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A GENETIC STUDY OF MILK YIELD OF NATIVE BREEDS OF CATTLE AND CROSSES WITH BROWN SWISS IN INDIA

By

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ABSTRACT

A GENETIC STUDY OF MILK YIELD OF NATIVE BREEDS OF CATTLE AND CROSSES WITH BROWN SWISS IN INDIA

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A study was conducted to evaluate environmental and genetic factors affecting milk production of three Zubu breeds of cattle (Tharpakar, Sahiwal, Red Sindhi) and three crosses with Brown Swiss (Three-way cross, Inter Se cross, 3/4-Brown Swiss) under similar tropical environment at Karnal, India. Two objectives were pursued:

1. To determine the influence of breed group, year, season, lactation number, age, calving interval and lactation length on milk production.
2. To obtain heritability and repeatability estimates for milk yield.

The data were collected at Karnal, India. A total of 9,086 lactation records of 2,958 cows that calved in the period 1930-1975 were used in this study. Statistical Analysis System (SAS) by Barr *et al*. (1979) was used in all computations.

All the main effects of year (Y), breed group (B), season (S), lactation (L), and age within lactation (A(L)) were important for milk yield. The two-way interactions of breed group by year, breed group by lactation, breed group by age within lactation, year by season, year by lactation, year by age within lactation, and season by age within lactation also were important for milk yield.

Tharpakar cows were superior to Sahiwal and Red Sindhi cows, outyielding Sahiwal and Red Sindhi by 232 kg and 204 kg, respectively. Difference between Sahiwal and Red Sindhi was only 28 kg, indicating equal potential for milk yield by the two Zebu breeds.

The Three-way cross was superior to the other crosses suggesting that 50% Brown Swiss inheritance was best for milk yield. However, results on the crosses should be interpreted with caution because they were based on relatively small data. The crosses outyielded purebred Zebus by 450 kg. or more suggesting better potential of the crosses for milk yield. However, it is known that the crosses were treated more favorably than contemporary Zebus.

Considering the purebred Zebus only, all cows that calved at the age of 61-90 months outyielded all other age groups within each lactation.

Fixed effects and their interactions accounted for 45% of the total variation in milk yield. A combination of linear, quadratic and product terms of calving interval and lactation length accounted for 29% of the total variation in milk yield. Linear and quadratic terms for lactation length accounted for 28%, and linear and quadratic terms for calving interval alone accounted for 8% of the total variation in milk yield. Because lactation length alone accounted for almost the same variation in milk yield (28%) as a combination of lactation length and calving interval (29%), it was concluded that calving interval was not important when lactation length was considered.

Estimates of heritability and repeatability of milk yield for each breed group were obtained from variance components for sires and cows. The phenotypic variance for the purebred was lower than that reported for temperate breeds. The crosses showed consistently higher phenotypic variance than the purebred Zebus. However, more research is needed because the crosses involved relatively few records.

Both estimates of heritability and repeatability for the purebred Zebus ranged from .10 to .30. Considering only estimates made from 500 or more records and the magnitude of standard errors, there was little change in heritability from one lactation to another.

. . . Dear Mum

and to the memory of my Dad

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INTRODUCTION

The need for genetic improvement of livestock in the tropics has been realized for several decades. After the "green" revolution new hopes have been placed on the "white" revolution to increase the milk yield within the stressful tropical environments.

In lieu of the relatively low-yielding indigenous *Bos indicus* dairy cattle, a number of *Bos taurus* have been introduced into many tropical areas. Because the climate in these areas differ markedly from that in the natural habitat of the European breeds the question has frequently been raised as to whether climatic factors have been responsible for the often disappointing results obtained from *Bos taurus* cattle. As pointed out by McDowell (1959, 1972), Branton *et al*. (1966), and Johnston *et al*. (1960), the reduced energy intakes, associated with management practices combined with summer weather conditions of high temperatures and humidity can reduce production even though the cattle may possess the genetic potential for high production. These environmental factors affect production traits both directly through effects on the physiological functions and indirectly through the nutrition status of the animals. Therefore, the main concern of the animal breeders has been to develop types of animals that would be able to "break through the performance barrier" under the various tropical environmental conditions.

Ansell (1976) concluded that if appropriate steps are taken to mitigate the effects of climate and a high level of management practices is maintained, there appears to be no reason why ambient temperatures and humidity should be inimical to successful dairy development with temperate breeds in the tropics. Similarly, Mayn and Wilkins (1971), pointed out ". . . In principle, high-yielding cattle can be kept anywhere in the world, provided enough capital and know-how are available to create the necessary environment."

Two schools of thought have been advanced as to what systems of mating will produce the types of livestock suited to the harsh tropical climates. Some animal breeders have recommended adoption of the system of mating that will most rapidly bring about replacement of the indigenous stocks. Others see selective breeding within the indigenous groups as the key to improvement. The resulting dilemma is whether to try to modify the local environment and utilize an improved germ plasm via crossbreeding or to gradually improve the local stock through selective breeding within the indigenous stocks.

The merits of crossbreds over the Zebu tropical breeds are supported by numerous studies. For instance, Stonaker et al. (1953), Amble and Jain (1965), and Moulick et al. (1972) among others reported higher yields of crossbreds over purebred Zebu cattle. A review by McDowell (1971) on crossbreeding in 48 herds from seven countries in the tropical region indicated the same kind of result.

On the other hand, Alim (1960), Amble et al. (1958), Mahadevan (1966) and others have demonstrated that it is possible to improve milk yield by selective breeding in groups of cattle indigenous to tropical regions. However, they were not clear as to the limitation of this type of improvement. McDowell (1971) with an opposed idea asserted that on the basis of "total dairy merit" there is serious doubt about the usefulness of local native cattle for commercial dairying. However, this remains to be proved.

In view of the contradicting stands, a logical approach to the problem would seem to evaluate indigenous stocks and their environments before initiating any rigorous breeding program. Because the observable performance of an animal is a combination of its genotype and environment, accurate evaluation of the former is only possible from data collected when the environmental influence common to all animals in a herd is statistically removed. Unfortunately, only limited research has been directed to evaluation of the dairy merit of most breeds evolved in the tropical areas.

The present study seeks to evaluate performance of three Zebu breeds (Sahiwal, Red Sindhi and Tharpakar) and their crosses with Brown Swiss at the National Dairy Research

Institute (NDRI), Karnal, India. The specific objectives are:

1. To examine the effects of year, season, lactation number and age at calving on milk yield of six breed groups namely Tharpakar (T), Sahiwal (S), Red Sindhi (RS), Three-way cross (S x RS x BS), Inter Se cross (S x RS x BS) x (S x RS x BS) and 3/4 - Brown Swiss (3/4 - BS).
2. To assess the relationships of milk yield with calving interval and lactation length.
3. To estimate repeatability and heritability of milk yield.

LITERATURE REVIEW

Essential to the success of any livestock program is a knowledge of the genetic and environmental influences associated with the economically important traits in the population. For instance, a lactation record is the result of a cow's genetic potential and environmental conditions. Therefore, it is imperative to be able to make accurate allowance for the latter, so as to arrive at a good estimate of the former.

A number of investigations have been made in temperate regions to determine the importance of various non-genetic factors on milk yield of dairy cattle. However, similar studies in the tropics are relatively few. The following literature review summarizes some of the previous studies concerning the effects of breed group, year, season, lactation number, age at calving, calving interval and lactation length on milk yield. Also, heritability and repeatability estimates for milk yield, lactation length and calving interval are summarized. Wherever possible, comparisons will be made between temperate and tropical regions.

Breed Differences

Information on breed differences is of paramount importance in sorting out the most appropriate management and selection strategies in a dairy enterprise. An interesting feature common to all breeds indigenous to the tropics is the large coefficient of variation ranging from 40 to 50% for lactation yield as compared to that for temperate breeds, ranging from 10 to 20% (Robertson, 1950). Similar range of coefficient of variation was reported by Sikka (1931). The lax management systems prevalent in most tropical areas indicate that the large coefficient of variation is largely associated with increased environmental variability. This contention is supported by the findings (Mahadevan, 1956) which indicated that temperate cattle raised in the tropics under the same conditions as the native breeds had similar coefficients of variation for milk production.

Mahadevan (1966) gave expected ranges of milk yield of different tropical breeds according to their location. The production in kgs ranked from highest to lowest was Criollo in Latin America ranging from 1835 kg to 2752 kg, cattle from India ranging from 1043 kg to 1668 kg, and African indigenous types ranging from 626 kg to 1043 kg.

Because of the problem of low producing animals, a lot of research in the tropics in the last several years was geared toward crossbreeding with temperate breeds. The main strategy has been either to upgrade the Zebu breeds or to develop a new breed that is better adapted to the tropical environments with some potential for higher milk yield.

Various reports on the performance of different breeds in the tropics are available, in particular India, where crossbreeding of the native Zebu breeds to the temperate breeds has been going on since the turn of the century. The evidence seems to support the arguments that crossbreds in general are more adaptable than temperate breeds.

Kartha (1934) compared crosses of Ayrshire and Holstein sires with Sahiwals. The results indicated superiority of 60-70% for the production of crosses over that of the purebred Sahiwals. As cited by Mahadevan (1966), Lecky (1951) examined the data compiled by Kartha and, after adjusting for the location effect, indicated that 5/8-Holstein excelled other crosses. Of the three Zebu breeds considered (Hariana, Sahiwal, and Red Sindhi), the Hariana breed was relatively inferior to the Sahiwal and Red Sindhi breeds for milk yield.

Stonaker _et_ _al_. (1953) reported on the crossbreeding in India of Red Sindhi cows to either Jersey or Brown Swiss bulls, and concluded half-breds were the most effective producers. Backcrossing to either breed reduced production. Cows with varying proportion of Jersey inheritance exceeded the production of Red Sindhi, but production decreased as relationship to either Jersey or Red Sindhi deviated from

50%. Also, results by Amble and Jain (1967), and Bhatnager et al. (1970, 1971) indicated that 1/2-Zebu (Sahiwal/Red Sindhi) crosses with temperate breeds (F1) exceeded all other breed groups in production. However, contrary results were reported by Verma (1973). Using crossbred grades of Holstein and Sahiwal, he found both first and second lactation milk yields were significantly greater in 5/8- and 3/4-Holstein than in 1/2-, 1/4-, and 1/8-Holstein, suggesting the 5/8- and 3/4- Holstein were the best producers.

An interesting study involving some economic evaluation of different breed groups were reported by Pandey and Desai (1973). They evaluated the suitability of crossbred cows for economic level of milk production in India. Milk yield of 2,000 kg per lactation were taken as the minimum economic yield for urban areas in India. Of 67 Holstein x Sahiwal/and Red Sindhi cows (with at least 50% Holstein blood) 55 of 67 reached that level, compared with 9 of 38 half-bred Jersey x Red Sindhi and 2 of the 54 Red Sindhi cows. The 5/8-Holstein-3/8 Sahiwal/Red Sindhi were the best yielders, with 41 of 44 cows reaching the economic level.

For rural areas, 1,100 kg milk per lactation was taken as the minimum economic yield under a Jersey crossbreeding scheme. This yield was reached by 79 of 97 halfbred Jersey x Desi, 10 of 18 3/4-Jersey-1/4-Desi, but less than 1% of the Desi cows.

A very promising "break through" in the development of a new breed in Australia for the tropics has been reported by Hayman (1974). The main goal of the project was to improve performance in *Bos indicus* through crossbreeding combined with selection among the filial generations to establish a new breed which would combine the hardness and resistance to parasites of *Bos indicus* with the higher milk potential of *Bos taurus*. Two breeds, Red Sindhi and Sahiwal were used as *Bos indicus* parental material. Jerseys were chosen as the *Bos taurus* parent. Selection among the filial generations was strictly on the basis of milk production, tolerance to hot climate stress and resistance to ticks. The eventual breed obtained through the crossing and selection is known as the Australian Milking Zebu (AMZ). Table 1 shows the production of AMZ compared to Jersey, the *Bos taurus* (Jersey) production being equalled by that of the new breed (AMZ). Thus, there are high hopes in this new breed as an eventual tropical breed capable of withstanding the harsh environment and with a good potential for relatively high milk production.

Contrary to the results from the tropics, crossbreeding results in United States generally seem to favor the straightbred *Bos taurus* over the crossbreds for milk production. A series of projects were set up in several southern states to identify the breeds adapting best to the stress environments typical of southern summers. The projects (McDowell, 1959; Johnston *et al*., 1960; Branton *et al*.,

Table 1.--Means and standard errors for first lactation records of Jersey and Australian Milking Zebu (AMZ) heifers.

Description	Number of Animals	Milk Yield (kg)	Age at Calving (Months)
All Jerseys used in Badgery's Creek Herd	212	1944 ± 82	27
Jerseys, born in Lismore, reared and milked at Badgery's Creek	31	1805 ± 189	28 ± .66
AMZ born, reared and milked at Badgery's Creek	35	1917 ± 209	28 ± .39
AMZ born at Lismore, reared and milked at Badgery's Creek	19	2056 ± 103	34 ± .95

Adapted from Hayman (1974).

1966) dealt with crossing Red Sindhi (imported from India), with Jerseys, Brown Swiss, and Holsteins. The ultimate goal was to develop a breed or strain that exhibited an optimum combination of productivity and adaptability. In all cases the average milk and butterfat yields for the crossbreds were less than those of their European ancestry, so this approach was abandoned for the United States.

Hollon et al. (1969) compared Holsteins, Brown Swiss, Jerseys, Red Sindhi and their crosses for first lactation milk production traits. The means of the purebred Holsteins were equal or superior to all crossbred groups for milk, fat and fat-corrected milk (FCM).

McDowell and McDaniel (1968) obtained all possible combinations of two- or three-breed crosses of the Ayrshire (A), Brown Swiss (S) and Holstein (H) breeds. Data obtained from the crossbreds were compared to parental means. Crossbreds with 50% or higher Holstein inheritance produced more milk and milk fat than other crossbreds. Ayrshire, Brown Swiss and A x S crosses were significantly lower than purebred Holstein in production traits. However, A x H, S x H and 3-breed crosses were slightly lower than the Holsteins in milk and FCM yield but generally showed superiority in fat yield.

Results from 20 years of an experiment at Illinois involving Holsteins, Guernseys and their crosses, have indicated higher milk and milk fat yields for crossbreds than for Guernseys (Bereskin & Touchberry, 1966; Touchberry, 1970).

The most recent report on crossbreeding in United States is by Rincon (1975) involving Ayrshires (A), Jerseys (J), Brown Swiss (S), Holstein (H) and their crosses. His results indicated the following:

a. Milk yield of crosses increased but fat content declined as the fraction of Holstein inheritance increased.

b. None of the breed groups exceeded the Holsteins for milk or FCM yields.

c. There were breed differences in general combining ability for milk yield, with additive effects of Holsteins greater than those of Ayrshires or Brown Swiss.

d. Differences in maternal ability among Holsteins, Ayrshires, and Brown Swiss were important for milk yield.

Season Differences

Season exerts its influence on production in two main ways. Changes in temperature and humidity act directly on the homeostatic mechanism of the animal and bring about adjustments in behavior which as a consequence affect production. The second important influence of season is directly on forage quality and quantity (McDowell, 1972).

Several reports are available on seasonal effects on milk production traits for various breeds commonly used in the United States for milk production.

