception; AFC, age at first calving.
[b]Year-season of birth fitted instead of year-season of calving in the analysis of AFC.

4.2.3. Statistical analysis

Variance components were estimated using univariate, bivariate and trivariate models. All runs were carried out using the DFREML software package (Meyer, 1989). An animal model was used throughout, incorporating all the pedigree information available. Univariate models were used for each trait while bivariate models were used to estimate genetic and phenotypic correlations between milk production and fertility traits and between LMY, LL, CI and NSC within each lactation. Trivariate models were used in the analysis of LMY, LL, CI and NSC in the first three lactations.

For each trait, the effects fitted were similar to those presented in section 3.2.3. But in the analysis of LMY, LL CI and NSC within the first three lactations, the year/season of calving and age at calving were the only fixed effects fitted in the model. The data structure and effects fitted in the mixed models are presented in Table 8. The basic animal model used for the analysis of each trait was:

$$y = Xb + Zu + e \quad (13)$$

where y is a vector of observations, X and Z are design matrices for fixed effects and random effects respectively, b vector of fixed effects, u is a vector of individual animal breeding values and e vector of random error term. The y vector consisted of the five traits (LMY, LL, CI, NSC and AFC) in the univariate analysis, of all pairs of these five traits and of LMY, LL CI and NSC within each lactation in the bivariate analysis and of LMY, LL, CI or NSC in the first three lactations in the trivariate analysis. The records used in the bi- and trivariate analyses

were the same as in the univariate analysis. Table 9 shows the characteristics of the milk production and fertility traits in the first three lactations.

For traits (i.e. LMY, LL, CI and NSC) for which more than one lactation record from each animal was analysed, the animal model allowed for repeated records per cow by fitting an additional random effect that represented the permanent environment. It was assumed that the covariances of the three random effects were zero and that levels of each were independently distributed with variance σ_a^2 for animal, σ_{pe}^2 for permanent environmental effects, and σ_e^2 residuals. For AFC and LMY, LL, CI or NSC within the first three lactations, the same model was fitted but permanent environmental effects were ignored. Mixed model equations were solved iteratively and the simplex procedure was used to locate the maximum of the log-likelihood function.

Table 9. Characteristics of the milk production and fertility traits in the first three lactations

Trait[a] in lactation no.	No. of records	Mean	SD	CV (%)
LMY				
1	2,463	1,226	517.0	42.2
2	1,788	1,413	600.0	33.5
3	1,250	1,475	654.0	52.3
LL				
1	2,447	284.6	52.1	18.3
2	1,779	281.7	53.2	18.9
3	1,240	281.5	54.3	19.2
CI				
1	2,024	468.2	119.2	25.5
2	1,431	463.2	113.2	24.4
3	973	458.7	128.9	28.1
NSC				
1	2,840	2.1	1.7	80.9
2	1,412	2.1	1.7	80.9
3	1,412	2.1	1.7	80.9

[a]See Table 8 for description of the traits

The genetic level of a herd in a year is the average breeding value of the animals that had records in that year. Breeding values were obtained by back solutions. Genetic trends of cows were estimated by averaging the predicted breeding value from the trivariate analysis within the year. Phenotypic trends were estimated by regressing the average of unadjusted records on year of calving. Year-season solutions were averaged and regressed on the year to obtain environmental trends.

4.3. Results and discussion

4.3.1. Estimates of heritability and repeatability

Table 10 shows the estimates of heritability and repeatability of milk production and fertility traits from univariate repeatability analysis. The estimates of heritability of within

lactation number of milk production and fertility traits from uni- and trivariate analysis are presented in Table 11. Heritability estimate for LMY was 0.16 while the repeatability estimate was 0.46 (Table 10). The moderate repeatability estimate implies that with good management, culling of animals on the basis of first lactation performance could be done with a reasonable degree of accuracy. The heritability estimate for LMY was consistent with that reported in the literature for the Sahiwal breed (Dahlin et al., 1998; Bajwa et al., 2002; Choudhary et al., 2003). Higher estimates than reported in the present study have been reported for Holstein-Friesian (Rege, 1991; Ojango and Pollot, 2001) and Jersey (Musani and Mayer, 1997) breeds in Kenya and for crossbred populations in Ethiopia (Demeke et al., 2004a). The current estimate for LMY is also lower than the overall mean heritability (0.25) published for tropical dairy breeds (Lôbo et al., 2000).

Table 10. Estimates of heritability (h^2) with standard errors, repeatability (r), additive (σ_a), permanent environmental (σ_{pe}), residual (σ_e) and phenotypic (σ_p) standard deviations of milk production and fertility traits from univariate repeatability analysis

Trait[a]	h^2	s.e.	r	σ_a	σ_{pe}	σ_e	σ_p
LMY	0.16	0.03	0.49	189.1	268.1	336.0	469.6
LL	0.07	0.03	0.40	13.5	28.9	38.5	50.0
CI	0.03	0.02	0.11	59.0	33.7	105.1	112.0
AFC	0.04	0.02	-	20.7	-	143.3	157.1
NSC	0.01	0.01	0.18	0.2	0.4	1.6	1.6

[a]See Table 8 for description of traits.

Differences in the estimated heritability estimates between the current and those reported in the literature could be due to the use of different models, random environmental errors and other unidentified environmental factors whose effects are more pronounced under tropical environments. Other factors such inbreeding (Falconer and Mackay, 1996), and large variation in phenotypic performance (Sorensen and Kennedy, 1984) have also been reported to contribute to low heritability estimates. Heritability estimates in univariate analysis considering lactations as different traits ranged from 0.13 to 0.22 for LMY (Table 11). The estimates were generally low in lactation two and high in the third lactation. Heritability estimates were higher for the trivariate (ranges 0.32 to 0.45) than for univariate analysis (Table 11). The higher heritability estimates found under the trivariate than univariate model was due to the high additive genetic variance associated with the former. Trivariate models effectively account for selection across lactations and better adjust for environmental factors. Dahlin et al. (1998) and

Dematawewa and Berger (1998) have also reported increases in heritability estimates across lactations as a result of fitting multivariate models.

The heritability estimate for LL was low (0.07) while the repeatability was moderate (0.41) (Table 10). This implies that variation in LL is as a result of factors associated with the cow and to some extent with variation in management. The heritability estimate was lower than estimated for the Sahiwal populations in Pakistan (Ahmad and Sivarajasingam, 1998; Dahlin et al., 1998;), but within the range of 0.07-0.12 reported in the Sahiwal populations in India (Singh and Nagarcenkar, 1997; Choudhary et al., 2003). This estimate is comparable to that reported for the Holstein-Friesian (Ojango and Pollot, 2001). There was a large additive genetic variance in older cows, resulting in a higher heritability (0.17) in the third lactation compared to the other lactations (Table 11). These findings were consistent with those of Dahlin et al. (1998) for Sahiwal populations in Pakistan.

The heritability and repeatability estimates for CI were 0.03 and 0.1, respectively (Table 10). The low repeatability estimate implies that temporal environmental factors contribute appreciably to the variation in CI among lactation and therefore cows should not be culled on the basis of a single or few available records. The heritability estimate for CI was lower than reported previously using a sub-set of the current data (Kimenye, 1978; Rege et al., 1992) but comparable to estimates reported by Khan et al. (1999) in a population of Sahiwal cattle in Pakistan. The low heritability for CI indicates that improvement in this trait could primarily be achieved by improving herd reproductive management practices. Heritability estimates from univariate analysis show that CI was more heritable in heifers than in cows (Table 11). This is consistent with what has been reported in the Sahiwal cattle in Pakistan (Khan et al., 1999). There was no definite pattern in the heritability estimates obtained using univariate and trivariate models (Table 11). This suggests that the breeding programme puts little emphasis on CI when making selection decisions

Table 11. Estimates of heritability (h^2) with standard errors, additive (σ_a), and phenotypic (σ_p) standard deviations of the twelve milk production and fertility traits from uni- and trivariate analyses

	Univariate analysis				Trivariate analysis [b]				
Trait[a] (lactation no.)	h^2	s.e.	σ_a	σ_p	1	2	3	σ_a	σ_p
LMY									
1	0.22	0.04	207.1	438.10	0.32±0.01	0.40	0.36	257.75	458.74
2	0.13	0.04	158.9	446.60	1.00±0.10	0.45±0.03	0.57	297.62	441.69
3	0.14	0.05	185.63	488.41	0.98±0.10	1.00±0.01	0.41±0.03	290.69	452.22
LL									
1	0.11	0.04	16.14	48.64	0.26±0.04	0.32	0.30	25.48	49.43
2	0.09	0.05	14.53	48.70	0.99±0.06	0.31±0.04	0.39	28.08	50.32
3	0.17	0.08	19.98	49.19	0.92±0.08	0.99±0.07	0.34±0.06	29.60	50.27
CI									
1	0.05	0.03	25.17	112.52	0.03±0.03	0.01	0.02	22.61	123.96
2	0.02	0.03	19.29	123.91	0.99±0.50	0.02±0.04	0.04	19.96	126.83
3	0.03	0.03	21.41	117.60	0.91±0.60	0.97±0.40	0.06±0.05	29.07	117.35
NSC									
1	0.03	0.02	0.26	1.52	0.06±0.02	0.06	0.02	0.37	1.53
2	0.03	0.02	0.25	1.49	0.99±0.30	0.05±0.03	0.03	0.36	1.58
3	0.03	0.03	0.28	1.55	0.99±0.70	0.99±0.90	0.04±0.04	0.30	1.55

[a]See Table 8 for description of the traits.

[b]Phenotypic correlations above the diagonals, genetic correlations below the diagonals and heritability on the diagonals.

The heritability (0.01) and repeatability (0.18) estimates were low for NSC (Table 3). The low repeatability indicates that cows requiring more services per conception in one lactation may not necessarily require such services in later lactations. Low heritability estimates for NSC have been reported elsewhere (Berger et al., 1981; Hansen et al., 1983; Rege et al., 1992; Dematawewa and Berger, 1998). The within lactation heritability estimate for NSC was similar across lactations (Table 11). This points to the current management policy where cows with a high NSC are not selected against. The heritability estimates for AFC (0.04) was lower than reported in the literature (Rege et al., 1992; Khan et al., 1999; Ojango and Pollot, 2001; Demeke et al., 2004b). The low heritability for AFC was expected because the management policy at the NSS requires that heifers be served at an age of 27 months and when they have attained a body weight of 270 kg (Muhuyi, 1997). Therefore, management would play a big role in determining AFC and not the inherent ability of the animal to attain puberty. Improvement in this trait could be achieved through better feeding which would considerably improve on growth rate. The targeted weight at first service (270 kg) corresponds to about 80% of mature size on average, which suggests that heifers could probably be served at a lower weight if they are in good condition.

This study showed that CI and NSC are to a large extent influenced by herd management policies. Improvement in fertility traits should be easier to achieve through better management than through selection. Proper management has been shown to bring about superior phenotypic performance for fertility traits and reduction in correlated genetic deterioration in these traits (Castillo-Juarez et al., 2000). Therefore, the NSS should develop a strategic plan to improve the level of management which should include proper feeding, accurate heat detection and culling of cows that persistently show poor reproductive performance. However, Khan et al. (1999) noted that it would also be important to consider including fertility traits in the Sahiwal breeding programmes.

Heritability estimates for milk production traits were higher in trivariate analyses (Table 11) than in other analyses (Table 10 and Table 11). A similar pattern was observed for NSC. However, there was no definite pattern in the change of heritability estimates for CI in the three analyses. The high heritability estimates in trivariate analyses could probably be due to a proportionally large increase in the additive genetic variance. Trivariate models effectively account for selection across lactations and better adjust for environmental factors, resulting in higher heritability estimates. Similar results have been reported elsewhere (Dahlin et al., 1998; Khan et al., 1999; Choudhary et al., 2003). Multi-trait models should be the most

preferred in the genetic evaluation of milk production traits in the Sahiwal cattle breeding programme.

4.3.2. Genetic and phenotypic correlations

Table 12 shows the estimates of genetic and phenotypic correlations between milk production and fertility traits from bivariate analysis. The genetic correlation between milk production traits (LMY and LL) was essentially unit while the phenotypic correlation was moderate (0.41). These estimates were similar to those obtained within a lactation. In that case, the phenotypic correlation ranged from 0.44 in the first lactation to 0.61 in the third lactation. These results imply that genes that positively influence LMY would result in longer LL, therefore cows that produce more LMY will be milked for longer periods. The results are consistent with those reported in the same breed in Pakistan (Dahlin et al., 1998). The high positive genetic correlation between LMY and LL implies that the latter would be used for selection in production systems constraint by poor milk recording as pointed out by Syrstad (1993).