Frick *et al*. (1947) looked at relationship of season of freshening to milk production for Guernseys, Holsteins, Ayrshires and Jerseys. Milk yields were 14.9% greater for cows freshening in the most favorable months. Average yields were highest for cows calving in July. Yields increased from one month to the next, from February to July.

Woodward (1945) studied lactation records according to month of calving. Cows that calved in April reached a higher peak of production than any other group. Cows that calved in August had a lower peak of production than any other group. For all of the states from which records were obtained, May was the most favorable month for total production. Cows calving in hot seasons produced less milk than those calving in cool seasons.

Fosgate and Welch (1960) studied effects of season of calving and breed upon production of fat-corrected milk (FCM) and butterfat (BF). Regressions due to season of calving for FCM and BF were as follows:

	FCM	BF
a. Fall	-297.01	-10.98
b. Winter	249.53	7.74
c. Spring	522.55	19.32
d. Summer	-468.07	-16.07

Differences in production between Holsteins, and Jerseys and Guernseys were highly significant.

Lee *et al*. (1961) studied breed and seasonal effects upon milk and fat production. Cows calving in winter and spring months produced significantly more FCM and fat than did cows calving in summer months. Lactation yields decreased in the following order: winter, spring, fall and summer.

Miller *et al*. (1970) studied the influence of month and age of calving on milk yield of Holstein cows in the Northern United States. The results revealed that month, age and month by age interaction were significant for milk yield. They concluded that all records should be adjusted for both season and age of calving by multiplicative factors which simultaneously adjusted records to the expected yield. A similar study was reported by Mao *et al*. (1974) working with Canadian dairy production records. The results indicated summer calvers produced less than winter calvers for all the age sets. Older cows were more affected by summer calving and the magnitude of differences between November and July, the respective months of highest and lowest yield, were positively correlated with ages. Age, month, and age by month interaction effects were highly significant; thus, it was concluded that a joint adjustment for age and seasonal variation was necessary.

Overall, the results in the temperate region on seasonal and breed effects seem to indicate cows calving in summer are greatly affected by the stress of hot summer conditions. Holsteins are more stressed by hot summer conditions than are Jerseys, Brown Swiss, Guernseys and Ayrshires. Winter seems to be the ideal season for highest production, followed by spring, fall and summer, respectively. The differential responses to different seasonal conditions are suggestive of interaction of breeds and seasons.

Most of the evidence in the tropics also seems to suggest significant seasonal effect on the lactation yield. Kohli and Suri (1960) observed some seasonal trend for the Hariana cattle, with the lowest average production for cows calving from August to November. Pearson et al. (1968) observed seasonal differences in lactation yields for Bon cattle in Columbia. Cows that started lactation during period of heaviest rains, in October and November, gave lower total yields for the lactation. Ngere et al. (1973), and Moulick et al. (1972) also reported significant seasonal effects on milk yield, respectively, for Hariana cattle and Deshi cattle of India.

A comprehensive preliminary report by Sundaresan et al. (1965) on the dairy herds at the NDRI, Karnal, India indicated the same trend of significant seasonal effects for the Tharpakar, Sahiwal and Red Sindhi breed groups. Milk production dropped in the months of July to September each year. There was a trend of high production in cows which calved during the months of January to June. Also, the results indicated strong evidence that differences between five-year periods were important, suggesting that over long periods sizable environmental and/or genetic changes had taken place.

Studies in the tropics using temperate breeds have also shown significant season effects on milk yield (Camoens et al., 1976; Lindström & Solbu, 1977; McDowell et al., 1976).

Contrary (nonsignificant) results of effects of season have been reported. Sharma and Singh (1974) indicated nonsignificant effect of month of lactation on lactation yield. Similarly, Alim (1962), working with Butana cattle in Sudan, found no real differences in milk yield due to month of calving.

Year or Time Differences

Year effect on milk production is well established. Generally, as a nuisance factor, it has been taken into account in nearly all recent analyses with dairy records. It tends to affect production in several ways:

a. Changes in yearly temperatures, and precipitation. The effect of this variation is felt chiefly in areas largely dependent on forage and crop production. Animal production would tend to vary with variation in availability and quality of forage and crop production.

b. Changes in management practiced and/or feeding regimes.

c. Selection. The use of superior stock resulting from either selection from the female side or from the male side could result in increased production.

The above changes, if they occur, are usually reflected in differences between years.

Hardie *et al*. (1972) found significant differences between years for milk, fat and fat percent. Lee (1974) fitted linear, quadratic, and cubic curves for years with respect to milk production, and found different curves for different years. Other workers have reported similar trends (Sundaresan *et al*., 1965; Camoens *et al*., 1976). However, Hooven *et al*. (1968) found no significant variation between years for milk yield, fat yield, or fat percent, and Gacula *et al*. (1968) could show no annual differences for fat test.

Calving Interval, Days Open, Days Dry and Lactation Length

Studies of the influence of calving interval on milk production have involved the relation of the entire period to lactation yield in current or subsequent lactations. Through the efforts of trying to obtain optimum calving interval, Sanders (1927) concluded that it should not be less than 12 months. He recommended as a general principle that cows should calve at intervals of not less than a year, and not more than 13 months.

Norman (1967) found calving interval was an important source of variation in milk yield. In the same study the author indicated that previous calving accounted for 1.9-3.7% of the variation in the succeeding lactation yield.

Miller et al. (1967) showed a phenotypic correlation of approximately .2 between calving interval and milk production, but stated that it would not be advantageous to select for calving interval.

Camoens et al. (1976), reporting on performance of Holsteins in Puerto Rico, indicated substantial effect of calving interval on milk yield. Calving interval accounted for 6.0% of the milk yield out of the 13.4% variation that was accounted for by a combined effects of days open, days dry and calving interval.

On the contrary, Asker et al. (1966) found calving interval not correlated with milk yield, Kohli (1962), working with Hariana data, also did not find any significant relationship between calving interval and milk yield.

Most of the studies using components of calving interval have looked at days dry or days open in relation to milk yield.

Sanders (1928) studied effect of dry period on high and low milk producers. He concluded that the high yielders maintained their milk flow longer, and, as a natural corollary that they were dry a shorter time as reflected in the differences in the mean days dry for both the high and low yielders. Dickerson and Chapman (1939) compared production records of lactations following dry periods of different lengths with those of the first lactation and found that low producing cows showed a higher percentage increase through lengthening the dry period than did high producing cows.

Klein (1943) compared cows having lactation records following dry periods of different lengths. Cows dry 1-2 months gave 9.2% more milk than those dry less than a month. Cows dry 2-3 months gave 4.3% more milk than those dry 1-2 months. A dry period of 55 days was found to be of optimal length for cows yielding 10,000 pounds and calving at 12-months interval. He suggested ". . . either a longer or a shorter dry period reduces the milk yield, the longer because more milk would be gained in the following lactation, the shorter because more milk would be lost in the following lactation than would be gained in the current lactation."

Johansson and Rendel (1968), working with Swedish dairy breeds, found optimum dry period was 6-7 weeks, which suggested a curvilinear relationship between length of dry period and production in the following lactation.

Smith (1962) indicated that the length of the dry period depends on the length of the calving interval and the length of the preceeding lactation. The length of the previous dry period accounted for less than 0.1% of the variation in milk production. Smith and Legates (1962) reported that .3% of the variation in lactation milk yield could be attributed to the length of the previous dry period.

Schaeffer and Henderson (1972) concluded that high producing cows received shorter dry periods than low producing cows and that cows which survive for another lactation are those with longer dry periods. Dry periods of 50 to 59 days resulted in the highest average production in the subsequent lactation. However, the production of cows with 40 to 49 and 60 to 69 days dry were not greatly different on a practical basis. Schaeffer et al. (1973) found that a dry period of 30 to 60 days seems attainable by proper management and is the optimum from an economical point of view.

Reports from the tropics suggest findings similar to the temperate results (Mahadevan, 1966). The difference is in length of dry period which is longer in the tropics than in the temperate region. Sikka (1931) reported dry period of 120 days and a mean calving interval of 404 days. The dry period represents about 30% of the period between two consecutive calvings. That is very high compared with temperate countries where the dry period is generally one half as long.

A recent study on effect of dry period on milk yield of crossbreds in India was reported by Gurnani and Bhatnagar (1974). Optimum dry period for maximum yield was estimated to be in the range of 40-80 days using F1 Brown Swiss x Zebu (Sahiwal and Red Sindhi). Only correlation between first dry period and second lactation was positive and significant. Cows having dry periods shorter than optimum tended to have positive relationship of dry period with production in the subsequent lactation. Cows having dry period longer than optimum tended to have negative association of length with subsequent production.

More results indicating positive correlations between length of dry period and subsequent yield have been reported by Ragab et al. (1954), Jha and Biswas (1964), and Nagpaul and Bhatnagar (1972). On the other hand, nonsignificant correlations were obtained by Plum (1935), Amble et al. (1958), Asker et al. (1958).

Days open is a term for the interval between parturition and conception. Its importance on milk yield has been reported by Wilton et al. (1967), Smith and Legates (1962), Ripley et al. (1970). They found milk yield is influenced by days open during the current lactation.

Schaeffer and Henderson (1972) stated that as days open increased, cumulative milk production also increased at each successive stage of lactation. Miller and Hoven (1969) reported that 2% of the variation in milk yield could be attributed to days open. Ripley et al. (1970) found that days open accounted for 4.8% to 5.8% of the variation in milk yield in the first or second lactations.

Lactation length has important influence on total milk yield. Temperate breeds of cattle show comparatively little variation in lactation length (Mahadevan, 1966). About 5% of all lactations end before 200 days. The number of lactations ending before 300 days is also relatively small, with the result that lactation length shows little relation to actual yield. The main factor governing the lactation yield of dairy cattle in these areas is the maximum daily yields. By contrast, among unimproved Zebu breeds as many as 25% of the lactations may end before 200 days, and even among improved Zebu 60% of the lactations have sometimes been recorded as ending before 300 days. Consequently, it is not surprising to note that lactation yield of cows in the tropics is highly correlated with the length of lactation. Sikka (1931), Robertson (1950), Mahadeva (1953, 1955), Asker et al. (1958), Alim (1960), Mahadevan and Marples (1961), Galukande et al. (1962), and Singh and Deasi (1962) obtained correlations ranging from .04 to .9 in different populations of indigenous cattle in various tropical areas.

Because of the large variation and short lengths of lactations associated with Bos indicus breeds, caution should be exercised in choosing truncation point for discarding records as "abnormal" records on the basis of length of lactations. Selected truncation points have ranged from less than 100 days (Mahadevan, 1966) to 280 days (Lecky, 1962), depending upon the investigator. Deletion of the short records on an arbitrary basis has meant loss up to 50% of all records in some studies (Ngere et al., 1973). If the cause of short records is genetic, arbitrary deletion may have led to biases in the interpretation of data.

Age of Calving and Lactation Number

Of all the measureable non-genetic factors affecting the dairy cattle production, one that has been studied extensively is age at calving. Miller and Hooven (1969), stressing the importance of age, pointed out that age and year were more closely related to variation in milk yield than any other environmental factors.

Lush and Shrode (1950) reported that milk yield per lactation increased from first lactation until the cow was about ten years of age and then declined. White and Drakely (1927), using different breeds, studied the influence of age of the cow on yield and quality of the milk. Yield of milk of all the breeds increased rapidly with age, reached a maximum and then gradually declined. The age at which maximum production was reached differed slightly among breeds. Shorthorns attained maximum yield rather later than Jersey and Guernsey cows and their yields showed a greater variation with age. Wunder and McGilliard (1971) showed that three-year-olds produced more than two-year-olds, age being a more important source of variation than season. Most other studies have shown the same trend of results (Blanchard et al., 1966; Branton et al., 1974; Fimland et al., 1972; Johansson & Hansson, 1940).

Realizing that age at calving was an important factor affecting milk yield, many investigators directed research toward obtaining factors to adjust yields for age. The chief problem in this area was to obtain factors free from biases caused by year, season, selection, etc.

Gowen (1920) used curvilinear equations relating milk yield to age and arrived at factors designed to correct for differences in ages of cows. These figures were deemed suitable at the time in a population subjected to comparatively little selection. To avoid selection bias, Sanders (1928) devised the "paired comparison" method. However, confounding of herd, season of calving, and times milked with the producing ability of cows remained a problem with the factors he developed.

Sanders (1928), Norton (1932), and Johansson and Hansson (1940) indicated that estimates of production using the simple averages for all cows of each age, and the regression techniques for age adjustments contained bias because of effects of selection, or culling in different age groups of cows. In addition, Johansson and Hansson (1940) mentioned calving interval as a further confounding factor.

Henderson (1949), in considering differences in herd environment, pointed out the possible biases in least squares estimates resulting from incomplete repeatability. He applied maximum likelihood methods for estimating age correction factors. Lush and Shrode (1950) followed by showing that biases could result from selection when all animals did not have records at maturity, or from differences of estimates over periods or incomplete repeatability. They studied gross comparison and paired comparison for estimating the effects of age on milk production. The gross comparison method uses the simple average for all cows of each age and the paired comparison method compares production of the same cow at different ages. They found age-adjustment factors from paired comparison method were greater than those obtained from the gross comparison method. Kendrick (1953) developed gross comparison age-adjustment factors from DHIA data which were used extensively in the United States for a few years.

Subsequent research in this area was directed to finding unbiased methodology for adjusting the lactation records for age at calving. In 1967 USDA published age-adjustment factors computed by the gross comparison method, which combined the months November through June into season I and July through October into Season II (McDaniel et al., 1967). Miller and Henderson (1968) computed age-adjustment factors by maximum likelihood, gross, and paired comparison using the two USDA seasons. They found seasonal difference was large for gross factors but was small for paired comparison and maximum likelihood factors. They suggested that season effects were obscured by inappropriate grouping of months into seasons. Several other studies on the importance of herd-level production and herd by age interaction in developing age factors have been reported (Searle & Henderson, 1959, 1969; Searle, 1962; Hickman, 1962; Lee & Hickman, 1967). Also, the importance of seasonal differences of calving were reported by Syrstad (1965), Gravir and Hickman (1966), McDaniel and Corley (1966), Wunder and McGilliard (1967), Miller et al. (1970), and Mao et al. (1974).

Miller et al. (1970) reported the importance of month-age-adjustment factors obtained by the maximum likelihood method with elimination of biases due to environmental trend, herd differences and selection. They recommended replacing the seasonal mature equivalent factors with factors which adjust simultaneously for age and month of calving. In the same study the authors developed multiplicative factors for the Holstein breed which simultaneously adjusted for month and age of calving. Similarly, Mao et al. (1974), using the same maximum likelihood technique, recommended age-month factors within breeds for Canada.

An excellent review on the development of ideas about age-season adjustment of records is presented by Freeman (1973). To mention a few, Miller et al. (1966), McDaniel et al. (1967), Miller et al. (1968), Miller and Henderson (1968), Miller et al. (1970), and Mao et al. (1974) among others have contributed to the development of the age-adjustment factors now in use nationally in the United States and in Canada.

The trend of milk yield with age for Zebu cattle in the tropics is illustrated by the statements by Mahadevan (1966) that

> The yield of milk with age shows some striking peculiarities in the tropical cattle. Whereas European cattle in temperate regions usually attain peak production by about the fifth lactation, the time of maximum productivity of Zebu cattle in the tropics is usually reached by the third lactation. The rate of increase in yield from first lactation to maturity is also usually lower in tropical cattle than in temperate ones.