The genetic and phenotypic correlations between milk production and fertility traits were positive (Table 12). The genetic correlation estimates ranged from 0.31 (LL vs CI) to 0.91 (LMY vs. AFC). Within lactation, the genetic correlation estimates ranged from 0.85 (LMY vs. CI) to 1.00 (LL vs. CI). The high pooled and within lactation genetic correlations estimate between milk production and fertility traits indicate that high producing cows were bred later, took longer to conceive and required more services per conception than low-producing cows. The phenotypic correlations between milk production and fertility traits estimated from pooled data and within lactation were low and in the range 0.03 (LL vs NSC in the second lactation) to 0.17 (LMY vs. NSC in the first lactation). The high genetic correlations are evidence for common genetic and physiological mechanism controlling milk production and fertility traits. This strengthens the evidence for an antagonistic relationship between fertility and yield reported in the literature (Berger et al., 1981; Hansen et al., 1983; Raheja et al., 1989; Oltenacu et al., 1991; Ahmad and Sivarajasingam, 1998; Dematawewa and Berger, 1998; Khan et al., 1999).

Table 12. Genetic (r_g with s.e.) and phenotypic (r_p) correlations between milk production and fertility traits from bivariate analysis

					Lactation number								
		Pooled[b]			1			2			3		
Trait1[a]	Trait 2[a]	r_g	s.e.	r_p	r_g	s.e.	r_p	r_g	s.e.	r_p	r_g	s.e.	r_p
LMY	LL	1.00	0.01	0.41	1.00	0.42	0.44	1.00	0.40	0.60	1.00	0.41	0.61
LMY	CI	0.78	0.10	0.13	0.85	0.11	0.17	0.90	0.21	0.10	0.99	0.20	0.09
LMY	AFC	0.91	0.03	0.13									
LMY	NSC	0.86	0.30	0.13	0.70	0.10	0.17	0.98	0.26	0.04	0.93	0.34	0.04
LL	CI	0.31	0.02	0.16	0.99	0.14	0.15	1.00	0.35	0.11	1.00	0.31	0.15
LL	AFC	1.00	0.20	0.06									
LL	NSC	0.80	0.20	0.30	0.98	0.60	0.03	0.99	0.56	0.03	0.99	0.5	0.10
CI	AFC	1.00	0.50	0.10									
CI	NSC	0.77	0.20	0.30	0.68	0.12	0.16	0.72	0.06	0.14	0.84	0.25	0.20
AFC	NSC	0.93	0.60	0.05									

[a]See Table 8 for description of the traits.
[b]Estimates from the first three lactations.

The genetic relationship between milk production and fertility traits are undesirable. Various factors might have caused the high positive genetic correlation. It is well known that high yield causes stress due to a negative energy balance, which in turn impairs fertility and that pregnancy also affects milk production (Nebel and McGilliard, 1993). Other factors such as under feeding during unfavourable years coupled with a hot climate and diseases can also result in reduced reproductive efficiency. These problems are more likely to be severe for high yielding cows and result in longer oestrus. The phenotypic antagonism between milk yield and fertility traits is inversely related to the level of management (Laben et al., 1982).

The genetic and phenotypic correlations between fertility traits were positive (Table 4). The genetic correlations were high (>0.68) while phenotypic correlations were in the range 0.05 (AFC vs. NSC) to 0.30 (CI vs. NSC). The positive genetic correlations between CI and NSC indicate that the same genes that delayed breeding produced an effect requiring more additional services per conception. Extended intervals between calvings are as result of more services to conception. Positive relationships among fertility measures have been reported earlier (Berger et al., 1981; Hansen et al., 1983; Dematawewa and Berger, 1998; Khan et al., 1999).

Genetic and phenotypic correlation estimates from the trivariate analysis are shown in Table 11. The genetic correlations among milk production traits were high while phenotypic correlations were correspondingly lower. The high genetic correlations indicate that selection for improved performance in milk production in the first lactation would result in genetic progress in later lactations as well. Similar findings have been reported for the Holstein-Friesian (Rege, 1991; Dematawewa and Berger, 1998) and the Sahiwal (Dahlin et al., 1998) cattle breeds.

4.3.3. Genetic, environmental and phenotypic trends

The genetic, environmental and phenotypic trends among cows for first LMY, LL and CI are shown in Figure 4, 5 and 6, respectively. Genetic trends for all traits were close to zero or slightly above zero. In general, there was an annual genetic decline of 0.4 kg and 0.03 days in LMY and LL, respectively, while CI increased by 0.01 days. Considerable fluctuations were observed in the phenotypic and environmental trends over the study period. The effect of the environment under which the animals were performing was unfavourable. The adverse environment accounted for a loss of 19 kg and 1.2 days per year of LMY and LL, respectively. Calving interval was extended by 2.3 days under the same environmental

conditions. The close relationship between the phenotypic and environmental trends for all traits is as a result of the impact of the year-season effect on phenotypic variation.

In earlier years (1962 to 1980), environmental and phenotypic trends were favourable because of the good management policy of supplementary feeding during adverse seasons. A previous genetic evaluation of the long term breeding programme showed a lower than expected genetic improvement and phenotypic trends, that were largely undermined by fluctuation environmental circumstances under which the herd was performing (Rege and Wakhungu, 1992). Adverse environmental factors have also resulted in low genetic improvement and undesirable phenotypic trends for milk production and fertility traits in the Sahiwal herds in Pakistan (Dahlin et al., 1998; Khan et al., 1999). In contrast, favourable genetic progress has been reported for milk yield in some Sahiwal herds in India (Singh and Nagarcenkar, 1997) and in the Jersey (Musani and Mayer, 1997) and Holstein-Friesian cattle breeds in Kenya (Ojango and Pollot, 2001). In those studies, remarkable progress was attributed to improvement in management of environmental factors that affect cow performance.

Genetic improvement of the Sahiwal cattle is constraint by herd replacement policies and adverse environmental effects. Milk yield is reducing despite high selection emphasis on this trait. Extended CI was evident, which implies that productivity per cow was also reduced. The magnitude and direction of the change reflect failure of the existing genetic improvement and management strategies. These suggest that proven sires may not have been selected and utilised effectively and that the cow replacement programme may be ineffective. Unfavourable environmental effects would obscure genetically superior animals if an evaluation procedure does not effectively adjust for these effects.

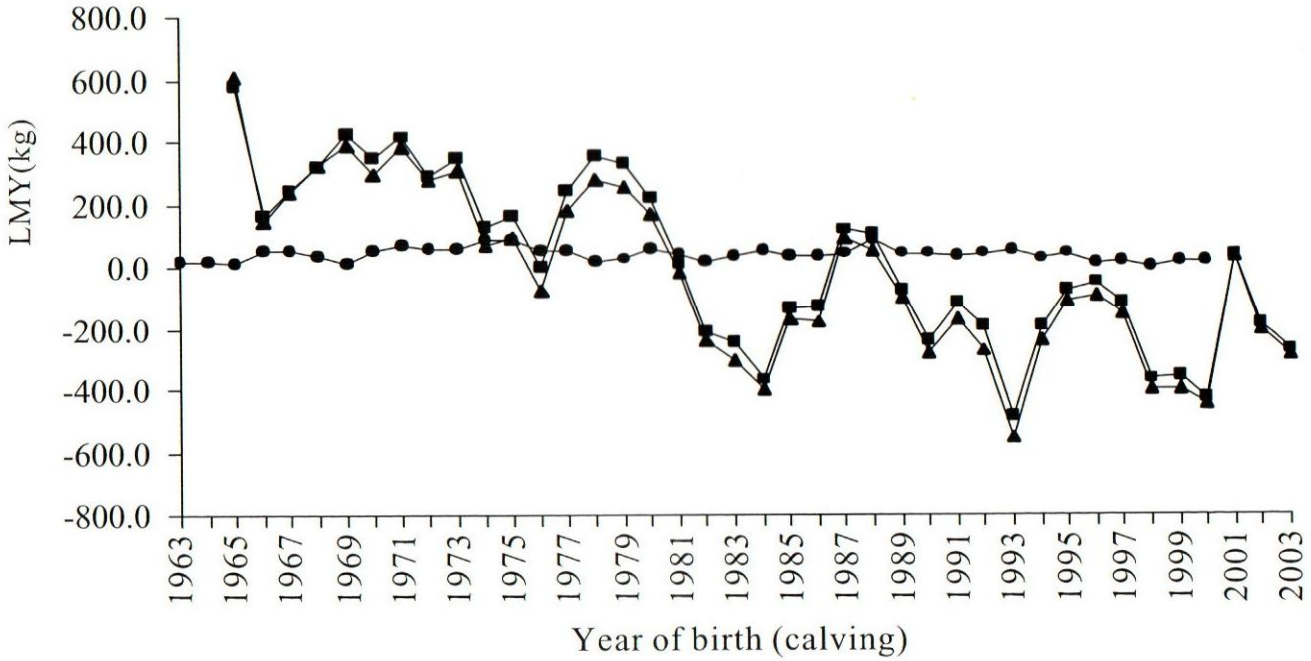


Figure 4 Genetic (·), environmental (?), and phenotypic trends (¦) for LMY. The genetic trend is shown by year of birth, others by year of calving. The environmental and phenotypic trends are expressed as deviations from the overall mean

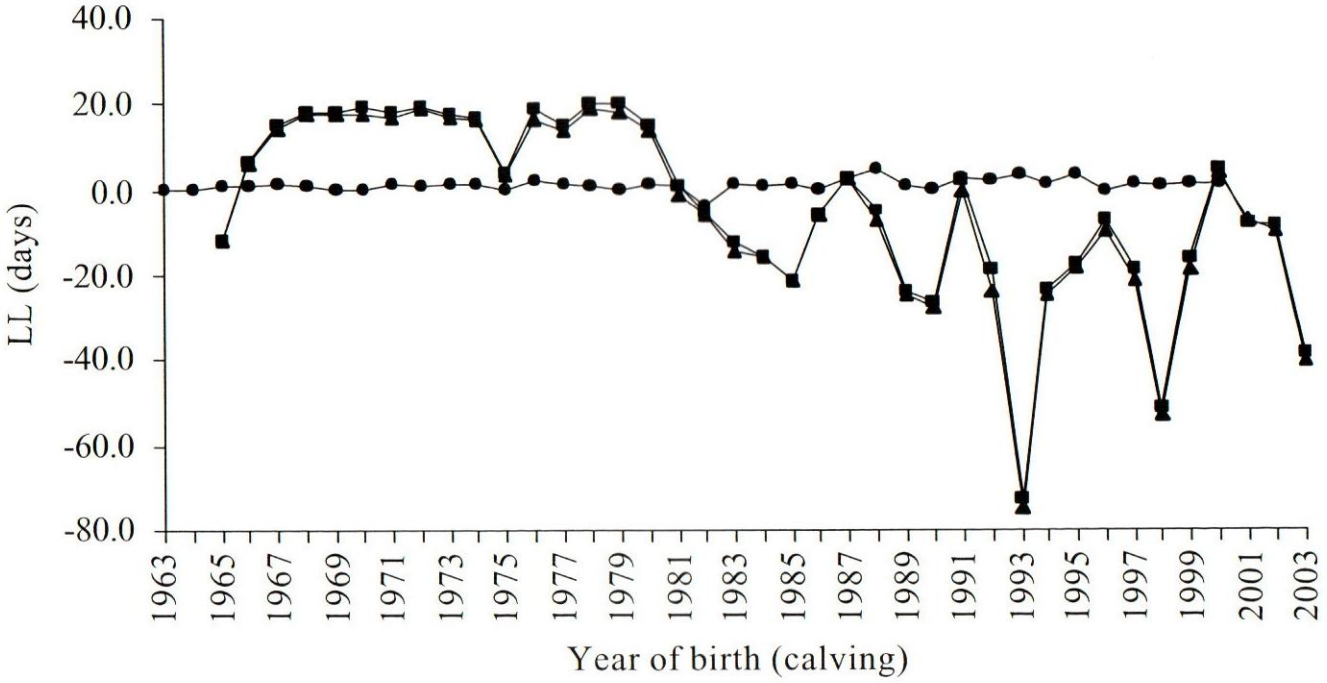


Figure 5. Genetic (·), environmental (?), and phenotypic trends (¦) for LL. The genetic trend is shown by year of birth, others by year of calving. The environmental and phenotypic trends are expressed as deviations from the overall mean