However, such statements are only true if the number of calvings before maximum lactation yield is used as a measure of maturity. If age at peak production is used as a measure of maturity, then the average age for peak production would be between 6-8 years for temperate zone cattle (Gowen, 1920). This is usually the fifth lactation for the temperate breeds. Because of the late age at first calving and the long calving intervals (Table 2), the average age for the third lactation, the peak lactation for tropical Zebu is between 6-9 years. Therefore, if maturity is defined as age at maximum production both temperate and tropical breeds mature at about the same age.

Sikka (1931) reported that purebred Sahiwals in India increased to the extent of only about 10% of their first lactation yield until the age of maximum productivity. Mahadevan (1953, 1955) gave values of 15% and 6%, respectively, for the increase in yield from first lactation to maturity. Galukande _et al_. (1962), working with East African cattle, obtained a corresponding figure of 8%. Chhabra _et al_. (1970), working with Hariana cattle, reported maximum production was attained by third lactation with an increase of 25% from first lactation. Age expressed as lactation number was twice as important in accounting for the variation in milk yield as age expressed in years.

Kushwaha and Misra (1962) studied records of 245 Sahiwal cows. Cows calving at 42-48 months of age produced highest quantity of milk during first lactation. Highest milk yield of that age group was significantly different from the yield of cows calving below 36 months of age. The

Table 2.--Mean lactation yield, average lengths of lactation, calving interval, days dry and age at first calving of various breeds and their crosses in various countries.

Breed Group	Location	Milk Yield (kg)	Lactation Length (Days)	Days dry (Days)	Calving Interval (Days)	Age 1st Calving (Months)	Source
Ayrshire (A)	USA	5355					Freeman (1979)
Guernsey (G)	USA	4883					Freeman (1979)
Holstein (H)	USA	6736					Freeman (1979)
Holstein (H)	USA	4471	304			28	Branton _et al_. (1966)
Holstein (H)	Puerto Rico	4229	265	102			Camoens _et al_. (1967)
Jersey (J)	USA	4537					Freeman (1979)
Jersey (J)	USA	2989				26	Branton _et al_. (1966)
Brown Swiss (BS)	USA	5637					Freeman (1979)
(BS)	USA	2565				31	Branton _et al_. (1966)
Red Sindhi (RS)	India		624		447	42	Mahadevan (1966)
(RS)	India	1449	255		430		Johar and Taylor (1970)
(RS)	Phillipines			245	510		Rigor and Melmida (1958)
(RS)	India	1664	305			43	Venkayya and Anantakrishnan (1956)
(RS)	India	1753	305		452		Sundaresan _et al_. (1965)
(RS)	India	1558					Mason (1974)
½A x ½RS	India	2280				31.5	Mason (1974)

Table 2.--Continued.

Breed Group	Location	Milk Yield (kg)	Lactation Length (Days)	Days dry (Days)	Calving Interval (Days)	Age 1st Calving (Months)	Source
F1J x RS	USA	2360	270			27	Branton et al. (1966)
F1BS x RS	USA	1493				30	Branton et al. (1966)
Sahiwal (S)	India	2236				38	Gopal and Bhatnagar (1969)
Sahiwal (S)	India	1800	270	184	439		Gehlon and Malik (1967)
Sahiwal (S)	India	2009	302		479		Bhasin and Desai (1967)
(S)	India	2417			472		Sundaresan (1965)
(S)	India	1780					Mason (1974)
Tharpakar (T)	India	1287	254	188			Nagarcenkar (1969)
(T)	India	1207	279		408	50	Prasad and Prasad (1972)
(T)	India	1743	277	146	540		Wahid (1971)
(T)	India	1074	268	147	430	38	Nagpal (1971)
(T)	India	2211			461		Sundaresan et al. (1965)
J x T	India	2079	302	94			Nagarcenkar (1969)
Hariana (HA)	India	1907	275		419		Bhasin and Desai (1967)
½S x ½HA	India	2109	284		431		Bhasin and Desai (1967)
½RS x ½HA	India	1507	231		440		Bhasin and Desai (1967)
(HA)	India	664	265			41	Mason (1974)
½J x ½HA	India	1898	305			28	Mason (1974)

Table 2.--Continued.

Breed Group	Location	Milk Yield (kg)	Lactation Length (Days)	Days dry (Days)	Calving Interval (Days)	Age 1st Calving (Months)	Source
½H x ½HA	India	2162	345			19	Mason (1974)
Deshi (D)	India	374	276		452		Moulick et al. (1972)
J x D	India	1296	317		368		Moulick et al. (1972)
Fulani (F)	Nigeria	810	241				Armour et al. (1961)
H x F	Nigeria	1925	299				Armour et al. (1961)
Egyptian Native (EN)	Egypt	1385	237				Eltriby et al. (1958)
H x EN	Egypt	2327	339				Eltriby et al. (1958)
East African Zebu (EA)	Tanzania	1385			382	40	Mahadevan and Hutchison (1964)
H x EA	Tanzania	2120					Mahadevan and Hutchison (1964)
Jersey (J)	Costa Rica	2151	305			31	Mason (1974)
Criollo	Costa Rica	1945	305			36	Mason (1974)

results are in accord with reports by Singh and Chondhury (1961), as well as Batra and Deasi (1964), who reported that Sahiwal cows calving late produced more milk than those calving at an early age.

Nagpaul and Bhatnagar (1971) analyzed 1860 lactation records of 596 Tharpakar cows. Heifers calving first at 25-30 months produced more milk on average than those calving at other ages.

Even though researchers realized age is important in tropical breeds, there has been no intensive research directed toward the development of age factors for those breeds. Controversy on the usefulness of age factors, coupled with the meager data found in the tropics may have hindered any intensive study of the problem. Some researchers believed that due to the small variation in milk attributable to age as opposed to other environmental sources, there is no need for age adjustments in the tropics (Robertson, 1950). However, if the age effect is statistically significant and assumed non-genetic then it should be adjusted for to avoid bias in comparing records. On the other hand, the researchers opposed to the above argument have tried to develop some age correction factors (Ngere et al., 1973), but use is limited because the factors are based on meager data and their reliability is questionable.

Another controversial issue pertaining to tropical results is in certain analyses age has been replaced by lactation number (Chhabra, 1970) as if both of them imply the same "factor." However, age and lactation number would only be completely confounded in those breeds where calving interval is maintained at 12 months with lactation length of 305 days. With the high variation in age at calving in Zebu breeds and the large calving interval (Table 2), lactation number and age cannot be completely confounded. Thus, in tropical breeds to use age and lactation number interchangeably is not proper.

To give a general perspective of performance of different breeds under different environments, a summary of the performances of various breed groups and their crosses in various countries is given in Table 2.

Heritability and Repeatability

Heritability is defined as the proportion of the total variance in a character that is attributable to the average or additive effects of genes. This is referred to as "heritability in the narrow sense" by Lush (1940). Whereas he defined "heritability in the broad sense" as the variation due to genetic causes as a fraction of the total variance. Thus "heritability in the broad sense," in addition to containing variance due to additive effects, contains variance due to dominance and epistatic effects. In literature, "heritability"in almost all cases refers to "heritability in the narrow sense."

Heritability estimates for various traits are plenty in the literature. Although there are several methods of estimating heritability essentially all of them are based on computing the degree of resemblance between related individuals in a random-bred population. In Table 3 are listed estimates from literature for milk yield, calving interval and lactation length. Obviously, estimates for any given trait vary greatly, depending on the population sampled and estimation procedure as well as sampling variation. McDowell (1972), and Pirchner (1964), respectively, quote ranges of .20 to .30, and .20 to .40 for milk yield.

Hillers and Everson (1972) showed that even with the same data the number of subclasses and the skewness of distribution of frequencies affect heritability estimates. Markos and Touchberry (1970) showed heritability estimates may vary with respect to sample sizes. Norman et al. (1972) discussed the biases in estimates and stated that for milk yield these arise because of confounding between sires and herds and because of the correlation between herd effects. They stated that the biases could be avoided by stratifying production into levels. They showed that estimates obtained from deviations increased with increasing herdmate yields from .27 to .48. Butcher and Freeman (1969) commented that environmental variance could increase in later lactations, leading to lower estimates, but found that these differences were not significant.

Robertson (1977) warned about using a selected population in estimating heritability from the sire component with a strong statement ". . . I presume that no one would be stupid enough to do it between proven sires." He showed formulae for adjusting heritability estimates of direct and correlated traits for selection among sires.

The method of analysis could also affect the heritability estimates. For instance, Butcher and Freeman (1969) found estimates from daughter-dam regression were higher than those from half-sib analysis. Similarly, Bradford and Van Vleck (1964) reported higher heritability estimates from daughter-dam regression than from paternal half-sib correlation. An attempt to explain the differences between heritability estimates from these two methods led to a series of papers by Van Vleck and his co-workers. A summary of the findings and the reasons given for the differences are:

1. Environmental correlations between daughter and dam records account for .01 to .02 of the total variance (Van Vleck, 1966).
2. The increase in variance with change in time and production also could bias daughter-dam regression upward by about 10% (Van Vleck, 1966).
3. Genetic maternal effects may bias estimates of genetic variation among dams (Van Vleck & Bradford, 1966).
4. Unequal numbers of observations per subclass could give different heritability estimates for the two methods (Van Vleck, 1966).

Analysis with one observation per subclass gave highest heritability estimates from daughter-dam regression and the lowest from paternal half-sib correlation, while use of more than one observation per subclass yielded approximately the same heritability estimates from both methods.

Farthing and Steele (1967) gave an account of the effects of using incorrect analysis (improper model) in the estimation of heritability using the method of analysis of variance components. Gill and Jensen (1968) calculated the probability of getting negative estimates of heritability. Their conclusions were:

a. For a given heritability and equal numbers of total observations, the probability of obtaining a negative estimate from the dam component (within sire) of an analysis with two full-sibs per mating is much greater than from the sire component of either full-sib or half-sib analysis.

b. When one estimates heritability from a sire component, the difference in probability of obtaining a negative estimate from half-sib or full-sib analysis is small if total numbers are equal, but there appears to be some advantage in using more information per sire instead of using more sires, especially if the true heritability is moderately low.

c. If true heritability is relatively low (0.1), to have 95% chance of getting a non-negative estimates from a sire component at least 800 observations are needed (more if the information per sire is limited to less than 30-40 progeny).

d. If heritability is moderate (.25), to have 99% chance of getting a non-negative estimate from a sire component at least 500 observations are needed-more if the information per sire is limited to less than 30-40 progeny.

e. Approximately four times as many observations are needed for estimation by dam component (within sires and with two full-sibs per mating) than by sire component to achieve the same probability of obtaining a non-negative estimate of heritability.

A lucid exposition of alternative methods of estimating heritability is given by Turner and Young (1969).

As for heritability, estimates of repeatability have been well-documented in literature. Again the nature of the data and the methodology of arriving at the estimates could introduce biases. A selected summary of reported estimates of heritability and repeatability for milk yield, calving interval and lactation length for various breeds is shown in Table 3.

Table 3.--Estimates of heritability (h^2) and repeatability (r) of milk yield, calving interval and lactation length.

Trait	Breed	Climate	h^2	r	Source
Milk	Holstein	Temperate	.29		Bereskin and Freeman (1965)
	Holstein	Temperate	.28		Butcher and Freeman (1968)
	Holstein	Temperate	.31		Freeman (1969)
	Holstein	Temperate	.41		Norman *et al.* (1972)
	Holstein	Temperate	.31	.46	Specht and McGilliard (1960)
	Holstein	Temperate	.34	.62	Thomson and Freeman (1970)
	Holstein	Tropical	.12	.45	McDowell *et al.* (1976)
	Holstein	Tropical	.21	.32	Verde *et al.* (1970)
	Several Breeds	Temperate	.2-.4		Pirchner (1964)
	Native Cattle	Tropical	.16-.20	.41-.65	McDowell (1972)
	Red Sindhi	Tropical	.37		Amble *et al.* (1958)
	Sahiwal	Tropical	.31		Tomers *et al.* (1974)
	Sahiwal	Tropical	.41		Taneja *et al.* (1978)
	Sahiwal	Tropical	.14		Gurnani *et al.* (1976)
	Sahiwal	Tropical	.33		Archarya and Nagpal (1971)
	Grade Sahiwal	Tropical	.14	.65	Mahadevan (1966)
	Tharpakar	Tropical	.05		Prasad and Prasad (1972)
	Tharpakar	Tropical	.15		Gurnani *et al.* (1976)
	Tharpakar	Tropical	.25		Reddy and Bhatnagar (1971)

Table 3.--Continued.

Trait	Breed	Climate	h^2	r	Source
Milk	Dairy Zebu	Tropical	.36	.39	Osman (1970)
	Kenana	Tropical	.24		Alim (1960)
	Deshi	Tropical	.64	.42	Moulick et al. (1972)
	Hariana	Tropical	.15		Singh and Desai (1962)
	Butana	Tropical	.28		Alim (1962)
	Nganda	Tropical	.20	.70	Mahadevan (1966)
	East African Zebu	Tropical	.50	.55	Mahadevan (1966)
Calving Interval	Red Sindhi	Tropical	-.80		Amble et al. (1958)
	Sahiwal	Tropical	.20	.34	Kushwaha (1964)
	Sahiwal	Tropical	.18		Taneja et al. (1978)
	Sahiwal	Tropical	-.45		Gurnani et al. (1976)
	Sahiwal	Tropical	.28	.42	Johar and Taylor (1968)
	Sahiwal Grade	Tropical	.06	.23	Mahadevan (1966)
	Red Sindhi	Tropical	.13	.08	Mahadevan (1966)
	Tharpakar	Tropical	.28		Mahadevan (1966)
	Tharpakar	Tropical	.23		Gurnani et al. (1976)
	Nganda	Tropical	-.10	.21	Mahadevan (1966)
	Small Kenya Zebu	Tropical	.00	.17	Mahadevan (1966)
	Deshi	Tropical	.09	.21	Moulick et al. (1972)

Table 3.--Continued.

Trait	Breed	Clinate	h^2	r	Source
Lactation Length	Native Breeds	Tropical	.05-.42	.05-.51	McDowell (1972)
	Tharpakar	Tropical	.09		Prasad and Prasad (1970)
	Nganda	Tropical	.06		Soof and Singh (1970)
	Several Breeds	Temperate	0-.05		Pirchner (1964)
Days Dry	Holstein	Temperate	.31		Wilton _et_ _al_. (1967)
	Holstein	Temperate	.34		Schaeffer and Henderson (1970)
	Sahiwal	Tropical	.17		Taneja _et_ _al_. (1978)
	Nganda	Tropical	.53	.15	Mahadevan and Marples (1961)
	Hariana	Tropical	.06		Soof and Singh (1970)
	Native Breeds	Tropical	.00-.11	-.01-.04	McDowell (1972)
	Holstein	Temperate	.32		Olds and Seath (1953)
	Holstein	Temperate	.09		Smith and Legates (1962)
	Holstein	Temperate	.45		Wilton _et_ _al_. (1967)
	Holstein	Temperate	.04		Schaeffer and Henderson (1971)

MATERIALS AND METHODS

Source of Data

The data used in this study were obtained from the National Diary Research Institute (NDRI), Karnal, India through Cornell University. There were 9,666 unedited records covering all calvings for the period 1928-1975. The data consisted of one or more lactation records of cows belonging to three Zebu breeds (Sahiwal, Red Sindhi, Tharpakar) commonly used for milk production in India plus their various crosses with Brown Swiss. Table 4 lists the breed groups and number of records for each breed group in the unedited data.

Due to limited information, the history of management and feeding practices is not discussed in great detail.

Foundation Herds

The herd of Tharpakar cattle was established in 1923 under the control of Indian Agricultural Research Institute. About 150 animals were purchased from the open market between 1923 and 1931 as the foundation stock.

In the early 1950s two other herds, Sahiwal from the Indian Agricultural Research Institute, New Delhi and Red Sindhi from Jabalpur and Bangalore were added. The Sahiwal

Table 4.--Frequencies of the various breed groups in the unedited data.

Breed Group Name	Number of Records
Unknown	2
Tharpakar (T)	4827
Sahiwal (S)	2613
Red Sindhi (RS)	1165
Brown Swiss (BS)	40
Three-Way Cross BS x (S x RS)	615
Inter Se Cross (BS x S x RS) x (BS x S x RS)	164
F_3 (BS x S x RS) x (BS x S x RS)	9
F_1 Crosses (Miscellaneous)	40
1/8 Brown Swiss Crosses	11
5/8 Brown Swiss Crosses	4
3/4 Brown Swiss Crosses	109
Crosses, unidentified	67

herd traces back to about 1910. The original was established in Pusa, Bihar, and later transferred to the Indian Agricultural Institute in New Delhi. In 1951, most of the Sahiwal herd was transferred to Karnal, leaving behind in New Delhi, a few high producing cows as a small unit attached to the Agronomy Division. The Red Sindhi herd was established from animals brought from the disbanded Central Government Breeding Farm at Jabalpur and from the Southern Regional Station of the National Dairy Research Institute. In 1955, the National Dairy Research Institute was founded and its officers took control of these herds. In addition, a crossbreeding project was launched in 1963, using Brown Swiss semen imported from the United States in Sahiwal and Red Sindhi herds. The purpose was to develop a strain of cattle with superior genetic productive and reproductive potential. Although the crossbred offspring did show substantial increase in production, farmers have not been satisfied with the crossbred males as draft animals. With animals a major source of power on Indian farms, this negative aspect has presented a restraint against development of the crossbreeding programs.

Feeding and Management

Prior to 1951 calves were raised on whole milk and animals were fed individually. During the period 1951 to 1956 group feeding was used because of increased numbers of animals without corresponding increase in accommodation.

However, in 1956 major changes were made in housing, general management and feeding practices.

The feeding and general management were the same for all the pure Zebus. The crosses, however, were favorably treated and were given more feed than their contemporary purebreds. Green fodder of chopped whole material, pasture and silage according to season formed the common means of feeding roughage. Concentrate feeding was strictly on the basis of production. Each purebred was fed 1.5 kg. of concentrate per milking or 3.0 to 4.5 kg. per day. Corn, oats and sorghum formed the main source of silage, whereas Napier grass was the common source of whole green chopped material. The concentrate was 50-60% TDN, a mixture mainly of wheat bran and cotton seedcake.

The purebreds were managed in facilities separate from crosses. Milking was 3-times daily for all breed groups. However, the Zebus were milked by hand, whereas the crosses were milked by machine. Limited culling was done in all breed groups, either on the basis of low production or poor health.

Sires used for breeding the purebreds were selected largely on a high record of the dam without any due consideration to her age or her superiority over relatives and herdmates. Semen from Brown Swiss sires used in the crossbreeding scheme was imported from the United States.

Screening of the Data

The most fundamental of the many problems associated with records from the tropics has been the relatively few numbers of records coupled with many inaccurate recordings as compared to the larger volume of records from temperate countries. The twin problems have led to use of few records in statistical analyses, sometimes leading to estimates with less than desirable reliability.

The data used in this study was no exception to the perennial problems. The records were scrutinized carefully to save the maximum number of "normal" records. In this study a "normal" record was defined as a complete record of 305 or more days, or one which had been terminated earlier because daily production was low, without recording any major influence of disease or physical injury.

The principal criterion for editing the data was to exclude those observations exhibiting evidence of inaccurate recordings. Initially, the records were screened for duplications or incorrect recordings in calving month, calving year, birth year, birth month, lactation number, etc. Several records were definitely wrong and those which could not be corrected were deleted.

The next major screening was on the basis of "cause of termination" (Table 5).

Due to lack of information on the date of death and the small number of records for cows that died during lactation, had mastitis or physical injury or that aborted,

Table 5.--Distribution of records by cause of termination after eliminating incorrect records.

Number of Records	Cause of Termination
549	None Recorded
7,622	Dry Normal
0	Dry, Mastitis
0	Dry, Physical Injury
5	Dry, Low Production
481	Dry < 100 days
429	Sold during Lactation
0	Died during Lactation
0	Abortion > 152 Days Pregnant

it was not possible to compute factors to extend records to 305 days. Therefore, such records were excluded in further evaluation of the data.

Cows sold during lactation and those with no recorded cause of termination were not deleted. It was assumed these cows were removed from the herd because of low production. Where these records had no indication of a severe environmental disturbance, they were considered "normal."

The lactation records identified as terminated by "dry, low production," and "dry < 100 days" represent cows that completed their lactation without showing any identifiable disturbance during the lactation. These too were included in further analyses.

After screening the initial 9,666 records, about 9,086 records were found useable. However, as will be shown later, not all 9,086 records were used in each analysis. Depending on the type of statistical model, further screening was done.

Methods of Analysis

All lactation records of 305 days or less were included in all analyses. For the records longer than 305 days, only milk yield for the first 305 days was used.

It was not possible to examine simultaneously all variables likely to influence milk yield because the equations for estimation involved a matrix too large to invert. Step by step considerations of different variables in different models, with the help of absorption procedure, made it possible to examine the importance of each variable. Model manipulations were done according to the variables found to be important for milk yield at each step. If a factor was found not to be important in one model, it was deleted in subsequent models. In the last step a "final complete" model computationally easy to handle was used to examine the effects that were important at different steps in greater details. Statistical Analysis System (SAS) by Barr et al. (1979) was used to obtain results for linear models in following sections:

Effects of Lactation Length and Calving Interval on Milk Yield

There are three specific goals in this section:

1. The overall contribution of calving interval and lactation length as covariates in explaining variation in milk yield.
2. The relative importance of each covariate in explaining the variation in milk yield.
3. The homogeneity of the regression coefficients across breed groups for each of the covariate terms.

A priori postulation of the sources of variation affecting milk yield considered seven sources to be potentially important. These were year of calving (Y), breed groups (B), month of calving (M), lactation number (L), age at calving (A), length of lactation (DIM), and calving interval (CI).

The year effects were grouped into four year-classes of records of cows that calved in 1930-1950, 1951-1960, 1961-1970, and 1971-1975. The basis of grouping years into classes was arbitrary. The only criterion considered was approximate equalization of numbers of records in each class. Table 6 shows the frequencies and the mean milk yield of records in each year-class.

Age at calving involves six age classes of records of cows calving at ages less than 31 months, 31-60 months, 61-90 months, 91-120 months, 121-150 months, and greater

Table 6.--Number of records (N) and mean milk yield (kg) for each of the main effects of breed, year, month, lactation, and age at calving.

Breed	Mean	(N)	Year	Mean	(N)	Month	Mean	(N)	Lactation	Mean	(N)	Age	Mean	(N)
Tharpakar (T)	1819	(4677)	1930-1950	2118	(1866)	January	2034	(862)	1	1748	(2521)	≤30 months	2175	(516)
Sahiwal (S)	1995	(2458)	1951-1960	1868	(2676)	February	2046	(829)	2	1897	(1967)	31-60	773	(4397)
Red Sindhi (RS)	1637	(1109)	1961-1970	1858	(2804)	March	2013	(875)	3	2096	(1414)	61-90	2166	(2259)
Three-Way Cross (BS x RS x S)	3300	(591)	1971-1975	2103	(1740)	April	2003	(887)	4	2167	(1026)	91-120	2227	(1195)
Inter Se Cross (F2)	2542	(152)				May	1974	(758)	5	2152	(766)	121-150	1932	(552)
3/4 Brown Swiss (3/4 - BS)	2651	(99)				June	1960	(563)	6	2160	(538)	≥151	1690	(167)
						July	1919	(722)	7	2122	(362)			
						August	1802	(725)	8	2025	(234)			
						September	1771	(607)	≥9	1719	(258)			
						October	1916	(711)						
						November	2005	(710)						
						December	2009	(837)						

than 150 months. Table 6 shows the number of records and mean milk yield in each age-class.

Six breed groups were well-identified and had a reasonable number of records. Twelve calving months and nine lactations were available. Because of the few records in the later lactations, all lactations greater than or equal to nine were combined to form the "ninth" lactation. Again the number of records and the mean milk yield for each factor are shown in Table 6.

Tabulations of age-classes by lactation (Table 7) indicated some overlap of ages between sequential lactations, making it appropriate to use age within lactation.

(i) <u>The overall contribution of calving interval and lactation length in explaining variation in milk yield.</u>

The following statistical model was used.

$$X_{ijklmn} = \mu + B_i + Y_j + M_k + L_l + A_{lm} + BY_{ij} + BM_{ik} + BL_{il} + BA_{ilm} + YM_{jk} + YL_{jl} + YA_{jlm} + ML_{kl} + MA_{klm} + b_1CI_{ijklmn} + b_2CI^2_{ijklmn} + b_3DIM_{ijklmn} + b_4DIM^2_{ijklmn} + b_5CIDIM_{jklmn} + e_{ijklmn}$$

Where:

X_{ijklmn} = n^{th} production record in the m^{th} age-class in the l^{th} lactation in the k^{th} month in the j^{th} year of the i^{th} breed group.

μ = the population constant common to all records;

B_i = the effect of i^{th} breed group; i = 1...6;

Y_j = the effect of the j^{th} year of calving; j = 1...4;

Table 7.--Number of records in age by lactation subclasses.

Age (months)	Lactation								
	1	2	3	4	5	6	7	8	9
≤30	513	2							
31-60	1996	1729	507	84	50	31			
61-90	12	235	887	770	331	44			
91-120		1	20	171	386	372	195	50	
121-150				1	18	90	158	164	121
≥151					1	1	9	20	137

M_k = the effect of the k^{th} month of calving; k = 1...12;

L_l = the effect of l^{th} lactation number; l = 1...9;

A_{lm} = the effect of m^{th} age at calving in l^{th} lactation; m = 1...6;

BY_{ij} = the interaction effect between the i^{th} breek group and j^{th} year;

BM_{ik} = the interaction effect between i^{th} breed group and k^{th} month;

BL_{il} = the interaction effect between i^{th} breed group and l^{th} lactation;

BA_{ilm} = the interaction effect between i^{th} breed group and m^{th} age in l^{th} lactation;

YM_{jk} = the interaction effect between j^{th} year and k^{th} month;

YL_{jl} = the interaction effect between j^{th} year and l^{th} lactation;

YA_{jlm} = the interaction effect between j^{th} year and m^{th} age in l^{th} lactation;

ML_{kl} = the interaction effect between k^{th} month and l^{th} lactation;

MA_{klm} = the interaction effect between k^{th} month and m^{th} age in l^{th} lactation;

CI = Calving Interval;

CI^2 = Calving Interval squared;

DIM = Days in Milk (lactation length);

DIM^2 = Days in Milk squared (lactation length squared);

CIDIM = Cross-product of calving interval and lactation length;

b_1, b_2, b_3,
b_4, b_5 = the regression coefficients of X_{ijklmn} on CI, CI^2, DIM, DIM^2, and CIDIM, respectively;

e_{ijklmn} = residual error associated with X_{ijklmn}.

All effects were assumed to be fixed except the residual error which was assumed to be normally distributed with a mean of zero and homogeneous variance.

Three-way and higher-order interactions were assumed to be trivial.

There were many records without information on calving interval, reducing the data from 9,086 to 7,099 records (lossing 21% of the data).

Because the classification effects were not of interest, they were absorbed into equations for the effects of calving interval and lactation length with linear, quadratic and cross-product terms. By using the absorption option in the General Linear Models (GLM) procedure (Barr et al., 1979), the results pertaining to the covariates should be free from effects of the classification factors and their interactions. The squared multiple correlation (R^2) was used as indicator of the variation in milk explained by the covariates and all fixed effects.

(ii) Relative importance of each covariate in explaining variation in milk yield.

Starting with Model 1a, the covariates were dropped singly and in pairs from the model to determine their relative importance. Differences in squared coefficients of multiple correlation (R^2) were used as indicators of the combination of each covariate to explanation of variation of milk yield.

(iii) Homogeneity of regression coefficients across breed groups for each covariate term.

The intriguing question here was to find out whether the adjustments for covariates should be made within or across breed groups. A comparison of two models was necessary: one that assumed homogeneous regression across the breed groups versus one that assumed different regressions for each breed group:

1. Model 1a:

   The statistical model assuming homogeneous regressions across breed groups as discussed previously.

2. Model 1b:

   The statistical model assuming different regressions for each breed group was:

$$X_{ijklmn} = \mu + B_i + Y_j + M_k + L_l + A_{lm} + BY_{ij} + BM_{ik} + BL_{il} + BA_{ilm} + YM_{jk} + YL_{jl} + YA_{jlm} + ML_{kl} + MA_{klm} + b_{1i}CI_{ijklmn} + b_{2i}CI^2_{ijklmn} + b_{3i} DIM_{ijklmn} + b_{4i}DIM^2_{ijklmn} + B_{5i}CIDIM_{ijklmn} + e_{ijklmn}$$

All effects and assumptions of the model are as explained in Model 1a except b_{1i}, b_{2i}, b_{3i}, b_{4i}, and b_{5i} for each of the covariates were within breed group instead of across breed groups. In other words, the assumption is that regressions are not homogeneous across all breed groups.

The test of homogeneity of regression hinged on the significance test of difference in regression sums of squares between the two models (Searle, 1971).

Preliminary Examination of Fixed Effects of Breed Year, Season, Lactation, Age Within Lactation and Their Two-Way Interactions

The main interest in this part of analysis was to test the significance of the fixed effects and their two-way interactions. Any effects found nonsignificant ($P > .10$) were deleted in subsequent analyses.

The statistical model used was:

Model 2:

$$X_{ijklmn} = \mu + B_i + y_j + S_k + L_l + A_{lm} + BY_{ij} + BS_{ik} + BL_{il} + BA_{ilm} + YS_{jk} + YL_{jl} + YA_{jlm} + SL_{kl} + SA_{klm} + b_3DIM_{ijklmn} + b_4DIM^2_{ijklmn} + e_{ijklmn}$$

where:

S_k = the effect of k^{th} season; $k = 1...2$;

BS_{ik} = the interaction effect between i^{th} breed and k^{th} season;

YS_{jk} = the interaction effect between j^{th} year and k^{th} season;

SL_{kl} = the interaction effect between k^{th} season and l^{th} lactation;

SA_{klm} = the interaction effect between k^{th} season and m^{th} age within l^{th} lactation.

The remaining effects and the assumptions of the model are as explained in Model 1a.

There were two changes made from Model 1a to Model 2:

a. Calving interval was excluded.

b. Calving month effect was replaced by season.

Because of the size of matrix to invert in obtaining fixed effects, it was deemed necessary to group calving months into seasons. Two criteria were considered in grouping the months into seasons. The first criterion was magnitude of unadjusted means for months (Table 8). The means seemed to form two possible distinct groups; one group consisting of the month of August and September with low mean yields, the other consisting of the remaining months. Scheffé's test (Gill, 1978) was applied to differences of monthly means. Means for August and September each were lower ($P < .05$) than monthly yields of November, December, January, February, March, and April, but comparisons of other months were not statistically significant ($P < .05$).