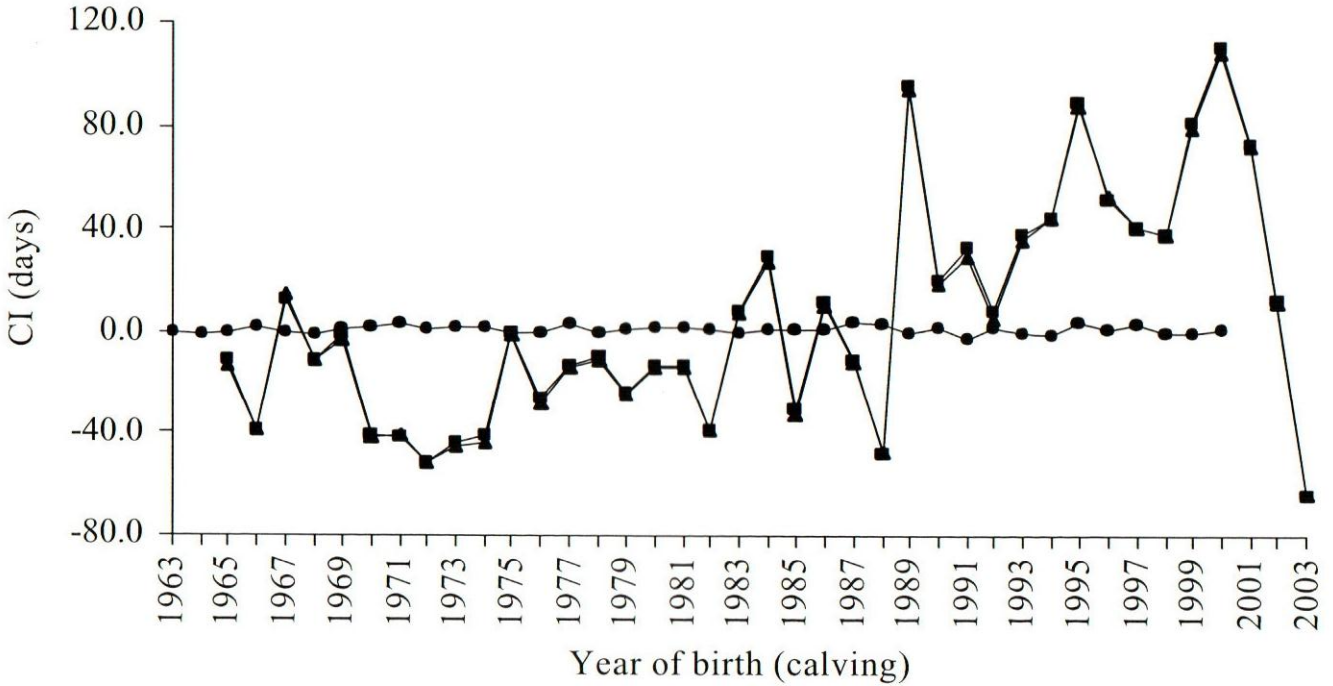


Figure 6. Genetic (·), environmental (?), and phenotypic trends (¦) for CI. The genetic trend is shown by year of birth, others by year of calving. The environmental and phenotypic trends are expressed as deviations from the overall mean

4.4. Conclusions

Heritability estimates from univariate and trivariate models were different for milk production traits but similar for fertility traits. Milk production traits are moderately heritable in the Sahiwal cattle in Kenya. The results indicate opportunities for genetic improvement of milk yield by selection. Considering both models, heritability estimates for fertility traits were generally low. Genetic relationship between milk production and fertility were undesirable. This indicates that continued genetic selection for increased milk yields would result in depressed reproductive performance. Use of a multi-trait (including both milk production and fertility traits) animal model evaluation based on BLUP would be valuable in the ranking of breeding stock. This method would effectively account for changes in environmental factors and genetic trends.

References

Ahmad, M. and Sivarajasingam, S. 1998. Analysis on the production and reproductive traits in Sahiwal cows. *Sixth World Congress on Genetics Applied to Livestock Production.* **25**: 399-402.

Bajwa, I. R., Khan, M. S., Ahmad, Z. and Gondal, K. Z. 2002. Genetic parameters of lactation milk yield as affected by lactation length adjustment procedures. Seventh World congress of genetics applied to livestock production. Montpellier, France, CD-ROM communication N° 01-56.

Berger, P. J., Shanks, R. D., Freeman, A. E. and Laben R. C. 1981. Genetic aspects of milk yield and reproductive performance. *Journal of Dairy Science.* **64**: 114-122.

Castillo-Juarez, H., Oltenacu, P. A., Blake., W., Mcculloch, C. E. and Cienfuegos, E. G. 2000. Effect of Herd management on the genetic and phenotypic relationships among milk yield, conception rate, and somatic cell score in Holstein Cattle. *Journal of Dairy Science.* **83**: 807-814

Choundhary, V., Kotherkar, M. D., Raheja, K. L., Kasturiwale, N. N., Khire, D. W. and Kumar, P. 2003. Genetic parameters of first lactation traits in Sahiwal cattle using restricted maximum likelihood technique. *Asian-Australasian Journal of Animal Sciences.* **16**: 639-643.

Dematawewa, C. M. B. and Berger, P. J. 1998. Genetic and phenotypic parameters for 305-day yield, fertility, and survival in Holsteins. *Journal of Dairy Science* **81:** 2700-2709.

Dahlin, A., Khan, U. N., Zafar, A. H., Saleem, M., Chaundhry, M. A. and Philipsson, J. 1998. Genetic and environmental causes of variation in milk production traits of Sahiwal cattle in Pakistan. *Animal Science.* **66**: 307-318.

Demeke, S., Neser, F. W. C. and Schoeman, S. J., 2004a. Estimation of genetic parameters for Boran, Friesian and crosses of Friesian and Jersey with Boran cattle in the tropical highlands of Ethiopia: milk production traits and cow weight. *Journal of Animal Breeding and Genetics.* **121**: 163-175.

Demeke S., Neser F. W. C. and Schoeman, S. J. 2004b. Estimation of genetic parameters for Boran, Friesian and crosses of Friesian and Jersey with Boran cattle in the tropical highlands of Ethiopia: reproductive traits. *Journal Animal Breeding Genetics.* **121**: 57-65.

Falconer, D. S. and Mackay, T. F. C. 1996. Introduction to Quantitative Genetics 4th Edition Longman Group, London.

Hansen, L. B., Freeman, A. E. and Berger, P. J. 1983. Yield and fertility relationship in dairy cattle. *Journal of Dairy Science.* **66**: 293-305.

Kimenye, D. 1978. A Genetic Study of the Kenyan Sahiwal Breed. Ph.D. thesis, University of Nairobi, Kenya.

Khan, U. N., Dahlin, A., Zafar, A. H., Saleem, M., Chaudhry, M. A. and Philipsson, J. 1999. Sahiwal cattle in Pakistan: genetic and environmental causes of variation in body weight and reproduction and their relationship to milk production *Animal Science.* **68:** 97-108.

Laben, R. L., Shanks, R. D., Berger, P. J. and Freeman, A. E. 1982. Factors affecting milk yield and reproductive performance. *Journal of Dairy Science.* **65**: 1004-1015.

Lôbo, R. N.B., Madalena, F. E., and Vieira, A. R. 2000. Average estimate of genetic parameters for beef and dairy cattle in tropical regions. *Animal Breeding Abstract.* **68:** 433-462.

Meyer, K. 1989. Restricted maximum likelihood to estimate variance component for animal models with several random effects using a derivative free algorithm. *Genetics, Selection and Evolution.* **21**: 318-327.

Muhuyi, W. B. 1997. A Comparison of the Productivity of Kenya Sahiwal and their Crosses in Large Scale Dairy Dual Purpose and Beef Production Systems. Ph.D. thesis, University of Nairobi, Kenya.

Muhuyi, W. B., Lokwaleput, I. and Sinkeet, S. N. 1999. Conservation and utilisation of the Sahiwal cattle in Kenya. *FAO Animal Genetics Research Information.* **26:** 35-44.

Musani, S. K. and Mayer, M. 1997. Genetic and environmental trends in a large commercial Jersey herd in the central Rift Valley, Kenya. *Tropical Animal Health and Production.* **29:** 108-116.

Mwandotto, B. N. 1985. Weight, Growth and Maturing Characteristic of Kenya Sahiwal cattle. Ph.D. thesis, Texas A &M University, U.S.A.

Nebel, R. L., McGilliard, M. L. 1993. Interaction of high milk yield and reproductive performance in dairy cows. *Journal of Dairy Science.* **76**: 3257-3268.

Ojango, J. M. K. and Pollot, G. E. 2001. Genetics of milk yield and fertility traits in Holstein-Friesian cattle on large scale Kenyan farms. *Journal Animal Science.* **79**: 1742-1750.

Oltenacu, P. A., Frick, A. and Lindhe B. 1991. Relationship of fertility to milk yield in Swedish cattle. *Journal of Dairy Science.* **74:** 264-268.

Raheja, K. L., Burnside, E. B. and Schaeffer, L. R. 1989. Relationship between fertility and production in Holstein dairy cattle in different lactations. *Journal of Dairy Science.* **72**: 2670-2678.

Rege, J. E. O. and Wakhungu, J. W. 1992. An evaluation of a long term breeding programme in a closed Sahiwal herd in Kenya. Genetic and phenotypic trends and levels of inbreeding. *Journal of Animal Breeding and Genetics.* **109**: 374-384.

Rege J. E. O. 1991. Genetic analysis of reproductive performance of Friesian cattle in Kenya 1. Genetic and phenotypic parameters. *Journal of Animal Breeding and Genetics.* **108**: 412-419.

Rege, J. E. O., Lomole, M. A. and Wakhungu, J. W. 1992. An evaluation of a long-term breeding programme in a closed Sahiwal herd in Kenya. I. Effects of non-genetic factors on performance and genetic parameter estimates. *Journal of Animal Breeding and Genetics.* **109**: 364-373.

Singh, S. K. and Nagarcenkar, R. 1997. Factors affecting milk yield and lactation length in Sahiwal cows. *Indian Journal of Animal Sciences.* **67**: 989-992.

Sorensen, D. A. and Kennedy, B. W. 1984. Estimation of genetic variance from unselected and selected populations. *Journal of Animal Science.* **59:** 1213-1223.

Syrstad O. 1993. Milk yield and lactation length in tropical cattle breeds. *World Animal Review.* **74**: 68-72.

CHAPTER FIVE

ESTIMATES OF GENETIC AND PHENOTYPIC PARAMETERS USING TEST DAY MODELS

5.1. Introduction

Genetic improvement of the Sahiwal breed has been based on selection for increased LMY. These yields are generated from sets of TMY records made throughout the entire LL of an animal. Evaluation based on LMY does not effectively account for effects that are specific to individual TMY because CG are formed on year-season of calving (Jamrozik and Schaeffer, 1997; Swalve, 1998; Rekaya et al., 1999; Serrano et al., 2001). Genetic merit of animals can be predicted based on TMY records from early lactations, and cost reduced by less frequent TMY recording as opposed to daily recording currently practised (Pander et al., 1992). However, use of TMY data in genetic evaluation programmes requires accurate estimates of genetic and phenotypic parameters of specific TMY records. Information on genetic parameter estimates and subsequent genetic evaluation of *B. indicus* cattle based on TMY data is lacking. The decision to use a particular TMY record depends on the relationship between TMY and LMY. Such relationships have not been determined for the Sahiwal cattle under semi-arid conditions in Kenya. This chapter presents the estimates of genetic and phenotypic parameters for TMY data. The relationship between TMY and LMY are also presented.

5.2. Materials and methods

5.2.3. Characteristics of the data

Test day records from the first three lactations of the Sahiwal cows at the NSS obtained from 1978 to 2002 were used in this study. Details of the data source, climate and herd management have been described in Chapter 3. Table 13 shows the characteristics of the data in different fixed effects in the first three lactations.

Table 13. Number of and percent missing records, average days in milk (DIM) and TMY records in each test day (TD) and in the first three lactations and distribution of records in the fixed effects

	TD								Lactation		
	1	2	3	4	5	6	7	8	1	2	3
No. of records	3,260	2,678	2,330	2,330	2,397	2,194	2,016	2,171	8,404	6,448	4,524
DIM	7	23	53	83	117	147	178	212	-	-	-
% missing records[a]	0	17.8	28.5	28.5	26.4	32.7	38.1	33.3	0	23.3	46
Milk yield	6	6.4	5.6	4.8	4.2	3.7	3.4	3	4.4	5	5
SD	2.5	2.6	2.5	2.3	2.1	1.9	1.8	1.6	2.3	2.7	2.7
Min	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Max	17	17	14.5	14.5	12	10.5	10.5	11.5	14.5	14.5	17
Season											
1	681	593	552	608	610	509	498	557	2,011	1,518	1,079
2	882	738	562	494	536	539	530	531	2,049	1,645	1,118
3	876	698	681	651	639	526	432	507	2,173	1,684	1,153
4	821	649	535	577	612	620	556	576	2,171	1,601	1,174
Lactation											
1	1,376	1,176	1,015	1,018	1,041	952	873	953			
2	1,110	880	766	764	789	738	673	728			
3	774	622	549	548	567	504	470	490			
Age class											
1	201	177	153	155	165	150	139	142	1,277	5	
2	586	510	432	433	443	412	382	410	3,511	94	3
3	876	714	618	624	620	579	526	576	2,778	2,319	36
4	642	510	436	428	457	403	368	411	753	2,123	779
5	492	390	355	350	360	331	303	318	82	1369	1,448
6	275	215	197	201	207	185	171	180	3	389	1,239
7	138	117	104	105	105	99	92	97		113	744
8	50	45	35	34	40	35	35	37		36	275

[a]Relative to first TMY and LMY.

The final analysis consisted of cows that had at least the first TMY. Records on LMY were obtained for cows with at least the first four TD milk records. No restrictions were imposed on the minimum TD and LL because of the considerable variation in LL and daily milk yield in *B. indicus* breeds (Madalena et al., 1988; Maule, 1990; Dahlin et al., 1998). As a result, the number of TMY records was variable throughout the eight TD (Table 13). A total of 19,385 TMY records from the first three lactations of 1,618 cows daughters of 162 sires were used to make inferences on genetic and phenotypic parameters.

5.2.4. Statistical analyses

Variance components were estimated using univariate and multivariate TD models. All runs were carried out using the DFREML software package (Meyer, 1989). Animal models were used throughout, incorporating all the pedigree information available. Variance components were estimated based on two different definitions of CG. Contemporary groups were defined either based on the year-season of calving (YSCV) or on the year-season of TD milk sampling (YSTD).

Five sets of analyses were performed. In the first analysis, two multivariate repeatability models differing in the definition of CG were used. The repeatability TD model proposed by Ptak and Schaeffer (1993) was extended to a multiple trait model under which the TMY records within lactation were considered as repeated traits and the three lactations treated as separate traits (Reents et al., 1995; Rekaya et al., 1999). The shape of the lactation curve was accounted for by fixed regression of yield DIM, while the additive genetic effect of the animal was modelled as a constant for each DIM. The covariances between the residuals were assumed to be zero. The equation of the model applied in this case was as follows:

$$y_{ijklm} = \mu + CG_{im} + age_j + b(DIM_{klm}) + b^2(DIM_{klm}) + g_{km} + p_{km} + e_{ijklm} \quad (14)$$

where y_{ijklm} is the TMY in animal k, in lactation m (m = 1, 2, 3) and TD l (l = 1,…,8), μ the mean TMY for cows in lactation m, CG_{im} the effect of contemporary group i for cows in lactation m (in the first multivariate repeatability model, i = YSCV while i =YSTD in the second model), age_j the fixed effect of age class j (j =1,…,8), b and b^2 are the linear and quadratic effect of DIM in animal k and lactation m on TD l, respectively, g_{km} the additive genetic effect of animal k in lactation m, p_{km} the permanent environmental effect of animal k in lactation m and e_{ijklm} the residual term. The year of calving or of TD sampling were from 1978 to 2002 each with four seasons and ages at calving was grouped into 8 classes as indicated in section 3.2.3.

In the second analysis, a univariate repeatability model was used within a lactation with CG alternatives defined as above. The model applied in this case was similar to that used in the first analysis but the effects were fitted within the lactation. In the third analysis, a multitrait TD model including eight TMY within lactation was used. The eight TMY were considered as separate traits. The model fitted was similar to that fitted in the first analysis but only one alternative of CG (YSTD) was considered. In addition, the permanent environmental effect of animal was not fitted. In the fourth analysis, a model similar to that used in the third analysis was used. In this case, TMY in the three lactations were pooled together and treated as repeated measures in each lactation. This allowed for a permanent environmental effect to be fitted. In the fifth analysis, a bivariate model was used to estimate genetic and phenotypic correlations between TMY and LMY in the first three lactations. The model used for TMY was similar to that used in the YSTD alternative in the first analysis but the permanent environmental effects were ignored. For LMY in each lactation, the fixed effects fitted included YSCV and age at calving.

5.3. Results and discussion

5.3.1. Genetic and phenotypic parameters under different alternatives of CG

Table 14 shows the estimates of variance components and of heritability, repeatability and genetic and phenotypic correlations from multivariate models under the two alternatives of CG (i.e., YSCV and YSTD). The estimates of variance components and of heritability and repeatability from univariate models under two alternatives of CG are shown in Table 15. Additive genetic and permanent environmental variances were higher under the YSTD model than the YSCV across the three lactations. This implies that assigning cows to year-season of TD milk sampling than to year-season of calving enhances the detection of differences among animals, both at genetic and environmental levels. The residual variances were lower in the YSTD model than in the YSCV in all lactations and under both analyses. These indicate that more environmental variation is removed by comparing cows based on the TD than on the period of calving. Similar findings have also been reported in the Holstein-Friesian cattle (Rekaya et al, 1999).. A comparison of residual variances between lactations showed that they were highest in the third lactation in both models under multivariate (Table 14) and univariate (Table 15) analyses. The large residual variance associated with the third lactation could be due to changes in the mean lactation milk yield and other sources of variation not accounted for in the two models, such as lengths of the dry and gestation periods influencing

subsequent lactations. Increased residual variance in later lactations has also been reported elsewhere (Teepker and Swalve, 1988; Rekaya et al., 1999).

The estimates of heritability were higher in the YSTD model than in the YSCV in all lactations under both multivariate (Table 14) and univariate (Table 15). This was attributed to a proportionally large increase in the additive genetic variance with a corresponding reduction in the residual variance in the YSTD model. Heritability estimates obtained under the YSTD model are within the range of estimates obtained for TMY in Holstein-Friesian (Rekaya et al., 1999). Apart from lactation one and three, repeatability estimates were higher in the YSTD model under both multivariate (Table 14) and univariate (Table 15) analyses. Repeatability estimates in the present study were comparable to those reported by Lidauer et al. (2003). Genetic correlations were moderately high in the two models (Table 14). Phenotypic correlations were correspondingly lower than genetic correlation estimates. Genetic correlations were higher between lactations one and three in both models than between lactations one and two. To the contrary, phenotypic correlations were higher between adjacent lactations than non-adjacent ones. Similar trends in the genetic and phenotypic correlation estimates between lactations have been reported by Rekaya et al. (1999) in the Holstein-Friesian population in Spain.

Table 14. Additive genetic (σ_a^2), permanent environmental (σ_{pe}^2) and residual (σ_e^2) variances, heritability (h^2), genetic and phenotypic correlations and repeatability (r) in the first three lactations under different multivariate repeatability models[c]

Model[a]	Lactation	Component			Lactation[b]			
		σ_a^2	σ_{pe}^2	σ_e^2	1	2	3	r
YSCV	1	0.78	1.32	1.86	0.20	0.63	0.66	0.53
	2	0.77	1.65	1.95	0.27	0.18	0.53	0.55
	3	0.94	1.39	2.11	0.24	0.30	0.20	0.54
YSTD	1	0.85	1.40	1.68	0.22	0.60	0.61	0.58
	2	1.32	1.45	1.67	0.29	0.30	0.61	0.52
	3	0.97	1.63	1.83	0.27	0.37	0.22	0.59

[a]See text for the description of models.
[b]Heritabilities (diagonal), genetic (above diagonal) and phenotypic (below diagonal) correlations.
[c]Standard errors for heritability estimates and genetic correlations ranged from 0.04 to 0.06 and from 0.10 to 0.14 in both models, respectively.

Table 15. Additive genetic (σ_a^2), permanent environmental (σ_{pe}^2), and residual (σ_e^2),) variances, heritability (h^2)[a] and repeatability (r) in the first three lactations under different univariate repeatability models[a]

Model[b]	Lactation	σ_a^2	σ_{pe}^2	σ_e^2	h^2	r
YSCV	1	0.67	2.14	1.79	0.15	0.61
	2	0.62	2.40	1.94	0.13	0.60
	3	0.35	2.36	2.03	0.07	0.56
YSTD	1	0.78	2.02	1.62	0.18	0.64
	2	0.72	2.46	1.68	0.15	0.66
	3	0.44	2.44	1.83	0.09	0.61

[a]Standard errors for heritability estimates ranged from 0.04 to 0.05 in both models.
[b]See text for the description of models.

5.3.2. Genetic and phenotypic parameters within lactation

The additive genetic and residual variances of TMY in the first three lactations and in the pooled data set are shown in Table 16. In all the lactations, there was an increase in the additive genetic variance from TD 1 to TD 2. Thereafter, there was a general reduction but only in lactation 1 and 2. In the pooled data, there was a gradual reduction in the additive genetic variance from TD 1 to TD 8. This pattern in additive genetic variance is similar to that reported in the literature for cattle (Kettunen et al. 1998; Olori et al., 1999; Rekaya et al., 1999) and sheep (Serrano et al., 2001). The residual variances were highest in TD 1 in all lactations. This could possibly be due to uncontrolled environmental effects at the start of lactation and problems associated with milk let-down in the absence of the calf in *B. indicus* breeds especially in the early stages of lactation. Consistent with other studies (e.g., Swalve, 1995; Pool et al., 2000; Druet et al. 2003), there was generally a reduction in residual variances with increase in the TD number both within and pooled lactations.

Table 16. Additive genetic (σ_a^2), and residual variances (σ_e^2) of TMY in the first three lactations and in the pooled data set

TD	Lactation							
	1		2		3		Pooled	
	σ_a^2	σ_e^2	σ_a^2	σ_e^2	σ_a^2	σ_e^2	σ_a^2	σ_e^2
1	1.55	2.57	1.88	2.70	1.76	2.69	1.76	2.85
2	1.64	2.10	2.20	2.03	2.08	2.20	1.70	2.67
3	1.46	1.69	1.98	1.80	1.24	2.45	1.60	2.41
4	1.41	1.85	1.49	1.52	2.00	1.62	1.50	2.26
5	0.75	1.94	1.35	1.37	1.73	1.62	1.40	2.21
6	1.02	1.68	1.03	1.68	1.73	1.58	1.35	2.19
7	0.76	1.79	1.08	1.28	1.18	1.30	1.20	2.13
8	0.96	1.57	1.00	1.55	1.44	1.20	1.19	1.46

Heritabilities for, and genetic and phenotypic correlations between TMY in the first three lactations and in the pooled data set are shown in Table 17. Heritability estimates ranged

from 0.28 to 0.46, 0.38 to 0.52 and 0.33 to 0.52 for TMY in the first, second and third lactation, respectively, and from 0.25 to 0.30 for the pooled data set. Heritability estimates were lower when the pooled data set was considered than when each lactation was analysed individually. Heritability estimates in lactation one in the present study are within the range of 0.28 to 0.48 reported for British-Holsteins (Pander et al., 1992). Estimates in lactation two and three fall within the range of estimates obtained using random regression TD models (Jamrozik and Schaeffer, 1997; Kettunen et al., 1998). In those studies, heritability estimates ranged from 0.40 to 0.59 (Jamrozik and Schaeffer, 1997) and 0.41 to 0.58 (Kettunen et al., 1998).

A comparison of heritability estimates between lactations showed that they were lowest in the first lactation. Low heritability estimates for first lactation TMY have been reported (Meyer et al., 1989; Machado et al 1998). Heritability estimates in those studies ranged from 0.17 to 0.28 (Meyer et al., 1989) and from 0.04 to 0.32 (Machado et al., 1998). In the first and second lactation, the heritability estimates were highest between TD 2 and TD 4. It has been shown that estimates of heritability are higher in mid-lactation than at the beginning and the end of the lactation (Rekaya et al., 1999; Lidauer et al., 2003). Heritability estimates were low but relatively stable across lactation in the pooled lactation except in TD 8 where the heritability increased due to the reduction in the error variance (Table 16). These low heritability estimates are attributed to a rather high phenotypic variance as result of accounting for repeated TD measures across the three lactations. Heritability estimates from the pooled lactations were comparable to estimates from the multivariate repeatability model with CG defined as YSTD (Table 14).