The second criterion considered climatic conditions and feeding practices at Karnal, where the data were collected. A comprehensive summary of the conditions at Karnal was given by Sundaresan _et_ _al_. (1965). He indicated that the period of better milk production corresponds to the period of regular supply of leguminous or nourishing fodders such as lucerne, berseem, and green oats. In the months of April, May and June temperatures are not favorable for dairy cattle performance, but milk yield was not affected because of better feeding in those months. During the months of July to September the temperatures are very high with high humidity and the major supply of fodder is sorghum. Thus,

Table 8.--Scheffé's test on unadjusted monthly means (ranked from highest to lowest).

Month	Mean (kg)
February	2046
January	2034
March	2013
December	2009
November	2009
April	2004
May	1974
June	1960
July	1919
October	1916
August	1802
September	1771

Means joined by the same line are not statistically different ($P < .05$).

high quality feed is not available to offset the severe environmental effects on the production. During the months of October to December dry sorghums are supplemented by silages. However, the climate in those months is not adverse to production.

Results from unadjusted means, coupled with the explanation by Sundaresan et al. (1965), led to formation of two seasons, the first comprised of the months of August and September, and the second comprised of all the other months.

Examination of the Fixed Effects and Heritability and Repeatability Estimation

In this analysis all factors found important in Models 1a and 2 were considered. Thus the "complete" working model was:

Model 3:

$$X_{ijklmnop} = \mu + B_i + Y_j + S_k + L_l + A_{ml} + BY_{ij} + BL_{il} + BA_{iml} + YS_{jk} + YL_{jl} + YA_{jml} + SA_{kml} + b_3 DIM_{ijklmnop} + b_4 DIM^2_{ijklmnop} + SIRE_n + COW_{on} + e_{ijklmnop}$$

where:

$SIRE_n$ = random effect of n^{th} sire $\sim N(\underset{\sim}{0}, \underset{\sim}{I}\sigma^2_s)$;

COW_{on} = random effect of 0^{th} cow from n^{th} sire $\sim N(\underset{\sim}{0}, I\sigma^2_c)$

The remaining effects are the same as explained previously in Model 1a.

This model was used for the following purposes:

a. To obtain estimates of heritability and repeatability of milk yield.

b. To re-examine the fixed effects previously found to have important impact on milk yield, after adjusting for random effects.

In solving for the fixed effects, mixed model equations (MME) were used. They involved the addition to least squares equations of variance ratios (σ_e^2/σ_s^2) and (σ_e^2/σ_c^2) obtained from the variance components estimated using Model 3 (refer to results and discussion section on heritability estimates) and the procedures outlined below.

(i) Estimation of heritability and repeatability.

Estimation of heritability $(\hat{h}^2)$ and repeatability $(\hat{r})$ involve ratios of variance components. Thus, to obtain either $\hat{h}^2$ or $\hat{r}$, one must estimate variance components, which are interpreted genetically through knowledge of covariance of relatives.

Because interest was in random effects only, a random model adjusted for the fixed effects was fitted by the Nested procedure (Barr *et al.*, 1979) based on Model 3. Because of concern that neglecting dam effect, if it is important, could result in biased estimates of sire variance component as indicated by Farthing and Steele (1967), three alternative analyses were explored. In all three analyses the fixed effects (Model 3) were common but the models differed in content of the random effects of sire, dam and cow.

In the first analysis the random factors of sire, dam within sire, and cow within dam were considered. Theoretically, this analysis should give the least biased estimates but it posed two practical problems.

1. Because dam identification was missing from many records, consideration of dam effect caused loss of 20% of the original data.
2. Inclusion of sire, dam within sire, and cow within dam in the same analysis resulted in very few degrees of freedom for estimating the variance component for error.

In the second analysis cow within dam was dropped from the model of the first analysis. That alleviated somewhat the problem of degrees of freedom, but still did not permit use of 20% of the original records.

In the third analysis, dam within sire and cow within dam were dropped from the model of the first analysis, and cow within sire was added. As a consequence of this modification, records without dam identification could be used, reducing both problems associated with the first analysis.

Results from the three analyses were compared to check for differences in the estimates.

Two sets of data were used. The first consisted of 6,962 records with both dam and sire identified. The second consisted of 8,293 records with sire identified, with or without dam identified.

Two types of estimates of heritability were computed:

1. Heritability for each breed group across all lactations. Model 3, excluding breed effect, was used to obtain estimates of variance components.
2. Heritability for each breed group for each of first, second, and third lactations. Again, Model 3, excluding breed, lactation and cow effects, was used to obtain estimates of variance components. Because each cow has only one record the cow effect is completely confounded with error in the second type of estimate.

Heritability was estimated as:

$$\hat{h}^2 = \frac{4\hat{\sigma}_s^2}{\hat{\sigma}_s^2 + \hat{\sigma}_c^2 + \hat{\sigma}_e^2}$$ for each breed group across lactations

or

$$\hat{h}^2 = \frac{4\hat{\sigma}_s^2}{\hat{\sigma}_s^2 + \hat{\sigma}_e^2}$$ for each breed group for each lactation

where:

$\hat{\sigma}_s^2$ is expected to contain 1/4 additive genetic variance (1/4 σ_A^2), 1/16 additive by additive (epistatic) variance (1/16 σ_{AA}^2).

The denominator $(\hat{\sigma}_s^2 + \hat{\sigma}_c^2 + \hat{\sigma}_e^2)$ or $(\hat{\sigma}_s^2 + \hat{\sigma}_e^2)$ represent the phenotypic variance $(\hat{\sigma}_p^2)$ after elimination of variance caused by the named fixed effects.

Two potential sources of bias in heritability estimates obtained by this method are:

1. Epistatic bias (Dickerson, 1969).
2. Ratio bias which arises, because the expected value of a ratio of two random variables is not equal to the ratio of expectations of numerator and denominator (Kendel & Stuart, 1969).

Thus, the expectation of the estimator of heritability is:

$$E\ (\hat{h}^2) = (h^2 + \text{epistatic bias})\ (1 + \text{ratio bias})$$

Standard errors of estimates of heritability were obtained by using the general formula for approximate standard error of the ratio of two sets of variance components (Dickerson, 1969):

$$\sigma(\hat{X}/\hat{Y}) = \frac{C}{\hat{Y}^2} \sqrt{\hat{Y}^2 V(\hat{X}) + \hat{X}^2 V(\hat{Y}) - 2\hat{X}\hat{Y}\ \text{Cov}\ (\hat{X},\hat{Y})}$$

where C is any constant multiplier of the numerator, $\hat{X}$, and $\hat{Y}$ is the denominator.

Procedures for computation of repeatability estimates (r) and their standard errors, are parallel to those for estimation of heritability. The only difference was in the ratios of the variance components.

Repeatability (intraclass correlation) was estimated as:

$$\hat{r} = \frac{\hat{\sigma}_s^2 + \hat{\sigma}_c^2}{\hat{\sigma}_s^2 + \hat{\sigma}_c^2 + \hat{\sigma}_e^2}$$

where:

$(\hat{\sigma}_s^2 + \hat{\sigma}_c^2)$ contains the sum of genetic and permanent environmental variances among cows;

$\hat{\sigma}_e^2$ contains temporary environmental effects associated with each observation.

RESULTS AND DISCUSSION

Lactation Length and Calving Interval

Model 1a was used to fit different combinations of calving interval and lactation length. Table 9 shows the squared coefficients of multiple correlation (R^2) resulting from fitting the different combinations.

The classification fixed effects and their interactions explained about 45% (R^2 = .446) of the variation in milk yield. When terms of linear, quadratic and cross-product effects of calving interval and lactation length were added, 74% (R^2 = .74) of the total variation in yield was explained. The increase in R^2 value suggested that linear, quadratic and cross-product of calving interval and lactation length accounted for an additional 29% of the total variation in milk yield.

The combination of the fixed effects with only lactation length linear and quadratic effects gave R^2 value of .727, suggesting that lactation length alone explained an additional 28% of the total variation in milk yield. The combination of the fixed effects with calving interval linear and quadratic effects produced R^2 value of .526,

Table 9.--Squared coefficients of multiple correlation (R^2) for different combinations of factors in the model.

Factors (effects) and Combinations	R^2
Fixed classification factors, two-way interactions.	.446
Fixed classification factors, two-way interactions, calving interval linear and quadratic.	.526
Fixed classification factors, two-way interactions, lactation length linear and quadratic.	.727
Fixed classification factors, two-way interactions, calving interval linear and quadratic, lactation length linear and quadratic, calving interval by lactation length interaction.	.741
Fixed classification factors, two-way interactions, lactation length linear and quadratic, the random factors.	.735

suggesting that calving interval only accounted for an additional 8% of the total variation in milk yield.

These results imply that calving interval and the interaction between calving interval and lactation length had very little influence on milk production that could not be explained by lactation length alone.

Results from other studies in the tropics generally suggest the same trend of relationship between lactation length and calving interval with milk yield as found in the present study. Camoens *et al*. (1976) reported that calving interval accounted for 6.0% of the milk yield out of the 13.4% variation that was accounted for by a combined effects of days open, days dry and calving interval. Milk yield was influenced by lactation length, calving interval and days dry in descending order of magnitude. However, exclusion of calving interval alone for the regression did not reduce the R^2 value to any great extent, which is consistent with the results obtained in this study.

McDowell et al. (1976) reported that lactation length accounted for about 34% of the variation in milk yield while days dry, days open and calving interval contributed less than 4%.

Significant correlations between calving interval and milk yield have been reported, ranging from 0.1 to 0.2 (Camoens et al., 1976; McDowell et al., 1976). Significant correlations between lactation length and milk yield have ranged from 0.4 to 0.9 (Sikka, 1931; Robertson, 1950; Mahadevan, 1955; Asker et al., 1958; Alim, 1960; Mahadevan & Marples, 1961; Galukande, et al., 1962; Singh & Desai, 1962; Camoens et al., 1976; Duran, 1976).

Parallel results from the temperate region involving directly calving interval and lactation length are scanty. Norman (1967) found calving interval was an important source of variation in current lactation, accounting for 4.1-14.7% of variation in milk yield. Correlations of .19 to .21 between calving interval and milk yield have been reported by Miller et al. 1967).

Results from tests of homogeneity of regressions across breed groups are given in Table 10. Models 1a and

Table 10.--Tests of significance of linear and quadratic parameters in regressions of yield on calving interval and lactation length, across and within breed groups.

Source of Variation	DF	MS
CI Linear within breed groups	6	515,066
CI Linear across breed groups	1	2,268,730**
CI Linear (Difference)[c]	5	164,333
CI Quadratic within breed groups	6	984,907**
CI Quadratic across breed groups	1	5,022,289**
CI Quadratic (Difference)[c]	5	177,430
DIM Linear within breed groups	6	1,032,558**
DIM Linear across breed groups	1	4,690,929**
DIM Linear (Difference)[c]	5	300,884
DIM Quadratic within breed groups	6	13,599,092**
DIM Quadratic across breed groups	1	79,625,533**
DIM Quadratic (Difference)[c]	5	393,804
CI by DIM interaction within breed groups	6	805,020**
CI by DIM interaction across breed groups	1	1,421,604**
CI by DIM interaction (Difference)[c]	5	681,703**
Error	5,188	293,927

[c]Mean squares (MS) for difference between regressions across and within breed group.

*P < .10. **P < .05.

lb were compared by testing differences in the sums of squares due to regressions for the two models.

The linear, quadratic and cross-product sums of squares pertaining to each of the covariates (calving interval and lactation length) were significant ($P < .05$). The tests of differences between the regression sums of squares within breed groups and across breed groups for the linear and quadratic effects gave F-values less than 1, implying that regressions were homogeneous across the breed groups. However, for the cross-product between calving interval and lactation length the difference was significant ($P < .05$) suggesting that the regressions pertaining to the interaction were not homogeneous across all the breed groups.

The similarity of R^2 values obtained when the covariates were fitted within breed groups ($R^2 = .75$) and across the breed groups ($R^2 = .74$) was a further indication of homogeneity of the regressions across the breed groups.

One may conclude that linear and quadratic terms for lactation length are important in explaining variation in milk yield. Calving interval is not important in presence of lactation length. Fitting the linear and quadratic terms across breed groups rather than within breed group was the better procedure in accounting for the effect of lactation length on milk yield.

Because calving interval was unimportant in presence of lactation length, it was deleted from subsequent analyses.

Further exploration on the effect of lactation length was done in conjunction with the "complete" model (Model 3).

Preliminary Examination of Fixed Effects

The specific goal in this analysis was to eliminate from subsequent analyses any fixed effects that were not significant ($P < .10$). Model 2 was used to obtain preliminary results. In this model calving interval was not considered and effect of season instead of month was used (see materials and methods section Model 2). The R^2 value for this model ($R^2 = .72$) was virtually the same as R^2 value in Model 1a ($R^2 = .74$) indicating the removal of calving interval and the grouping of seasons changed the goodness of fit only trivially.

A summary of results is presented in Table 11. All main effects of breed group, year, season, lactation and age within lactation were highly significant ($P < .001$). The significant two-way interactions were breed group by lactation ($P < .01$), breed group by age within lactation ($P < .05$), year by lactation ($P < .001$), year by age within lactation ($P < .001$) and season by age within lactation ($P < .10$). The two-way interactions that were not significant ($P > .10$) were breed group by season and season by lactation; these were eliminated in further analyses.

Table 11.--Mean squares (MS), degrees of freedom (DF), F-ratio (F), and tests of significance from Model 2.

Effects	DF	MS	F
Breed Group (B)	5	242,085,740	832.91****
Year (Y)	3	104,858,350	360.77****
Season (S)	1	63,848,877	219.68****
Lactation (L)	8	8,393,633	28.88****
Age within Lactation $A_{(1)}$	23	8,646,175	29.75****
BY	9	5,988,615	20.60****
BS	5	396,712	1.36
BL	32	512,931	1.76***
$BA_{(1)}$	40	417,512	1.44**
YS	3	1,060,001	3.65**
YL	24	1,265,970	4.36****
$YA_{(1)}$	47	785,239	2.70****
SL	8	191,670	0.66
$SA_{(1)}$	18	448,993	1.54*
Lactation Length: Linear (DIM)	1	441,602	1.52
Lactation Length: Quadratic (DIM^2)	1	161,405,445	555.32****
Error	8,591	290,650	

****P < .001. ***P < .01.

**P < .05. *P < .10.

Effects of Breed Group, Year, Season, Lactation Number, Age, Their Two-Way Interactions and Lactation Length on Milk Yield

Model 3 was considered to be the final practical model well suited to the data and computationally feasible. The R^2 value for this model was .74, approximately the same as for Model 1a (.74) or Model 2 (.72).

Whereas Model 2 was used for preliminary identification of significant factors with fixed effects on total milk yield, Model 3 was used to explore detailed contrasts between individual means. Also, because the random factors of sire and cow were considered in the latter model, estimates of the fixed effects were adjusted for these random factors. Results of analysis of variance from Model 3 are presented in Table 12. The least squares constants for the main classification factors are shown in Table 13. The constants are weighted values over two-way interactions that were important for milk yield. For instance, if any two-way interactions associated with two fixed classification factors were significant ($P < .05$) with F-value equal to or greater than 2, the constants for the two classification factors were weighted over those interaction constants. Each of the factors is examined specifically in following sections.