Genetic correlations among TMY ranged from 0.41 to 0.93, 0.50 to 0.83 and 0.43 to 86 in the first, second and third lactation, respectively, and from 0.34 to 0.68 in the pooled data set (Table 17). The phenotypic correlations were correspondingly lower. The genetic correlations estimated in this study were lower than those reported in the literature (e.g., Pander et al., 1992; Jamrozik and Schaeffer, 1997; Vargas et al., 1998), but within the ranges of 0.38-0.97 and 0.34-0.99 reported by Kettunen et al. (1998) and Druet et al. (2003), respectively. Contrary to studies elsewhere (e. g., Jamrozik and Schaeffer, 1997; Rekaya et al., 1999; Druet et al., 2003), there was no tendency of genetic and phenotypic correlations to decrease as the distance between TD increased. In this study, correlation estimates were not always consistent both when considering each lactation and the pooled data set. For example, the genetic correlation between TD 1 and TD 3 (0.53) was lower compared to the genetic correlation between TD 1 and TD 7 (0.60) in the first lactation. Inconsistency in the genetic

and phenotypic correlations among TD has also been reported elsewhere (Pander et al., 1992; Vargas et al., 1998).

Table 17. Heritabilities (along diagonal), genetic (above diagonal) and phenotypic (below diagonal) correlations between TMY in the first three lactations and in the pooled data set[a]

TD	TMY							
	1	2	3	4	5	6	7	8
Lactation 1								
1	0.38	0.63	0.53	0.55	0.47	0.49	0.60	0.41
2	0.25	0.44	0.64	0.62	0.66	0.57	0.61	0.45
3	0.22	0.29	0.46	0.63	0.69	0.57	0.60	0.43
4	0.22	0.27	0.28	0.43	0.85	0.69	0.72	0.58
5	0.15	0.23	0.25	0.30	0.28	0.65	0.71	0.66
6	0.18	0.23	0.23	0.28	0.21	0.38	0.92	0.93
7	0.20	0.20	0.22	0.26	0.21	0.31	0.30	0.73
8	0.18	0.20	0.20	0.26	0.24	0.31	0.28	0.38
Lactation 2								
1	0.41	0.65	0.56	0.53	0.52	0.65	0.58	0.50
2	0.30	0.52	0.67	0.63	0.65	0.70	0.61	0.63
3	0.26	0.35	0.52	0.52	0.84	0.72	0.80	0.70
4	0.24	0.32	0.27	0.49	0.62	0.77	0.62	0.56
5	0.23	0.33	0.43	0.31	0.49	0.78	0.79	0.83
6	0.32	0.39	0.40	0.41	0.43	0.38	0.84	0.73
7	0.25	0.30	0.39	0.30	0.38	0.44	0.46	0.66
8	0.20	0.28	0.32	0.24	0.37	0.36	0.28	0.39
Lactation 3								
1	0.40	0.65	0.68	0.66	043	0.50	0.79	0.50
2	0.29	0.49	0.77	0.69	0.50	0.53	0.83	0.53
3	0.24	0.31	0.33	0.63	0.70	0.66	0.86	0.79
4	0.31	0.37	0.28	0.51	0.58	0.61	0.78	0.58
5	0.25	0.32	0.37	0.41	0.52	0.63	0.57	0.70
6	0.24	0.28	0.29	0.36	0.44	0.52	0.65	0.57
7	0.34	0.40	0.34	0.42	0.36	0.34	0.48	0.79
8	0.23	0.27	0.34	0.33	0.48	0.31	0.40	0.54
Pooled								
1	0.27	0.50	0.45	0.40	0.44	0.50	0.41	0.34
2	0.37	0.26	0.55	0.47	0.55	0.56	0.45	0.45
3	0.37	0.41	0.26	0.57	0.51	0.59	0.61	0.61
4	0.35	0.32	0.41	0.26	0.57	0.53	0.50	0.50
5	0.35	0.35	0.40	0.41	0.25	0.60	0.55	0.52
6	0.38	0.36	0.43	0.41	0.43	0.27	0.65	0.57
7	0.36	0.33	0.44	0.40	0.42	0.46	0.25	0.68
8	0.36	0.36	0.47	0.43	0.44	0.47	0.50	0.30

[a]Standard errors for heritability estimates and genetic correlations ranged from 0.06 to 0.17 and from 0.06 to 0.18, respectively.

When making decisions on how TMY records could be used in genetic evaluation, it must be decided whether these measurements are repeated records or are observations on different uncorrelated traits (Swalve, 2000). The univariate repeatability model could be used if genetic correlations among TMY records are consistently close to unit and where computational resources are a constrain. It is clear that genetic correlations in this study differ from unit, both within the lactations and in the pooled data set. Therefore, a multiple trait

model should ideally be used for genetic evaluation of the Sahiwal cattle breeding programme.

5.3.3. Relationship between TMY and LMY

Table 18 shows the genetic and phenotypic correlations between TMY and LMY in the first three lactations. The genetic and phenotypic correlations were high and positive in the three lactations. Genetic correlations ranged from 0.84-0.99, 0.94-1.00 and 0.94-0.97 in the first, second and third lactations, respectively. Phenotypic correlations were also high ranging from 0.50-0.85, 0.50-0.83 and 0.53-0.87 in the first, second and third lactations, respectively. The estimates in this study were consistent with estimates from the literature (Meyer et al., 1989; Pander et al., 1992; Kettunen et al., 1998). These results imply that genes that positively influence TMY would also produce a similar effect for LMY. Therefore TMY and LMY could genetically be considered as expression of the same trait. Results of the phenotypic correlation suggest that cows with high TMY in a particular TD will also produce high LMY at the end of the lactation. This implies that genetic evaluation can be based on TMY data rather than LMY at the end of each lactation since selection based on TMY would result in a correlated response in LMY as well.

Table 18. Genetic (r_a) and phenotypic (r_p) correlations between LMY and TMY within the first three lactations[a]

TD	LMY					
	1		2		3	
	r_g^2	r_p	r_g^2	r_p	r_g^2	r_p
1	0.89	0.50	1.00	0.50	0.94	0.53
2	0.91	0.79	0.94	0.65	0.96	0.66
3	0.99	0.84	0.96	0.78	0.94	0.74
4	0.99	0.79	0.97	0.83	0.96	0.80
5	0.84	0.76	0.94	0.83	0.96	0.76
6	0.98	0.84	0.98	0.82	0.94	0.83
7	0.98	0.85	0.98	0.83	0.97	0.87
8	0.97	0.79	0.98	0.83	0.96	0.84

[a]Standard errors ranged from 0.06-0.13.

Genetic evaluations based on TMY data are robust because they consider both genetic and environmental factors that are unique to a particular TD, which gradually and continuously change over the lactation period (Ptak and Schaeffer, 1993; van der Werf et al., 1998; Rekaya et al., 1999). Since, information on TMY is not dependent on LL, inherent biases arising from culling of heifers before completion of a lactation is therefore eliminated (Pander et al., 1992). Furthermore, the least possible unit of a performance record, the TD record, gives substantial amount of data compared to complete lactation within the interval of

evaluation thus improving on the accuracy of cow evaluation (Strabel and Szwaczkowsski, 1997; Rekaya et al., 1999; Misztal et al., 2000). Even for completed lactations, selection on properly weighted index of TMY could be more accurate than selecting based on phenotypic records of total lactation production (Pander et al., 1992). With improved statistical methods associated with TDMs, both genetic and environmental effects associated with each TD are better accounted for (Rekaya et al., 1999; Schaeffer et al., 2000). This gives a more precise definition of the CG, and allows for more accurate description of stage of lactation, which would be difficult to model based on standardized lactation yield (Meyer et al.,1989; Ptak and Schaeffer, 1993; Vischer and Goddard, 1995).

5.4 Conclusions

In this study, genetic and phenotypic parameters (heritabilities and genetic and phenotypic correlations) were estimated for TMY and LMY for the Sahiwal cattle. The results showed that in the first and second lactations, the heritability estimates were highest between TD 2 and TD 4. The genetic and phenotypic correlations between TMY measured early in the lactation and LMY were favourable suggesting that TMY, mainly in early lactation, can be used in genetic evaluation instead of the total LMY. This study has demonstrated the potential of use of TMY records early in the lactation in determining the genetic merits of dairy sires and cows. The use of TMY records is not only desirable but also necessary in production systems constrained by the necessary infrastructure for proper milk recording. Evaluation based on TMY would offer a solution to handle such situations in the Sahiwal breeding programmes in Kenya because it is less costly as only a few data points would be recorded per lactation.

References

Dahlin, A., Khan, U. N., Zafar, A. H., Saleem, M., Chaundhry, M. A. and Philipsson, J. 1998. Genetic and environmental causes of variation in milk production traits of Sahiwal cattle in Pakistan. *Animal Science.* **66**: 307-318.

Druet, T., Jaffrezic, F., Boichard, D., and Ducroq, V. 2003. Modeling lactation curves and estimation of genetic parameters for first lactation test-day records of French Holstein cows. *Journal Dairy Science.* **86**: 2480-2490.

Jamrozik J. and Schaeffer, L. R. 1997. Estimates of genetic parameters for a test day model with random regressions for yield traits of first lactation Holsteins. *Journal of Dairy Science.* **80**: 762-770.

Kettunen, A., Mantysaari, E. A., Stranden, I., PÖsÖ, J. and Lidauer, M. 1998. Estimation of genetic parameters for first lactation test day milk production using random regression models. *Sixth World Congress on Genetics Applied to Livestock Production.* **23**:307-310.

Lidauer, M., Mantysaari, E. A. and Stranden, I. .2003. Comparison of test day models for genetic evaluation of production traits in dairy cattle. *Livestock Production Science.* **79**: 73-86.

Machado, S. G., Freitas, M. A. R. and Gadini, C. H. 1998. Genetic parameters of test day milk yield of Holstein cows. *Sixth World Congress on Genetics Applied to Livestock Production.* **21:** 427-430.

Madalena, F. E. 1988. A note on the effect of variation of lactation length on the efficiency of tropical cattle selection for milk yield. *Theoretical and Applied Genetics.* **76**: 830-834.

Maule, J. P. 1990. The Cattle of the Tropics. University of Edinburgh Centre for Tropical Veterinary Medicine, Edinburgh, UK.

Meyer, K. 1989. Restricted maximum likelihood to estimate variance component for animal models with several random effects using a derivative free algorithm. *Genetics, Selection and Evolution.* **21**: 318-327.

Meyer, K., Grasser H. U., Hammond, K. 1989. Estimation of genetic parameters for first lactation test day production of Australian black and white cows. *Livestock Production Science.* **21**: 177-199.

Misztal I., Strabel, T., Jamrozik, J., Mantysaari, E. A. and Meuwissen, T. H. E. 2000. Strategies for estimating the parameters needed for different test day models. *Journal of Dairy Science.* **83**: 1125-1134.

Olori, V. E., Hill, W. G., McGuirk, B. J. and Brotherstone, S. 1999. Estimating variance components for test day milk records by restricted maximum likelihood with a random regression animal model. *Livestock Production Science* **61**: 53-63.

Pander, B. L., Hill, W. G. and Thompson, R. 1992. Genetic parameters of test day records of British Holsteins heifers. *Animal Science.* **55**: 11-21.

Ptak, E. and Schaeffer, L. R. 1993. Use of test day yields for genetic evaluation of dairy sire and cows. *Livestock Production Science.* **34**: 23-34.

Pool M. H., Janss L. L. G. and Meuwissen, T. H. E. 2000. Genetic parameters of legendre polynomials for first lactation curves. *Journal of Dairy Science.* **83**: 2640-2649.

Reents R., Dekkers, J. C. M. and Schaeffer, L. R. 1995. Genetic evaluation of somatic cell score with multiple lactation test day model. *Journal of Dairy Science.* **78**: 2858-2870.

Rekaya, R., Carabano, M. J. and Toro, M. A. 1999. Use of test day yields for genetic evaluation of production traits of Holstein-Friesian cattle. *Livestock Production Science.* **57**: 203-217.

Schaeffer, L. R., Jamrozik, J., Kistemaker G. J. and Doormaal, B. J. 2000. Experience with a test day model. *Journal of Dairy Science.* **83**: 1135-1144.

Strabel, T., and Szwaczkowski, T. 1997. Additive and permanent environmental variance components for test day milk yields traits in Black-white cattle. *Livestock Production Science.* **8**: 91-98.

Swalve, H. H. 1995. The effect of test day models on the estimation of genetic parameters and breeding values for dairy yield traits. *Journal of Dairy Science.* **78**: 929-938.

Swalve, H. H. 1998. Use of test day records for genetic evaluation. *Sixth World Congress on Genetics Applied to Livestock Production* **23**: 295-302.

Swalve, H. H. 2000. Theoretical basis and computation methods for different test day genetic evaluation methods. *Journal of Dairy Science.* **83**: 1115-1124.

Teepker, G. and Swalve, H. H. 1988. Estimation of genetic parameters for milk production in the first three lactations. *Livestock Production Science.* **20**: 193-202.

Van der Werf, J. H. J., Goddard, M. E. and Meyer, K. 1998. The use of covariance functions and random regression for genetic evaluation of milk production based on test day records. *Journal of Dairy Science.* **81**: 3300-3308.

Vargas, B., Perez E. and Van Arendonk, J. A. M. 1998. Analysis of test day yield data of Costa Rican dairy cattle. *Journal of Dairy Science.* **81**: 255-263.

Visscher, P. M. and Goddard, M. E. 1995. Genetic parameters for milk yield, Survival, workability and type traits for Australian Dairy cattle. *Journal of Dairy Science.* **78**: 205-220.

CHAPTER SIX

GENERAL DISCUSSION AND CONCLUSIONS

6.1. Aim of the study

The Sahiwal breed is known to have the greatest potential for milk production, growth and reproductive efficiency in tropical environments compared to other *B. indicus* breeds (Trail and Gregory, 1981; Singh and Nagarcenkar, 1997; Islam and Bhuiyan, 1997; Dahlin et al., 1998; Muhuyi, 1999; Khan et al., 1999). Its ability to endure and produce in harsh environments, coupled with its dual-purpose role, makes the Sahiwal a very important animal for use in semi-arid and arid areas (ASALs) in Kenya and other tropical and sub-tropical countries. It is for this reasons that the Food and Agricultural Organisation of the United Nations (FAO) prioritised its development through proper management and genetic improvement (FAO, 1992). Therefore, genetic evaluation of this breed would form an important step in such an effort.

Genetic analysis of traits of economic importance is critical in determining the effectiveness of any genetic improvement programme. Knowledge of non-genetic factors affecting performance, extent of genetic variation, and genetic and phenotypic relationships among these traits have to be determined if specific genetic improvement strategies and other management options are to be explored. It is therefore important to have accurate estimates of genetic and phenotypic parameters in order to determine responses to selection and genetic gain expected from breeding programmes and to evaluate livestock improvement programmes (Roman and Wilcox, 2000).

With recent developments in quantitative genetics and the resultant tendency to apply more efficient breeding plans, accurate estimates of genetic and phenotypic parameters by fitting models that best describe the observation are required. Models for estimating genetic and phenotypic parameters have improved dramatically because of the development of more appropriate statistical methods that overcome inherent biases in genetic evaluations using field data. Such models have not been used to evaluate *B. indicus* dairy cattle breeding programmes in Kenya. It is for this reason that the present study was envisaged. The aim of this study was to genetically analyse milk production and reproductive traits of the Sahiwal cattle in semi arid Kenya using various conventional and TDMs. This study tested three hypotheses; (i) environmental factors are not the causes of observed variation in milk production and fertility traits, (ii) genetic and phenotypic parameters estimated using the

various models are comparable and (iii) No genetic improvement in milk production and fertility traits has occurred over the years.

6.2. Study methodology

In this study, both conventional and TDMs were used. Two data sets were formed. The first data set comprised of lactation milk yield (LMY), lactation length (LL), calving interval (CI), number of services per conception (NSC) and age at first calving (AFC). The second data set comprised of test day milk yield (TMY) records in the first three lactation. Genetic and phenotypic parameters were estimated using derivative free restricted maximum likelihood procedures (Meyer, 1989). In the first data set, univariate and multivariate models were fitted to obtain variance components. Univariate models were used for each trait to obtain heritability and repeatability estimates while multivariate models were used to estimate genetic and phenotypic parameters for milk production and fertility traits in different lactations. In the second data set, variance components were estimated using univariate repeatability test day TDM proposed by Ptak and Schaeffer (1993) and multivariate TDMs (Rekaya et al., 1999) with contemporary groups (CG) defined either based on year-season of calving (YSCV) or sampling a TD record (YSTD). In this case, eight TD within each lactation were considered as separate traits. A bivariate model was used to estimate genetic and phenotypic correlations between TMY and LMY in the first three lactations.

6.3. Contribution to the knowledge of local genetic resources

Conservation and sustainable utilisation of breed resources has received major concern in the recent past because of its implication to the future livelihoods of communities (FAO, 1992; Rege and Gibson, 2003). A Sahiwal genetic improvement programme has to focus on maintenance and genetic improvement of the breed in order to improve food security and promote sustainable agriculture, especially in the ASALs. Erosion of local genetic resources in the tropics is attributed to breed substitution and indiscriminate crossbreeding of the breed to the introduced temperate breeds which have not been evaluated in different production systems to emphasise their contribution to economic livelihoods of communities (FAO, 1992; Dahlin et al., 1995; Rege and Gibson, 2003; Riethmuller, 2003). These imply that strategic research is crucial in effective conservation and utilisation of the existing Sahiwal genetic resources through systematic documentation of their performance in harsh environments, estimation of the extent of additive genetic variances for traits of economic importance and quantification of progress from previous improvement strategies.

Knowledge of the performance of the Sahiwal is still scarce in the tropics. Chapter 3 of this thesis has quantified the level of performance of the Sahiwal cattle on milk production and reproductive traits in semi-arid Kenya. The results indicate that the Sahiwal breed is still unparalleled in terms of milk production compared to other *B. indicus* breeds in the tropics. The general decline in performance over the study period was attributed to large fluctuations in the climatic conditions and therefore appropriate management strategies should be able to reverse the observed performance. The results in Chapters 4 and 5 indicate that there is sufficient additive genetic variance for milk production traits, which offers an opportunity to improve these traits through selection. However selection for increased milk production should be exercised with some caution because of the unfavourable relationship between milk production and fertility traits reported in Chapter 4. It may become important to include measures of reproductive performance in routine genetic selection index in order to attenuate the rate of reproductive decline that would result from increased selection for milk yield. The estimates of the genetic parameters for milk production and fertility traits obtained in Chapter 4 and 5 are important. They have given an indication of the ability of the Sahiwal breed to respond to selection and consequently its potential to evolve in its own environment. They contribute to the better understanding of the Sahiwal breed and therefore better utilisation of local genetic resources. Those genetic parameter estimates when utilised in conservation programmes, will be very useful in indicating the genetic variability in the Sahiwal population.

Results in Chapter 5 clearly indicate that rapid genetic gains could be realised if early measures of genetic merit such as TMY could be used as selection criteria instead of aggregate the LMY. The reported genetic decline in milk production and fertility traits in Chapter 4 is of concern. The apparent decline is associated with both genetic and existing management practices. The magnitude and direction of the change reflect failure of the existing genetic improvement and management strategies. These suggest that proven sires may not have been selected and utilised effectively, and the effect of inimical environmental under which the herd was performing was not managed properly. Evaluation of genetic trends (Chapter 4) is required to quantify the results of selection, allowing evaluation and improvement of the present selection criteria. The evaluation of the genetic trends gives an indication of the rate of genetic improvement.

6.4. Competitiveness of the Sahiwal genetic resources

Tropical environments are characterised by poor nutrition, high disease challenge and ambient temperatures, which require that cattle breeds must endure such stresses (Cunningham and Syrstad, 1987; Syrstad and Ruane, 1998). Although germplasm of European origin have high genetic potential in intensive dairy production systems in the tropics, fitness is relatively less in tropical environments because of insufficient feed resources, disease and parasite challenges and high temperatures (Cunningham and Syrstad, 1987). Despite these challenges the production potential of the Sahiwal breed is still acceptable (Chapter 3). This shows that both artificial and natural selection over generations has provided this breed with high level of heat tolerance, some resistance to many tropical disease and the ability to survive long periods of scarce feed and water resources to produce both milk and meat (Syrstad and Ruane, 1998). The additive genetic variance for production traits in the Sahiwal breed is high compared to the other tropical breeds, which means that with a well defined and effective breeding programme, substantial improvement in performance can be achieved.

The Sahiwal breed has been utilised in crossbreeding programmes with the high yielding potentials of the exotic breeds (Muhuyi, 1997; Kahi et al., 2000a). Crossbreeding between the highly productive temperate breeds and the adapted Sahiwal cattle has allowed for the use of improved germplasm within the prevailing tropical constraints which has resulted in increased superior performance of the crossbreds in various production systems (Muhuyi, 1997; Kahi et al., 2000a, b and c). For further improvement of the crossbreds, within breed selection of pure Sahiwal breed is necessary. In designing future crossbreeding systems, estimates of additive genetic differences between breeds, the relative value of heterosis in crosses between them and their interaction with different environments and management levels is required (Cunningham and Syrstad, 1987).

6.5. Test day models versus conventional models for genetic evaluation

In cow and sire evaluation programmes in Kenya, selection is based on standardised or lactation yields, which are predicted from individual TD records taken at monthly intervals. Selection based on early TMY in early parts of lactation would result in reduction in the generation interval, cost of recording and cost of maintaining cows and bulls with low genetic merit (Pander et al., 1992; Vargas et al., 1998; Schaeffer et al., 2000; Swalve, 2000). Various models for estimating genetic and phenotypic parameters for TD yield data have been explored in Chapter 5. The results indicate that by fitting YSTD effect is the closest

approximation to the assumed production environment. This describes the origin of the variable more accurately and accounts for time dependent effects at a TD level than conventional models that usually fit year-season of calving (Pander et al., 1992; Rekaya, 1999; Schaeffer et al., 2000).

Genetic and phenotypic correlations were high between TMY and LMY (Chapter 5). These results were consistent with what has been reported in the literature on other breeds (Pander et al., 1992; Machado et al., 1998; Vargas et al., 1998). Therefore, TMY and LMY could genetically be considered as expression of the same trait in the Sahiwal cattle. Evaluation can be based on early TMY rather than LMY at the end of each lactation because selection based on TMY would result in a correlated response in LMY. Circumstances in Kenya are ideal for the application of TDMs for routine genetic evaluation of dairy cattle.

The heritabilities of milk yield obtained in TD 2 and TD 3 in the first lactation are high and comparable to heritability estimates for LMY reported in Chapter 4. Furthermore, genetic correlation between TMY and LMY are also high. The accuracy of selection based on these early TMY would be expected to be higher than when based on complete lactations because of increased selection intensity and reduced generation intervals (Pander et al., 1992; Machado et al., 1998; Vargas et al., 1998; Kettunen et al., 2000; Swalve, 2000). For instance use of TD 2 or TD 3 in the first lactation would result in higher genetic gains because sires and cows could be selected at approximately 23 and 53 days post-partum, respectively, rather than wait for the cows to complete the lactation. The genetic merit of bulls would be determined when their daughters are 23 to 53 days in milk in the first lactation. In progeny testing programmes based on aggregate LMY, bulls would be maintained in the herd until their daughters have completed an entire lactation. However, early selection based on TD records would result in reduced cost of recording by less frequent TD recording and maintaining progeny test bulls with low breeding values in the herd (Schaeffer et al., 2000; Swalve, 2000). Inherent biases arising from culling of heifers before completion of lactation is eliminated by use of early TD records since they are not dependent on the LL as is the case with conventional 305-day or LMY models. In addition, for completed lactations, selection on a properly weighted index of TD records could be more accurate than selection based on phenotypic records of standardised lactation production (Pander et al., 1992).

It is possible to predict the genetic merit of sires and cows for a complete LMY with high accuracy from TD 2 to TD 3 in the first lactation (Chapter 5). This is illustrated using sires with at least 20 daughters to investigate the relationship between estimated breeding values for TD 2 and TD 3 and LMY in the first lactation. The results are presented in Figure

7. The correlation between breeding values for TD 2 and LMY ($r = 0.70$) and TD 3 and LMY ($r = 0.61$) were strong. The magnitude of these correlations implies that evaluation based on either TMY and LMY would be the same, although each correlation differed markedly from unity suggesting that ranking of sires based on TMY and LMY would not exactly be the same.