Breed Group Effect

Table 12 shows that breed groups differed strongly ($P < .001$). The least squares constants are shown in

Table 12.--Model 3: Mean squares (MS), degrees of freedom (DF), F-ratio (F), and tests of significance.

Effects	DF	MS	F
Breed Group (B)	5	118,153,435	426.08****
Year (Y)	3	50,157,932	180.88****
Season (S)	1	17,313,213	62.43****
Lactation (L)	8	7,612,250	27.45****
Age within Lactation $A_{(1)}$	21	488,512	1.76**
BY	9	5,017,808	18.10****
BL	32	471,961	1.70***
$BA_{(1)}$	40	420,508	1.52**
YS	3	861,934	3.11**
YL	24	776,154	2.80****
$YA_{(1)}$	41	449,745	1.62***
$SA_{(1)}$	15	335,030	1.21
Lactation Length: Linear (DIM)	1	259,629	0.94
Lactation Length: Quadratic (DIM^2)	1	143,304,499	516.78****
Error	7,815	277,301	

****P < .001. ***P < .01.

**P < .05. *P < .10.

Table 13.--Model 3: Least squares constants for breed group, year, lactation and season.

Breed Group	Breed Constants[a] (weighted over Y, BY)	Year	Year Constants[a] (weighted over B, S, L, BY, YS, YL)	Lactation	Lactation constants[a] (weighted over Y, YL)	Season	Season Constants[a] (weighted over Y, YS)
Tharpakar	-271 (4039)	1930-1950	-993 (1600)	1	-1503 (2365)	1	-288 (1186)
Sahiwal	-503 (2398)	1951-1960	-1047 (2352)	2	-1892 (1753)	2	0 (7107)
Red Sindhi	-475 (1016)	1961-1970	-1521 (2709)	3	-1227 (1267)		
Three-way cross	540 (589)	1971-1975	0 (1632)	4	438 (916)		
Inter Se cross	160 (152)			5	53 (690)		
3/4-Brown Swiss	0 (99)			6	211 (487)		
				7	-252 (346)		
				8	250 (223)		
				≥9	0 (246)		

Figures in parentheses ( ) indicate number of records.

[a]The constants are deviations from the effects indicated by zero values.
B = breed effect; Y = year effect; L = lactation effect; S = season effect; BY, YS, YL = two way interactions.

Table 13. Tharpakar (T) excelled Sahiwal (S) and Red Sindhi (RS) by 232 kg and 204 kg, respectively in milk yield. Red Sindhi exhaled Sahiwal by only 28 kg. The results seem to suggest that Tharpakar is superior to both Sahiwal and Réd Sindhi, whereas both Red Sindhi and Sahiwal are about equal producers of milk under similar conditions. Comparable results in literature, under similar tropical environment, were limited.

Among crossbreds, the Three-way crosses, BS x (S x RS), were superior, followed by the Inter Se crosses, (BS x S x RS) x (BS x S x RS), and then by 3/4-Brown Swiss crosses, 3/4-BS. The Three-way crosses outyielded the Inter Se breed group and the 3/4-BS by 380 kg and 540 kg, respectively. However, it is imperative to acknowledge here the meager data on which evaluation of crossbreds were based.

Comparable results in literature suggest that 1/2-Zebu (Sahiwal/Red Sindhi) crosses with temperate breeds exceed all other breed groups in production (Amble & Jain, 1967; Bhatnagar et al., 1970, 1971; Stonaker et al., 1953). Contrary results were indicated by Verma (1973). He reported significantly greater milk yields in 5/8- and 3/4-Holsteins than in 1/2-, 1/4-, and 1/8-Holsteins. However, his results were based on a very limited data.

All crosses were superior to the purebreds. For example, the Three-way cross excelled Tharpakar, Sahiwal and Red Sindhi by 810 kg, 1043 kg, and 1015 kg, respectively, in milk yield. The merits of crossbreds over the tropical

Zebu breeds are supported by numerous other studies. For instance, Amble and Jain (1965), Branton *et al*. (1966), McDowell (1971), Moulick *et al*. (1972), among others reported higher yields of crossbreds over purebred Zebu cattle. In the present study caution should be taken in interpreting the results because, apart from the problem of limited data for crosses, they were managed and treated more favorably than the purebred Zebus. Thus, whether the apparent superiority of the crosses over the purebreds was caused fully or only partially by better genetic potential could not be ascertained in this study.

Year Effect

Differences of year-classes were significant ($P < .001$). The year constants showed no monotonic trend with time (Table 13). Class 4 (1971-1975) showed the highest production followed by Class 1 (1930-1950), Class 2 (1951-1960), and Class 3 (1961-1970).

The differences over time can be attributed to several complex factors among which are change in climate, change in feeding practices and change in management decisions which may or may not interact together to form year effects.

Evidence is available in literature on year differences for milk yield: Camoens *et al*. (1976), Hardie *et al*. (1972), Lee (1974), and Sundaresan *et al*. (1965), among others, have reported significant differences between years for milk yield.

Season Effect

The season effect was very highly significant ($P < .001$). Also, other reports from the tropics (Camoens *et al.*, 1976; Kohli & Suri, 1960; Lindström & Solbu, 1977; McDowell *et al.*, 1976; Moulick *et al.*, 1973; Pearson *et al.*, 1968) suggested significant season effects on milk yield. On the other hand, non-significant effects of season have been reported by Alim (1965), and Sharma and Singh (1974). Comparable reports from the temperate areas seem to indicate the same trend of significant season effects (Fosgate & Welch, 1960; Frick *et al.*, 1945; Lee *et al.*, 1961; Woodward, 1945; Miller *et al.*, 1970; Mao *et al.*, 1974).

The season effects found in this study can be explained by the differential climatic and feeding practices in the two seasons. The lower constants in season 1 (Table 13) may be attributed to the hot humid weather compounded by poor quality feed (Sundaresan *et al.*, 1965).

Lactation Effect

Lactation number was highly significant ($P < .001$) in its impact on yield, which is in agreement with other reports from the tropics (Moulick *et al.*, 1972; Chhabra *et al.*, 1970). The general tendency was for milk yield to increase with increasing lactation number up to the fourth lactation, then decline (Table 13).

Age Within Lactation Effect

The results in Table 12 indicate age differences within a given lactation significantly affect yield ($P < .05$). Similar findings of significant age effects on milk yield in the tropics have been reported (Camoens *et al.*, 1976; Batra & Desai, 1964; Kushwaha & Misra, 1962; Sikka, 1931; Galukande *et al.*, 1962; McDowell *et al.*, 1976; Nagpaul & Bhatnagar, 1971; Singh & Chondhury, 1961). Significant effect of age of calving on milk yield also have been found in temperate areas (Lush & Shrode, 1950; Mao *et al.*, 1974; Miller *et al.*, 1970; Wunder & McGilliard, 1972).

After the second lactation the younger cows produced more milk than the older cows (Table 14). The reason for this is unclear but the possible explanation might be that after the second lactation younger cows were nearer the mature age for peak yield (3 to 6 years) suggested by several researchers (Camoens *et al.*, 1976; Gowen, 1920; Wunder & McGilliard, 1971).

Although age differences within lactation were important, no effort was made in this study to develop age-adjustment factors. Generally, there are two ways to account for age differences in an analysis. One way is to incorporate the age effect in the model so that it is considered simultaneously with other factors in the analysis and thus eliminated as a nuisance factor. The other is to develop age-adjustment factors and adjust the records prior to further analysis.

Table 14.--Model 3: Least squares constants[a] for ages within lactation.

Age (Month)	Lactation								
	1	2	3	4	5	6	7	8	≥9
≤30	-2252(502)	-2025(1)							
31-60	-1919(1852)	-2131(1528)	-599(407)	-57(14)					
61-90	-1795(11)	-2009(223)	-1721(842)	-145(739)	619(302)	-406(43)			
91-120		-2086(1)	-1439(18)	-293(162)	-31(370)	-374(358)	1575(189)	880(49)	
121-150				290(1)	779(17)	-45(85)	-282(148)	678(156)	256(116)
≥151					-172(1)	46(1)	-287(9)	312(18)	0(130)

The figures in parenthesis ( ) indicate number of records.

[a]Each constant was computed by adding lactation constants to each age within lactation constant.

Because of the limited data available from the tropics as a whole, one cannot justify developing age factors. The factors obtained from such small data can only be applicable to that data set only and therefore their usefulness is limited. Until larger sets of data are available, including age effects in the model for a given analysis is the better method with tropical data.

Interaction Effects

Statistical tests for two-way interactions (Table 12) indicated that year by lactation and breed group by year had the highest significant level ($P < .001$); followed by breed group by lactation and year by lactation ($P < .01$); followed by breed group by age within lactation and year by season ($P < .05$), and lastly followed by season by age within lactation ($P < .25$).

The constants pertaining to the various interactions of interest are given in Tables 15, 16, 17, and 18. Because the data are badly unbalanced and relatively sparce in many combinations, relatively little insight can be gained from examining the interaction constants. The only significant ($P < .05$) interaction that could be studied in some detail was breed group by lactation.

The constants for interaction of breed group and lactation are presented in Table 15. The constants for the purebred Zebus indicate milk yield increased with lactation number, reached a maximum in the second lactation and then

Table 15.--Model 3: Least squares constants[a] for interaction of breed group and lactation.

Breed Group	Lactation								
	1	2	3	4	5	6	7	8	≥9
Tharpakar	1429(1147)	1720(853)	1517(600)	422(432)	763(321)	82(225)	246(173)	-151(126)	0(162)
Sahiwal	1772(649)	1962(494)	1755(374)	595(292)	903(228)	90(157)	288(103)	-154(52)	0(49)
Red Sindhi	1329(310)	1513(217)	1350(155)	267(103)	617(80)	-190(59)	39(37)	-291(25)	0(30)
Three-Way Cross	1115(149)	1305(113)	1423(98)	-128(72)	207(55)	0(44)			
Inter Se Cross	836(55)	1100(47)	1266(30)	-54(15)	476(4)	0(1)			
3/4-Brown Swiss	0(55)	0(29)	0(10)	0(2)	0(2)	0(1)			

Figures in parenthesis ( ) indicate the number of records.

[a]The constants are deviations from the effects indicated by zero values.

Table 16.--Model 3: Least squares[a] constants for interactions of year with lactation, season and breed group.

Year	Lactation								
	1	2	3	4	5	6	7	8	≥9
1930-50	261(485)	247(355)	353(264)	338(182)	481(125)	454(77)	366(47)	109(31)	0(34)
1951-60	773(665)	588(484)	561(370)	373(269)	332(189)	244(138)	18(95)	0.29(65)	0(77)
1961-70	187(758)	56(560)	56(405)	23(308)	173(252)	137(165)	-12(116)	-149(67)	0(78)
1971-75	0(457)	0(354)	0(228)	0(157)	0(124)	0(107)	0(88)	0(60)	0(57)

Year	Breed Group					
	Tharpakar	Sahiwal	Red Sindhi	Three-way Cross	Inter Se Cross	3/4-Brown Swiss
1930-50	655(1371)	669(222)				
1951-60	474(1098)	288(833)				
1961-70	-349(1014)	-468(990)	-360(436)	-479(241)	-258(24)	0(4)
1971-75	0(556)	0(353)	0(152)	0(348)	0(128)	0(95)

Season	Year			
	1930-50	1951-60	1961-70	1971-75
1	-147(286)	-142(386)	-111(401)	0(235)
2	0(1314)	0(1966)	0(2308)	0(1397)

Figures in parenthesis ( ) indicate the number of records.

[a]The constants are deviations from the effects indicated by zero values.

Table 17.--Model 3: Least squares constants[a] for interactions of age within lactation by year and season.

	Age (months	Lactation 1	2	3	4	5	6	7	8	≥9
Year										
1930-1950	≤30	35(205)								
	31-60	0(280)	344(347)	38(140)						
	61-90		0(8)	0(124)	86(172)	127(83)	-953(8)			
	91-120				0(9)	0(42)	-812(67)	-299(30)	-917(4)	
	121-150						0(2)	0(17)	-291(24)	104(19)
	≥151								0(3)	0(15)
1951-1960	≤30	-641(31)								
	31-60	-363(629)	-255(376)	8(75)						
	61-90	0(5)	0(107)	296(288)	-261(205)	-1058(73)	10(12)			
	91-120			0(7)	0(63)	-955(114)	176(107)	1368(60)	-831(24)	
	121-150					0(2)	0(19)	1542(34)	-512(37)	29(47)
	≥151							0(1)	0(4)	0(30)
1961-1970	≤30	131(110)								
	31-60	264(643)	-140(482)	219(111)	57(9)					
	61-90	0(5)	0(78)	201(284)	2(234)	-852(73)				
	91-120			0(10)	0(65)	-1067(164)	76(107)	63(40)	-528(3)	232(21)
	121-150					0(14)	0(53)	97(69)	-281(56)	0(57)
	≥151							0(7)	0(8)	
1971-1975		0	0	0	0	0	0	0	0	0
Seasons										
1	≤30	-88(55)								
	31-60	-172(208)	-65(212)	347(68)						
	61-90	0(1)	0(43)	287(124)	10(127)	-327(55)	-1036(6)			
	91-120			0(1)	0(25)	-313(60)	-187(36)	-175(30)	-393(7)	
	121-150					0(4)	0(15)	-271(26)	-101(25)	259(26)
	≥151							0(1)	0(2)	0(28)
2		0	0	0	0	0	0	0	0	0

Table 18.--Model 3: Least squares constants[a] for interaction of breed groups and ages within lactations.

Breed	Age (Months)	Lactation 1	2	3	4	5	6	7	8	≥9
Tharpakar	≤30	1077(185)	32(1)							
	31-60	587(958)	0(748)	-1339(170)	274(1)					
	61-90	0(4)		- 294(421)	-134(361)	-166(131)	470(8)			
	91-120			0(9)	0(69)	482(181)	301(181)	-1313(89)	-134(20)	
	121-150					0(8)	0(36)	551(82)	-227(95)	-384(74)
	≥151							0(2)	0(11)	0(88)
Sahiwal	≤30	332(133)								
	31-60	-83(512)	241(418)	-893(102)	435(1)					
	61-90	0(4)	0(75)	262(266)	-165(228)	-488(89)	462(16)			
	91-120			0(6)	0(63)	353(133)	380(106)	-2001(50)	8(2)	
	121-150					0(6)	0(34)	-233(48)	112(38)	-315(25)
	≥151							0(5)	0(2)	0(24)
Red Sindhi	≤30	420(21)								
	31-60	0(286)	133(176)	-1352(15)						
	61-90		0(41)	0(137)		-768(23)				
	91-120					0(54)		-1891(18)	658(2)	
	121-150							0(17)	0(18)	
	≥151									
Three-Way Cross	≤30	422(109)								
	31-60	0(40)		-1521(92)						
	61-90			0(6)						
	91-120									
	121-150									
	≥151									
Inter Se Cross	≤30	322(14)								
	31-60	0(41)		-1339(19)						
	61-90			0(11)						
	91-120									
	121-150									
	≥151									
3/4-Brown Swiss		0		0	0	0	0	0	0	0

Figures in parenthesis indicate the number of records.

[a]The constants are deviations from the effects indicated by zero values.