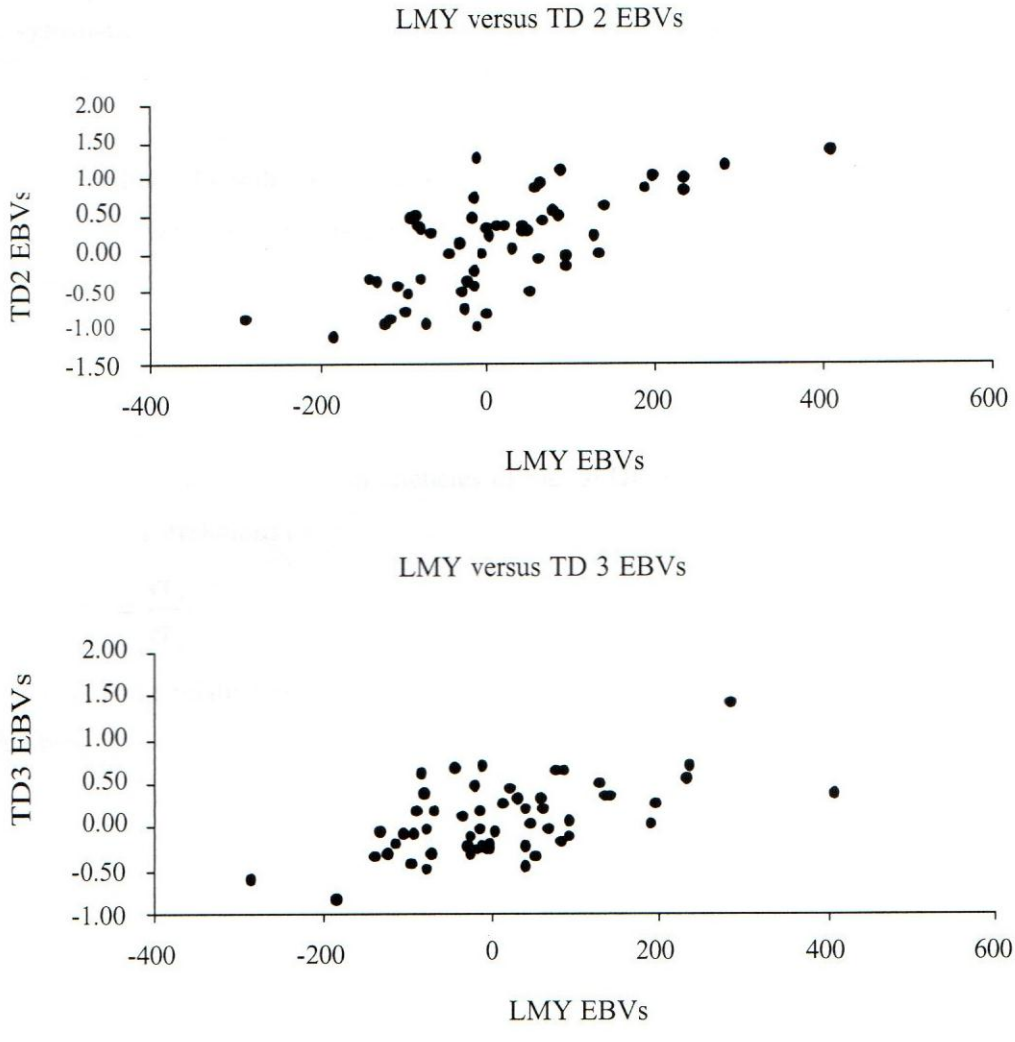


Figure 7. Relationship between EBVs for TD 2 and TD 3 and LMY

6.6 BLUP versus contemporary comparison method

Genetic evaluation has to be undertaken regularly to ensure that the best animals are given an opportunity to be parents of the next generation based on their genetic merit (Kelm et al., 1997). Evaluation procedures must therefore be used to accurately and reliably obtain EBVs and discriminate superior cows and bulls while accounting for variations that arise due to systematic environmental effects (Bebber et al., 1997; Togashi et al., 2004).

Ranking of breeding stock at the NSS has been based on CC. The efficiency of BLUP and CC was assessed by ranking 50 sires based on breeding values for LMY estimated using the two methods. In both cases, sires were ranked in descending order. Only sires with at least 15 daughters were used in this comparison. A rank correlation test was performed using the following formula (e.g., Mosi and Munuve, 2003):

$$p = \frac{1 - 6\Sigma d^2}{[m(m^2 - 1)]} \tag{15}$$

where p is the rank correlation coefficient, d^2 the squared rank difference, and m the total number of ranked sires. The efficiencies of the BLUP and CC indices of ranking animals were derived correlations as:

$$r_{IA} = \frac{\sigma_I}{\sigma_a} \tag{16}$$

where r_{IA} is the relative efficiency of the method expressed as a correlation between it and the true breeding value of the animal, σ_I the standard deviation of the index in the population and σ_a the additive standard deviation in the population. The results showed that the rankings by the two methods were clearly different (rank correlation coefficient of 0.69). The relative efficiency of the BLUP index was higher than for CC. This implies that the BLUP method of estimating BV is more efficient and therefore more a appropriate index for cow and sire evaluation. Pedigree merit calculated by BLUP has also been shown to be more accurate in predicting evaluation of AI sires than pedigree index from CC (Samuelson and Pearson, 1995). Selection based on BLUP EBVs results in high accuracy because more information is utilised and the effect of non-genetic factors on performance are better accounted for. The animal BLUP methodology would be robust in situations with fluctuations in environmental effects, small progeny groups and where discrimination of genetically superior dams is more important as in the dam-sire selection pathway (Dahlin et al., 1998).

Unfavourable environmental effects would obscure genetically superior animals if an evaluation procedure does not effectively adjust for these effects. Under adverse

environmental conditions, CC procedure would not effectively discriminate superior genotypes. This is because CC is biased by incorrect adjustment for age at freshening, genetic trends and non-random sampling of mates within a herd. Unlike the BLUP procedure, CC does not utilise a lot of available information in computing breeding values and ignores the dam's influence on performance of its progeny. Therefore, persistent use of CC would result in inaccurate ranking of breeding stock, which would subsequently lead to sub-optimal selection decisions. If suitable animals were not accurately selected based on their genetic merit then genetic progress would be slowed down and in some cases result in genetic decline. The most appropriate and suitable method for evaluating the Sahiwal cattle breeding programme would be to use BLUP in order to consider the environmental and animal effects simultaneously.

6.7 Redesigning the Sahiwal cattle breeding programme

6.7.1. Breeding goal

The definition of breeding goals is an important step in the systematic design of genetic improvement programmes (Smith, 1988; Ponzoni and Newman, 1992; Kahi et al., 2004). The breeding goal comprises of breeding values and economic values of traits a producer wants to improve because of the influence they have on revenue and costs in the production system. The definition of a breeding goal is made up of the following steps (i) specification of the production and marketing system, (ii) identification of sources of income and expense (iii) determination of biological traits influencing revenue and cost (iv) calculation of the economic value of each trait in the breeding objective (Ponzoni and Newman 1989). Currently, selection of the Sahiwal at NSS is based on their biological efficiency without due regard to the overall economic efficiency of such decisions. Selecting animals based on a well-defined breeding goal will result in an improvement in both the biological and economic efficiency of production systems that utilise the Sahiwal genetic resources. A breeding goal for the Sahiwal breed should be dual purpose because such goals would represent an efficient and realistic objective for its improvement (Kahi et al., 2004). However, there is an urgent need to develop breeding goals for different production systems that utilise the Sahiwal breed. This study has given an indication of the traits that could be included in the breeding goal. The results in Chapters 4 and 5 have provided useful estimates of genetic and phenotypic parameters based on an animal model which would allow for the development and evaluation of breeding goals

aimed at improved milk production and reproductive performance of the Sahiwal in semi-arid Kenya.

6.7.2. Selection criteria

The most effective method for evaluating breeding values for animals is to determine their genotypes directly. This involves finding animals with the best additive genetic effects (breeding values) to serve as parents for future generations (Kelm et al., 1997). However, in practice this is not possible because traits for improvement may not be directly measurable and therefore other measurable traits, which are highly correlated to the target traits, act as selection criteria. The basis for using a measurable character as a criterion lies upon the strength of the genetic relationship between the character and the target trait and its heritability.

The results in Chapter 4 indicate that unfavourable relationship exists between milk production and fertility traits. This implies that long-term selection for increased milk production would result in loss of reproductive efficiency. It may become important to include measures of reproductive performance such as CI in the selection criteria in order to attenuate the rate of reproductive decline in the Sahiwal cattle breeding programmes. Such an option would involve combining milk production and fertility traits in a multi-trait breeding goal. The genetic correlations among LMY in the first three lactations (Chapter 4) also indicate that selection based on milk production traits in the first lactation would result in increased yields in the other lactations as well. Furthermore, estimates of genetic correlations between TMY and LMY in Chapter 5 reveal that early TMY (TD 2 and TD 3) can be used as selection criteria instead of aggregate LMY.

6.7.3. Selection strategies

There are three main genetic improvement strategies applied in livestock production. Selection between breeds or strains of cattle, crossbreeding and selection within breeds (Bondoc et al., 1989; Syrstad and Ruane, 1998). Between breed selection can result in greater genetic gain when there is sufficient genetic differences between breeds in a population on the traits to be improved. Within breed selection is an improvement strategy practiced in individual populations with the aim of increasing the average level of genetic merit of the population. Within breed selection of local populations are generally recommended in low input systems where animals that are well adapted and reasonably productive are required to preserve the hardiness traits while maintaining production (Smith, 1988; Syrstad and Ruane,

1998). This is the strategy that has been used for genetic improvement of the Sahiwal breed for milk and growth characteristics in Kenya (Rege et al., 1992; Rege and Wakhungu, 1992: Mwandotto, 1994; Muhuyi et al., 1999). For successful within breed selection, information on the extent of additive genetic variance estimated based on appropriate models for traits of interest is required. Such estimates were lacking for the Sahiwal breed in Kenya. The results in Chapters 4 and 5 have indicated that there is sufficient additive genetic variance for milk production traits in the Sahiwal cattle despite the considerable climatic variations, diseases and other environmental factors, which are prevalent in the semi-arid environment. This offers an opportunity to improve production traits through selection. The large coefficients of variation for most traits studied also indicate prospects for realisation of rapid improvement for these traits.

There is substantial amount of improvement in performance when crossbreeding strategies involving *B. taurus* and *B. indicus* breeds are employed (Gregory and Trail, 1981; Kahi et al., 2000a). The Sahiwal has been the *B. indicus* breed most frequently used in dairy crossbreeding in Kenya (Gregory and Trail, 1981; Muhuyi, 1997; Kahi et al., 2000a, b and c). This study has shown sufficient additive genetic variance for milk production traits (Chapter 4 and 5). This indicates that systematic crossbreeding of the Sahiwal and exotic breeds could be exploited. For further improvement of the crossbreds, within breed selection of pure Sahiwal breed is necessary, as these would also be required in the crossbreeding programme. Specific and rotational crossing involving Sahiwal and *B. taurus* breeds would allow benefit of heterosis in each generation without the need to maintain separate purebred populations. This strategy would be self-sustaining because of the reduced cost of acquiring replacement stock and maintaining purebred herds (Bondoc et al., 1989). However, this strategy would not be suited for smallholder production systems because of the small herd sizes, organisational and management problems (Kahi et al., 2000b). Breed substitution by backcrossing could be practiced in agro-ecological zones where the exotic breeds are more desirable than the purebred Sahiwal cattle. Alternatively, crossbreeding of the Sahiwal and *B. taurus* breeds could be done with the sole aim of creating a synthetic population. Formation of synthetic populations involves combining two or more breeds to form a new breed. Use of the Sahiwal breed in formation of synthetic breed would be advantageous because of its adaptability to local environment and relatively large additive genetic variance for production traits (Chapters 4 and 5). In addition, the additive genetic difference between the Sahiwal and the exotic breeds is also large (Trail and Gregory, 1981; Kahi et al., 2000b) which imply that use of the two breeds in the formation of synthetic populations would result in improved

performance. In designing crossbreeding strategies, estimates of additive genetic differences between breeds, the relative value of heterosis in crosses between them, and their interaction with different environments and management levels are required (Cunningham and Syrstad, 1987).

6.7.4. Organisation of the breeding programme

Successful cattle improvement programmes should consist of clear definitions of breeding goals supported by farmers, accurate evaluation procedures of identifying superior genotypes and a practical delivery mechanism to allow the superior genetic material to be disseminated quickly throughout the whole population (Smith, 1988; Ponzoni and Newman 1989; Kahi et al., 2004). Breeding goals for dairy productions in Kenya have been developed (Kahi and Nitter, 2004; Kahi et al., 2004). The Sahiwal cattle breeding programme must have expected outputs, which should be commensurate with the objectives of the end users and driven by incentives. Currently KARI and commercial ranches, e.g., Elkarama, Dolereine, Oljorai, Olesentu are the custodian of majority of the purebred Sahiwal cattle in Kenya. They should take centre stage in improvement and conservation programmes.

A closed nucleus breeding scheme for the genetic improvement of the Sahiwal breed has been in operation at NSS for over 40 years (Rege et al., 1992; Mwandotto, 1994; Muhuyi, 1997). The NSS has been characterised by a comprehensive performance recording and animals are selected with the aim of achieving improvement in production traits. There is no migration of animals from other Sahiwal herds into the NSS. Rege and Wakhungu (1992) recommended the importation of semen from other Sahiwal herds into the NSS to reduce the inbreeding levels at the NSS. Opening the nucleus would allow the NSS to genetically progress more quickly and this would benefit the whole scheme because other Sahiwal herds will move simultaneously with NSS.

Kahi et al. (2004) recommended the establishment of two-tier open nucleus breeding schemes (ONBS) to maximise genetic improvement, reduce inbreeding rate and reduce the total cost of recording. For the Sahiwal breed in Kenya, a two-tier ONBS could be established with the NSS being the nucleus. Alternatively, the nucleus could be dispersed to include other elite Sahiwal ranches. The commercial sector would include other Sahiwal ranches, pastoralists and small-scale farmers. In the nucleus, sire and cow selection would be the main activity and this is where genetic gain would be generated. An ONBS would offer wide selection base where exceptionally good animals in the commercial ranches could be used and reduce inbreeding levels. Such females could be bought or loaned to the nucleus herd for a

certain period of recording then returned to the owners accompanied by genetically superior offsprings as an incentive to the owners. However, ONBS needs continuous comprehensive performance recording in the participating herds, which requires infrastructure, technical assistance and other operational costs (Kahi et al., 2004). This presents a challenge of how effectively an ONBS can be implemented for the improvement of the Sahiwal and how the Sahiwal owners could be organised to record their herds and monitor progress. Kahi et al. (2004) recommended several approaches to overcome these bottlenecks. These include good extension service aimed at boosting the experiences and skills of the commercial Sahiwal ranchers and small-scale farmers. The ranchers should be made aware of the potential benefits that would be derived from the recording activities. Provision of incentives e.g. less taxation, retention of a percentage of profits accrued from the sale of semen from bulls bred and raised in the herd, long term contracts for the supply of bulls to ranches for natural mating, discounts on electronic data processing and breeding advice would also motivate commercial Sahiwal ranchers and small-scale farmers to actively participate and have a feeling of ownership of the breeding programme. Most of the commercial ranchers aim to maximise profits from their herds and therefore a cost benefit analysis should be able to convince them to play an active role in the success of the breeding programme (Muhuyi, 1997).

There should be an effective way to disseminate and make optimum use of improved animals in the ONBS. The bulls available for dissemination should be young bulls selected on the basis of pedigree performance. Kahi et al. (2004) demonstrated that a well organised breeding programme utilising an ONBS with a young bull scheme would result in high genetic gain and easily sustain itself. In this system, young bulls from the best bull dams and sired by proven dual-purpose bulls can be used. The young bulls should also be evaluated on their own growth rates. The best males should be retained in the nucleus and the remaining used for breeding in the commercial herds. Selection of female animals would generate more genetic progress than selection of males alone.

6.8. Conclusions

This study has provided important information on the performance level and extent of additive genetic variances for milk production and fertility traits of the Sahiwal cattle in semi-arid environments. Performance would greatly be improved if satisfactory management is provided during adverse conditions. Knowledge of genetic and phenotypic parameters for these traits is important for the future design of an efficient breeding programme for the Sahiwal breed in Kenya. This study is one of the first documentation of genetic and

phenotypic parameters for milk yield based on TDM for *B. indicus* in the tropics. Use of TMY is not only desirable but also necessary in production systems constrained by lack of the necessary infrastructure for proper milk recording. Evaluation based on TMY would offer a solution to handle such situations in Kenya because it is least costly as only a few data points would be recorded per lactation.

Estimates of genetic parameters indicate that there is substantial additive genetic variation for milk production traits, which implies that remarkable improvement of these traits could be achieved through selection. The relationship between milk production and fertility suggests that there is need to include measures of fertility in routine selection index. The current selection method should be changed to a more effective multiple-trait BLUP animal model methodology incorporating both milk production and fertility traits. The rather slow genetic improvement at the NSS is associated with both inadequate genetic and management strategies.

Genetic and phenotypic parameters were only estimated for milk production and fertility traits. The Sahiwal breed is dual-purpose and it is therefore important that similar estimates be obtained for other economically important traits such as growth and survival traits. This will allow for the design of an efficient breeding programme that would lead to faster rates of genetic improvement within the breed. In addition the population structure of the Sahiwal breed has to be defined to quantify the levels of inbreeding and its effect on variance components and on traits of economic importance.

References

Bebber, J., Reinsch, N., Junge, W. and Kalm, E. 1997. Accounting for herd, year and season effects in genetic evaluation of dairy cattle. A review. *Livestock Production Science.* **51**: 191-203.

Bondoc, O. L., Smith, C. and Gibson, J. P. 1989. A review of breeding strategies for genetic improvement of dairy cattle in developing countries. *Animal breeding Abstracts.* **57**: 819-829.

Cunningham, E. P. and Syrstad, O. 1987. Crossbreeding *Bos indicus* and *Bos taurus* for milk production in the tropics. *FAO. Animal Production and Health. Paper No. 68;* Rome, Italy.

Dahlin, A., Khan, U. N., Zafar, A. H., Saleem, M., Chaudhry, M. A. and Pilipsson, J. 1995. Population structure of the Sahiwal breed in Pakistan. *Animal Science.* 60: 163-168.

Dahlin, A., Khan, U. N., Zafar, A. H., Saleem, M., Chaundhry, M. A. and Philipsson, J., 1998. Genetic and environmental causes of variation in milk production traits of Sahiwal cattle in Pakistan. *Animal Science.* **66**: 307-318.

FAO. 1992. Animal genetic resource conservation and management report of the FAO/UNEP Technical consultation held in Rome, 1992. *Food and Agriculture Organisation of the United Nations*, Rome Italy.

Gregory, K. E. and Trail, J. C. M., 1981. Rotational crossbreeding with Sahiwal and Ayrshire cattle in tropics. *Journal of Dairy Science.* **64**: 1978-1984.

Islam, S. S. and Bhuiyan, A. K. F. H., 1997. Performance of crossbred Sahiwal cattle at the Pabna milk shed area in Bangladesh. *Asian-Australasian Journal of Animal Science.* **10**: 581-586.

Kahi, A. K. and Nitter, G. 2004. Developing breeding schemes for pasture based dairy production systems in Kenya. I. Derivation of economic values using profit functions. *Livestock Production Science.* **88**: 161-177.

Kahi, A. K., Nitter, G. and Gall, C. F., 2004. Developing breeding schemes for pasture based dairy production systems in Kenya. II. Evaluation of alternative objectives and schemes using a two-tier open nucleus and the young bull system. *Livestock Production Science.* **88**: 179-192.

Kahi, A. K., Thorpe, W., Nitter, G. and Baker, R. L., 2000a. Crossbreeding for Dairy production in the Lowland tropics of Kenya. I. Estimation of individual crossbreeding effects on milk production and reproductive traits and cow live weight. *Livestock Production Science*. **63**: 39-54.

Kahi, A. K., Thorpe, W., Nitter, G. and Baker, R. L., 2000b. Crossbreeding for Dairy production in the Lowland tropics of Kenya. II. Prediction of alternative crossbreeding strategies. *Livestock Production Science*. **63:** 55-63.

Kahi, A. K., Thorpe, W., Nitter, G. Van Arendonk, J. A. M. and Gall, C. F. 2000c. Economic evaluation of crossbreeding for dairy production in a pasture based production system in Kenya. *Livestock Production Science*. **65**: 167-184.

Kelm, S. C., Freeman, A. E., and D. H. Kelly. 1997. Realised versus expected gains in milk production and fat production of Holstein cattle, considering the effect of days open. *Journal of Dairy Science*. **80**: 1786-1794.

Kettunen, A., Mäntyaari, E. A. and Pösö, J. 2000. Estimation of genetic parameters for daily milk yield of primiparous Ayrshire cows by random regressions test-day models. *Livestock Production Science*. **66**: 251-261.

Khan U. N., Dahlin A., Zafar A. H., Saleem M., Chaudhry M. A. and Philipsson J. 1999. Sahiwal cattle in Pakistan: genetic and environmental causes of variation in body weight and reproduction and their relationship to milk production *Animal Science*. **68**: 97-108.

Machado S. G., Freitas M. A. R., and Gadini, C. H. 1998. Genetic parameters of test day milk yield of Holstein cows. *Sixth World Congress on Genetics Applied to Livestock Production*. **23**: 427-430.

Meyer K. 1989. Restricted maximum likelihood to estimate variance component for animal models with several random effects using a derivative free algorithm. *Genetic Selection and Evolution*. **21**: 318-327.

Mosi, R. O. and Munuve, M. 2003. Assessment of the relative efficiency of dairy cow evaluation methods. *Bulletin of Tropical Animal Health and Production in Africa*. **51**: 198-203.

Muhuyi, W. B., 1997. A comparison of the productivity of Kenya Sahiwal and their crosses in large scale dairy dual purpose and beef production systems. Ph.D. thesis, University of Nairobi, Kenya.

Muhuyi, W. B., Lokwaleput, I. and Sinkeet, S. N., 1999. Conservation and utilisation of the Sahiwal cattle in Kenya. *FAO Animal Genetics Research Information*. **26**: 35-44.

Mwandotto, B. A. J. 1994. Phenotypic, genetic and environmental parameter estimates of weight, growth and maturing patterns in Sahiwal females. *Bulletin of Animal Production*. **42:** 61-67.

Pander B. L., Hill W. G. and Thompson R. 1992. Genetic parameters of test day records of British Holsteins heifers. *Animal Science*. **55**; 11-21.

Ponzoni, R. W. and Newman, S., 1989. Development of breeding objectives for Australian beef cattle production. *Animal Production*. **49**: 35-47.

Ptak, E. and Schaeffer L. R. 1993. Use of test day yields for genetic evaluation of dairy sire and cows. *Livestock Production Science*. **34**: 23-34.

Rege, J. E. O. and Wakhungu. J. W., 1992. An evaluation of a long term breeding programme in a closed Sahiwal herd in Kenya. Genetic and phenotypic trends and levels of inbreeding. *Journal of Animal Breeding and Genetics*. **109**: 374-384.

Rege, J. E. O. and Gibson, J. P. 2003. Animal genetic resources and economic development: issues in relation to econo mic evaluation. *Ecological Economics*. **45**: 319-330.

Rege, J. E. O., Lomole, M. A. and Wakhungu, J. W., 1992. An evaluation of a long-term breeding programme in a closed Sahiwal herd in Kenya. I. Effects of non-genetic factors on performance and genetic parameter estimates. *Journal of Animal Breeding and Genetics*. **109**: 364-373.

Rekaya R., Carabano M. J. and Toro M. A. 1999. Use of test day yields for genetic evaluation of production traits of Holstein-Friesian cattle. *Livestock Production Science*. **57**: 203-217.

Riethmuller, P. 2003. The social impact of livestock. A developing country perspective. *Animal Science Journal*. **74**: 245-253.

Roman, R. M. and Wilcox, C. J. 2000. Bivariate animal model estimates of genetic, phenotypic, and environmental correlations for production, reproduction, and somatic cells in Jerseys. *Journal of Dairy Science*. **83**: 829-835.

Samuelson, D. J., and Pearson, R. E. 1995. Accuracy of predicting genetic merit from pedigree information for bulls entering stud sampling programs. *Journal of Dairy Science*. **78**: 2057-2064

Schaeffer. L. R., Jamrozik, J., Kistemaker, G. J. and Doormaal, B. J. 2000. Experience with a test day model. *Journal of Dairy Science*. **83**: 1135-1144.

Singh, S. K. and Nagarcenkar, R. 1997. Factors affecting milk yield and lactation length in Sahiwal cows. *Indian Journal of Animal Sciences*. **67**: 989-992.

Smith, C., 1988. Genetic improvement of livestock using nucleus breeding units. *World Animal Review*. **65:** 2 – 10.

Swalve, H. H. 2000. Theoretical basis and computation methods for different test day genetic evaluation methods. *Journal of Dairy Science.* **83**: 1115-1124.

Syrstad, O. and Ruane, J. 1998. Prospects and strategies for genetic improvement of the dairy potential of topical cattle by selection. *Tropical Animal Health and Production.* **30:** 257-268.

Trail, J. C. M and Gregory, K. E., 1981. Sahiwal cattle. An evaluation of their potential contribution to milk and beef production in Africa. *International Livestock Centre for Africa (ILCA) Monogram. No. 3.* ILCA, Addis Ababa, Ethiopia.

Togashi, K., Lin, C. Y. and Yokouchi, K. 2004. Overview of genetic evaluation in dairy cattle. *Animal Science Journal.* **75:** 275-284.

Vargas, B., Perez E., Van Arendonk J. A. M. 1998. Analysis of test day yield data of Costa Rican dairy cattle. *Journal of Dairy Science.* **81:** 255-263.

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