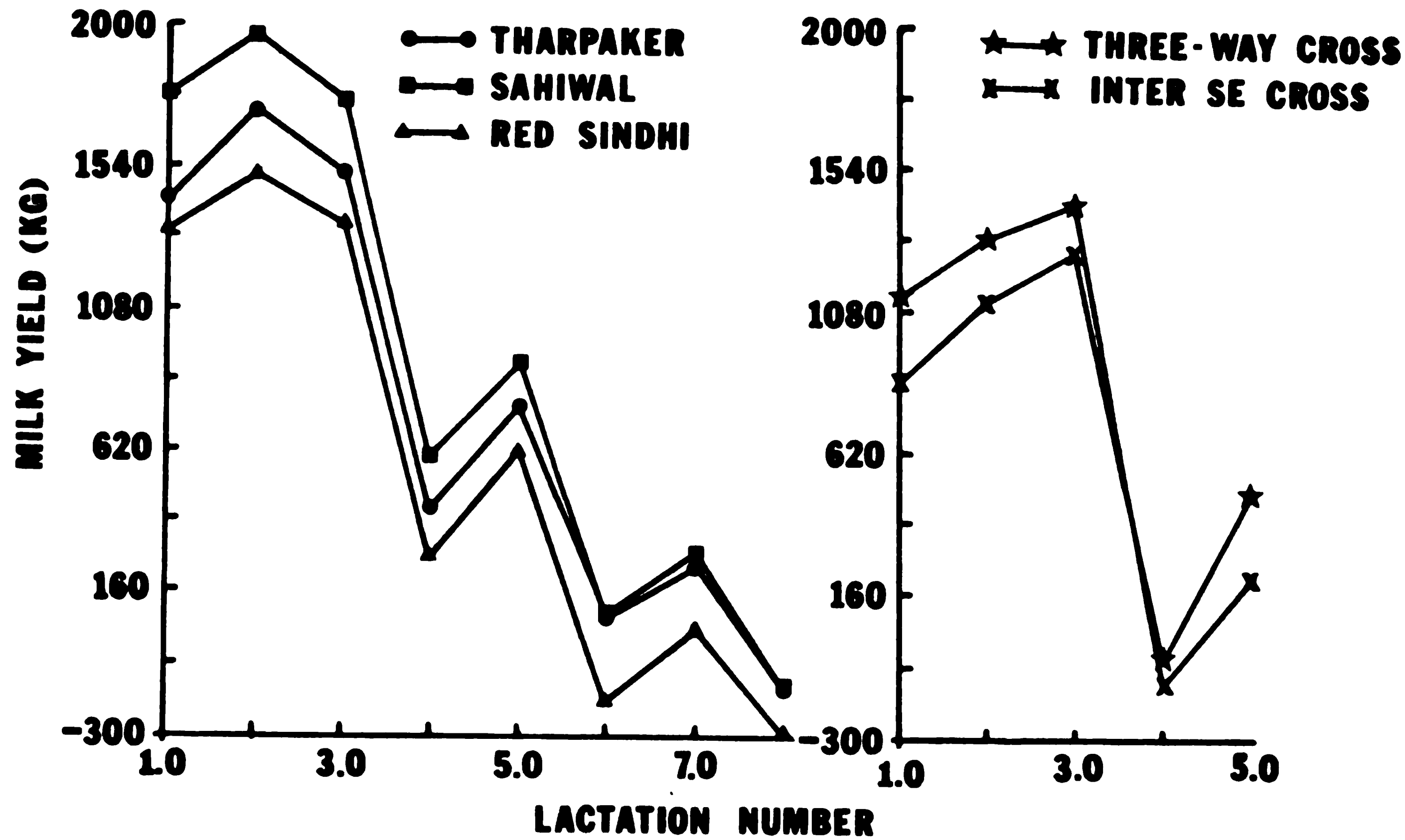
gradually declined (Figure 1). For the crossbreds milk yield increased with lactation number, reached a maximum in the third lactation and then gradually declined. Chhabra et al. (1970) working with Hariana cattle, found the maximum production was obtained in the third lactation. White and Drakely (1927) concluded that age at which maximum yield was reached differed among breeds. Whether the attainment of maximum yield by the second lactation for the purebreds vis-à-vis the third lactation for the crossbreds was an indication of earlier maturity by the purebreds could not be ascertained in the present study.

Lactation Length

Tests of significance for the linear and quadratic terms for lactation length are shown in Table 12. The linear term was not significant ($P > .10$) but the quadratic term was highly significant ($P < .001$). The partial regression coefficients for the linear and quadratic terms were -.3957 and .0243, respectively.

Based on the prediction equation from Model 3, the predicted milk yield was differentiated with respect to lactation length and equated to zero to find the minimum point. The results indicated that this point was at approximately eight days. However, because this estimate is not precisely determined, the true minimum could easily be zero, as one would suppose. If one deletes the non-significant linear term, then the curve is forced to have a minimum at zero day.

FIGURE 1. LEAST SQUARES CONSTANTS FOR EFFECT OF INTERACTION OF BREED GROUP AND LACTATION



A prediction curve based on the second degree polynomial regression of milk yield on lactation length, adjusted for the other effects in Model 3, is plotted to indicate the changes that would be expected in milk yield with lactation length (Figure 2).

Re-examination of the Fixed Effects and Their Interactions Using Records on the Purebred Breed Groups Only

Intuitively it is possible that the small numbers of records associated with the crossbreds could cause faulty interpretation of the results, particularly the interaction constants. As Dickerson (1969) put it ". . . the unequal and disproportionate numbers of observations in the subclasses have muddied the statistical waters for those working with data from animal population." Thus, the records on the crossbreds were set aside and only the purebred Zebus were reanalyzed using the same model, Model 3.

The principal goal in this analysis was to find out whether the exclusion of the crossbreds would change or give a clearer picture for interpretation of the other results. Table 19 shows the results from the analysis of variance. The R^2 value was .71. As in the previous analysis all main effects of breed group, year, season, lactation, age within lactation were highly significant. The difference was in the number of two-way interactions that were significant. The only two-way interactions significant were breed group by year ($P < .001$), year by season ($P < .05$), year by lactation

FIGURE 2. EQUATION FOR PREDICTION OF MILK YIELD USING LINEAR AND QUADRATIC PARAMETERS FROM REGRESSION ON LACTATION LENGTH ADJUSTED FOR THE OTHER EFFECTS IN MODEL 3.

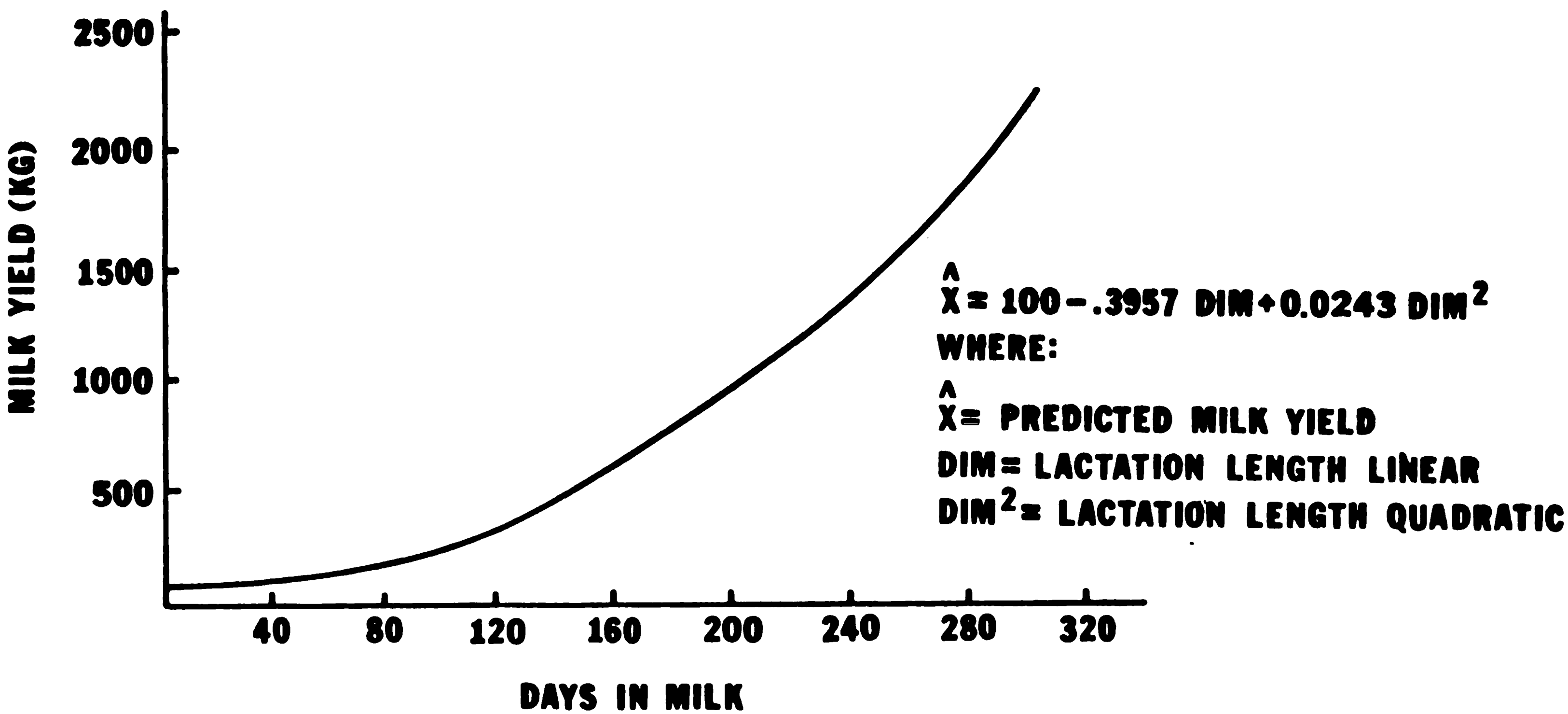


Table 19.--Model 3: Mean squares (MS), degrees of freedom (DF), F-ratio (F), and tests of significance using purebred Zebu data.

Effects	DF	MS	F
Breed Group (B)	2	5,780,513	23.21****
Year (Y)	3	51,226,168	205.67****
Season (S)	1	16,124,608	64.74****
Lactation (L)	8	6,393,881	25.67****
Age within Lactation ($A_{(1)}$)	19	3,639,411	14.61****
BY	6	7,252,760	29.12****
BL	16	298,306	1.20
$BA_{(1)}$	29	276,386	1.11
YS	3	850,860	3.42**
YL	24	733,830	2.95****
$YA_{(1)}$	40	434,121	1.74***
$SA_{(1)}$	15	171,070	0.69
Lactation Length: Linear (DIM)	1	393,937	1.58
Lactation Length: Quadratic (DIM^2)	1	131,148,561	526.56****
Error	7,058	249,066	

****P < .001. ***P < .01.

**P < .05. *P < .10.

(P < .001) and year by age within lactation (P < .01). The interactions of breed group by lactation, breed group by age within lactation which were significant in the previous analysis were not in this analysis (P < .10). The season by age within lactation remained non-significant (P < .10).

The constants for the main effects are presented in Table 20. Interpretation of the main effects of year, breed groups, season and lactation is similar to those appearing in Table 13. The differences between the breed groups remained important with Tharpakar outyielding Sahiwal and Red Sindhi by 233 kg and 185 kg, respectively. There was no systematic year trend, with the third year class showing the smallest yield and the first year class the highest. Yield seemed to increase with increasing lactation number up to the fourth lactation when it declined as previously. For the season constants, season one still showed lower yield constants than the second season again indicating the effect of the high humidity and high temperatures on the performance of the animals.

Constants for ages within lactation presented a slightly clearer picture (Table 21). The constants for the age class-3 (61-90 months) clearly indicated superiority over all the other age classes within each lactation. The higher yields (constants) for the age class-3 (61-90 months) clearly demonstrated that by the third age-class the Zebu purebreds had reached mature age for peak yield which has been suggested by the several researchers.

Table 20.--Least squares constants for breed group, year, season and lactation effects for purebred Zebus only.

Breed Group	Breed Constants[a] (weighted over Y, BY)	Year	Year Constants[a] (weighted over B, S, L, BY, YS, YL)	Lactation	Lactation constants[a] (weighted over Y, YL)	Season	Season Constants[a] (weighted over Y, YS)
Tharpakar	185	1930-1950	456	1	-329	1	-294
Sahiwal	-48	1951-1960	254	2	-159	0	0
Red Sindhi	0	1961-1970	-226	3	-29		
		1971-1975	0	4	585		
				5	552		
				6	-89		
				7	-340		
				8	-163		
				≥9	0		

[a]The constants are deviations from the effects indicated by zero values.
B = breed effect; Y = year effect; L = lactation effect; S = season effect; BY, YS, YL = two-way interactions.

Table 21.--Model 3: Least squares constants[a] for age within lactation for purebred Zebus only.

Age (months)	Lactation							
	1	2	3	4	5	6	7	≥9
≤30	-633(339)	-675(1)							
31-60	-669(756)	-643(1342)	-689(287)	639(12)					
61-90	-584(8)	-632(116)	-385(824)	-40(586)	1058(243)	-217(24)			
91-120		-731(1)	-152(15)	-95(132)	945(132)	-522(287)	-307(157)	1518(34)	
121-150				501(1)	457(14)	-266(70)	-187(147)	458(151)	242(111)
≥151						-142(1)	-250(7)	22(2)	0(130)

The figures in parenthesis ( ) indicate number of records.

[a]Each constant was computed by adding lactation constants to each age within lactation constant.

For the significant interactions, the constants showed no different interpretations from what was observed in the previous analysis. Also, the results on lactation length did not change. The partial regression coefficients were -.3653 and .0235 for the linear and quadratic terms, respectively, linear not significant ($P > .10$), but quadratic highly significant ($P < .001$).

Heritability ($\hat{h}^2$) and Repeatability ($\hat{r}$) Estimates

Model 3 was used to estimate variance components from which heritability and repeatability estimates were obtained for each breed group. Three alternative analyses were explored.

In Table 22 are results from "Analysis 1," considering sire, dam within sire and cow within dam. Results in Table 23 were obtained from "Analysis 2," considering sire and dam within sire, and results in Table 24 were obtained from "Analysis 3," considering sire and cow within sire.

The first concern was to examine differences in the estimates from the three analyses. Because of limited data on cross-breds, comparisons were made only on the purebred Zebus.

Comparison of estimates of sire variance and error variance indicated little difference in the three analyses. Sire component accounted for approximately 3%, 3%, and 8% of the total variation in milk yield, respectively for

Table 22.--Estimates of variance components, heritability ($\hat{h}^2$) and repeatability ($\hat{r}$) considering sire, dam within sire and cow within dam within sire (records without dam identification excluded).

Breed	Degrees of Freedom				Sire	Dam	Cow	Error	Total	Percent of Total Variance					
	Sire	Dam	Cow	Error	(σ^2_s)	(σ^2_d)	(σ^2_c)	(σ^2_e)	(σ^2_p)	σ^2_s	σ^2_d	σ^2_c	σ^2_e	$\hat{r}$	$\hat{h}^2$
Tharpakar	90	1014	94	2298	6,420	29,669	9,268	189,203	234,560	3	13	4	80	.19	.11
Sahiwal	43	466	138	980	5,674	42,990	1,434	157,690	207,788	3	21	1	76	.24	.11
Red Sindhi	33	246	63	419	15,704	*	17,158	180,218	213,080	7	0	8	85	.15	.29
Three-Way Cross	16	134	8	399	*	89,052	44,931	356,248	490,231	-	-	-	-	.27	*
Inter Se Cross	14	42	2	75	567	*	154,183	340,732	495,482	-	-	-	-	.31	.00
3/4-Brown Swiss	10	45	2	25	14,271	*	849,963	318,527	1,182,761	-	-	-	-	.73	.05

*Negative estimates (assumed a value of zero).

Table 23.--Estimates of variance components and heritability ($\hat{h}^2$) considering sire and dam within sire (records without dam identification excluded).

Breed	Degrees of Freedom				Sire (σ^2_s)	Dam (σ^2_d)	Error (σ^2_e)	Total (σ^2_p)	Percent of Total Variance			$\hat{h}^2$
	Total	Sire	Dam	Error					σ^2_s	σ^2_d	σ^2_e	
Tharpakar	3,595	90	1,014	2,392	6,420	38,096	190,066	234,582	3	16	81	.11 ± .04
Sahiwal	1,697	43	466	1,118	5,678	44,126	157,997	207,801	3	21	76	.11 ± .06
Red Sindhi	827	33	246	482	15,820	5,602	184,262	205,684	8	3	89	.31 ± .12
Three-way Cross	588	16	134	407	*	132,213	358,032	490,245	-	-	-	*
Inter Se Cross	151	14	42	77	229	37,168	352,747	390,144	-	-	-	.00 ± .21
3/4-Brown Swiss	98	10	45	27	18,157	123,784	425,563	567,504	-	-	-	.13 ± .32

*Negative estimates (assumed a value of zero).

Table 24.--Estimates of variance components, heritability ($\hat{h}^2$) and repeatability ($\hat{r}$) considering sire and cow within sire (records without dam identification excluded).

Breed	Degrees of Freedom				Sire	Cow	Error	Total	Percent of Variance			$\hat{h}^2$	$\hat{r}$
	Total	Sire	Cow	Error	(σ_s^2)	(σ_c^2)	(σ_e^2)	(σ_p^2)	σ_s^2	σ_c^2	σ_e^2		
Tharpakar	3,595	90	1,062	2,344	6,525	38,453	189,621	234,599	3	16	81	.11 ± .04	.20 ± .05
Sahiwal	1,697	43	597	987	6,180	43,371	158,264	207,815	3	21	76	.12 ± .06	.24 ± .07
Red Sindhi	827	33	307	421	15,681	9,206	180,560	205,384	8	4	88	.30 ± .11	.12 ± .09
Three-way Cross	588	16	138	403	*	132,543	357,509	490,052	-	-		*	.27 ± .16
Inter Se Cross	151	14	44	75	*	49,458	340,732	390,190	-	-		*	.13 ± .25
3/4-Brown Swiss	98	10	46	26	3,509	236,547	306,499	546,555	-	-		.03 ± .34	.44 ± .19

*Negative estimates (assumed a value of zero).

Tharpakar, Sahiwal and Red Sindhi breed groups. The error variance accounted for approximately 80%, 76%, and 88% of the total variation, respectively.

The sire variance component of 3% is in the lower range of estimates (3 to 10%) generally reported (Hooven et al., 1968; Camoens et al., 1976; McDowell et al., 1976). The error or unexplained variance of 76% to 88% was much higher than the estimates obtained with temperate breeds (Camoens et al., 1976; Hooven et al., 1968; McDowell et al., 1976; Van Vleck et al., 1961). Also estimates of cow component of variance (less than 25%) obtained in this study were lower than the percentages reported in literature.

The results from Analysis 1 for the two components of cow and dam (%) added together for each breed group were equivalent to the dam variance component (%) in Analysis 2 and to the cow component (%) in Analysis 3, again indicating the three analyses gave nearly identical results.

The estimated total phenotypic variations of yield for Tharpakar, Sahiwal and Red Sindhi were approximately 234,600 $kg.^2$, 207,800 $kg.^2$, and 205,300 $kg.^2$, respectively, much lower than reported estimates for temperate breeds. Van Vleck et al. (1961) reported 1,400,00 kg^2; Hickman and Henderson (1955) 1,800,000 kg^2; Camoens et al. (1976) 3,399,000 kg^2 and McDowell et al. (1976) 1,344,364 kg^2. The large temperate-tropical differences in variation correspond to large differences in mean yields. The crossbreds consistently showed higher total variation than the purebred

Zebus. The total variation for the Three-way cross, the Inter Se Cross and the 3/4-Brown Swiss were approximately 490,000 kg^2, 390,000 kg^2, and 546,000 kg^2, respectively. The higher total variation for the crosses might be explained by the higher mean milk yield shown by the crossbreds.

Van Vleck (1966) indicated that variance increased with increase in mean milk yield, therefore, the low variance estimates obtained in this study could be a function of the low production.

Estimates of heritability and repeatability from the three analyses also are presented in Tables 22, 23, and 24. The results indicate heritability of milk yield is higher for Red Sindhi ($\hat{h}^2 = .31$) than for Tharpakar ($\hat{h}^2 = .11$) and Sahiwal ($\hat{h}^2 = .12$). However, it is important to note that the Red Sindhi had relatively fewer records. The values obtained are in the range of values .05 to .64 previously reported for various breeds. The repeatability estimates were much lower than the values reported in literature which range from .37 to .55 (Table 2). In the present study the repeatabilities for Tharpakar, Sahiwal and Red Sindhi were, respectively, .20, .24, and .12. The reason for the low repeatability estimates in this study is not clear. Contributing factors might have been inferior environment and poor management practices which prevented genetic differences and permanent environmental effects from being fully expressed. Also, to the extent that poor management may have resulted in flawed recording, the error component may have been inflated.

Because the three analyses gave virtually identical estimates, in an effort to use as many records as possible, "Analysis 3" was repeated to use all records with or without dam identification. A total of 8,293 records were available. In Table 25 are the estimates of variance components, heritability and repeatability. The most surprising outcomes from the analysis were the large increases in estimates of variance components and heritability, not explainable solely by the increase in number of records. Table 26 shows the changes in the magnitude of the variance components (from the original estimates using 6,962 records).

Although most of the variance estimates increased, the most noteable increases were in the sire components of some breeds. For the Tharpakar, Sahiwal and Red Sindhi breeds, the changes were 64%, 56%, and -24%, respectively, of the original values. The reason for the large increase in the estimates is unclear, but a speculation is that incorrect data recording such as misidentification might have contributed to the large increases. Also, sires used on unidentified dams may have been grossly inferior.

Even if the heritability estimates seem high, they were well within the range reported in the literature. The estimates of heritability obtained by using the 8,293 records for Tharpakar, Sahiwal and Red Sindhi were .29, .22, and .25, respectively. The estimates of repeatability again were

Table 25.--Estimates of variance components and heritability ($\hat{h}^2$) considering sire and cow within sire (records without dam identification included).

Breed	Degrees of Freedom				Sire (σ^2_s)	Cow (σ^2_c)	Error (σ^2_e)	Total (σ^2_p)	Percent of Total Variance			$\hat{h}^2$	$\hat{r}$
	Total	Sire	Cow	Error					σ^2_s	σ^2_c	σ^2_e		
Tharpakar	4,038	96	1,157	2,684	18,306	37,078	196,895	252,279	7	15	78	.29 ± .06	.22 ± .05
Sahiwal	2,397	65	724	1,518	13,954	53,770	185,638	253,362	6	21	73	.22 ± .07	.27 ± .06
Red Sindhi	1,015	39	341	526	12,629	16,094	171,547	200,270	6	8	86	.25 ± .10	.14 ± .09
Three-way Cross	588	16	138	403	*	132,543	357,509	490,052	-	-	-	*	.27 ± .16
Inter Se Cross	151	14	44	75	*	49,458	340,732	390,190	-	-	-	*	.13 ± .25
3/4-Brown Swiss	98	10	46	26	3,509	236,547	306,499	546,555	-	-	-	.03 ± .34	.44 ± .19

*Negative estimates (assumed a value of zero).

Table 26.--Changes (Δ) in estimates of variance components using analysis considering sire and cow within sire when records without dam identification were included.

Breed	Sire $\Delta\sigma^2_s$	Cow $\Delta\sigma^2_c$	Error $\Delta\sigma^2_e$	Total $\Delta\sigma^2_p$	$\%\Delta\sigma^2_s$	$\%\Delta\sigma^2_c$	$\%\Delta\sigma^2_e$	$\%\Delta\sigma^2_p$	$\%(\Delta\sigma^2_s/\Delta\sigma^2_p)$
Tharpakar	11,780	-1,375	7,274	17,680	64	-4	4	7	67
Sahiwal	7,774	10,399	27,374	45,547	56	19	15	18	17
Red Sindhi	-2,989	6,888	-9,013	-5,114	-24	43	-5	-3	-58

lower than values reported in literature. The estimates for Tharpakar, Sahiwal and Red Sindhi were, respectively, .22, .27, and .14.

Estimates of variance components and heritability for each breed group within each lactation also were determined using Model 3. The estimates obtained by using the 6,962 records with dam identification are shown in Table 27. Due to the small numbers of records after the fourth lactation, estimation was not attempted for later lactations.

Many estimates of variance components increased with lactation number (Table 27). However, estimates of heritability did not suggest any major differences across four lactations (considering the large standard errors). For instance, from analyses of Tharpakar cattle with 500 or more records for each lactation the heritability estimates ranged between .10 and .20, with standard errors between .06 and .13. Therefore, heritabilities from this population appear to be very similar for the four lactations, a result in accord with reports by Barr and Van Vleck (1963) and Van Vleck and Bradford (1966).

The estimates obtained using the 8,293 records (with or without dam identification) showed a slightly different picture (Table 28). The estimates of variance components and heritabilities were much higher than those obtained using the 6,962 records with dam identified. For the analyses with 500 or more records the heritability estimates

Table 27.--Estimates of variance components and heritability ($\hat{h}^2$) for each breed group within lactation, considering sire (records without dam identification excluded).

Breed	Lactation	Degrees of Freedom			Sire (σ_s^2)	Error (σ_e^2)	Total (σ_p^2)	$\hat{h}^2$
		Total	Sire	Error				
Tharpakar	1	1050	82	953	4,911	185,374	190,285	.10±.07
	2	772	75	679	8,584	216,586	225,170	.15±.09
	3	535	70	446	12,596	237,870	250,466	.20±.12
	4	378	65	295	131	300,869	301,000	.00±.14
Sahiwal	1	508	41	453	2,492	196,416	198,908	.05±.09
	2	356	34	310	12,712	201,295	214,007	.24±.15
	3	258	30	214	7,329	218,914	226,243	.13±.16
	4	195	26	155	*	220,903	220,903	*
Red Sindhi	1	274	32	228	1,444	169,098	170,542	.03±.14
	2	182	25	145	9,255	196,706	205,961	.18±.22
	3	124	20	91	44,136	213,252	257,388	.69±.36
	4	78	17	49	43,007	183,243	226,250	.76±.51
Three-Way Cross	1	148	15	124	51,586	313,040	364,626	.57
	2	112	14	93	*	344,155	344,155	*

Table 27.--Continued.

Breed	Lactation	Degrees of Freedom			Sire (σ_s^2)	Error (σ_e^2)	Total (σ_p^2)	$\hat{h}^2$
		Total	Sire	Error				
Inter Se Cross	1	54	14	32	6,296	341,516	347,812	.07
	2	46	12	27	*	487,519	487,519	*
3/4-Brown Swiss	1	54	10	37	*	664,905	664,905	*
	2	28	6	8	*	1,339,700	1,339,700	*

*Negative estimates (assumed a value of zero).

Table 28.--Estimates of variance components and heritability ($\hat{h}^2$) for each breed group within lactation, considering sire (records without dam identification included).

Breed	Lactation	Degrees of Freedom			Sire	Error	Total	$\hat{h}^2$
		Total	Sire	Error	(σ_s^2)	(σ_e^2)	(σ_p^2)	
Tharpakar	1	1146	92	1039	26,005	191,883	217,888	.48±.10
	2	852	85	749	30,486	217,089	247,575	.49±.12
	3	599	78	502	28,901	236,436	265,337	.44±.14
	4	431	76	336	15,570	297,454	313,024	.20±.15
Sahiwal	1	648	63	567	12,803	214,972	227,775	.22±.11
	2	493	57	421	20,378	234,495	254,873	.32±.14
	3	373	52	302	13,569	272,467	286,033	.19±.15
	4	291	47	228	9,210	272,434	291,644	.13±.17
Red Sindhi	1	309	38	256	381	172,019	172,400	.01±.13
	2	216	30	173	1,547	194,173	195,720	.03±.17
	3	154	29	111	40,172	212,164	252,336	.64±.32
	4	102	25	65	38,148	159,382	197,530	.77±.44
Three-Way Cross	1	148	15	124	51,586	313,040	364,626	.57
	2	112	14	93	*	344,155	344,155	*

Table 28.--Continued.

Breed	Lactation	Degrees of Freedom			Sire	Error	Total	$\hat{h}^2$
		Total	Sire	Error	(σ_s^2)	(σ_e^2)	(σ_p^2)	
Inter Se Cross	1	54	14	32	6,296	341,516	347,812	.07
	2	46	12	27	*	487,519	487,519	*
3/4-Brown Swiss	1	54	10	37	*	644,905	644,905	*
	2	28	6	8	*	1,339,700	1,339,700	*

*Negative estimates (assumed a value of zero).

ranged between .44 to .49, and .22 to .32 for Tharpakar and Sahiwal, respectively. Again, estimates differed little from lactation to lactation.

SUMMARY AND CONCLUSIONS

This study was conducted to evaluate environmental and genetic factors affecting milk production of three purebred Zebu breeds (Tharpakar, Sahiwal, Red Sindhi) and three crosses with Brown Swiss (Three-way Cross, Inter Se Cross, 3/4-Brown Swiss) under similar tropical environment at Karnal, India. Three objectives were pursued:

1. To determine the effect of year, season, lactation, age and their two-way interactions on milk production of the six breed groups for milk production.
2. To assess the relationships of calving interval and lactation length with milk yield.
3. To obtain estimates of heritability and repeatability of milk yield.

The data consisted of 9,086 lactation records of 2,058 cows that calved in the period 1930-1975. Statistical Analysis System (SAS) by Barr et al. (1979) was used in all analyses.

The results of analyses of variance indicated that main effects of year, breed group, season, lactation and age within lactation were highly significant ($P < .001$). The two-way interactions of year by breed group, breed group by lactation, breed group by age within lactation, year by season, year by lactation, year by age within lactation and season by age within lactation also were important for milk yield. However, when the analysis was performed using only the data from purebred Zebus, breed group by lactation and breed group by age within lactation were not significant ($P > .10$) suggesting a consistent pattern of response of the purebred Zebus for milk yield across all lactations and age groups.

Tharpakar cows were superior to Sahiwal and Red Sindhi cows for milk yield, outyielding Sahiwal and Red Sindhi by 233 kg and 204 kg, respectively. Difference between Sahiwal and Red Sindhi was only 28 kg, indicating equal potential for milk yield by the two Zebu breeds. The three-way cross was superior to the other crosses, suggesting that 50% Brown Swiss inheritance was the best for milk yield. However, results on the crosses should be interpreted with caution because they were based on limited data.

All the crosses outyielded the purebred Zebus by 450 kg. or more. Such large differences may reflect better genetic potential of the crosses for milk production. However, one cannot be sure because the crosses were favorably treated.

Considering the purebred Zebus only, cows that calved at 61-90 months of age outyielded all other age groups within each lactation. It was, therefore, concluded that age 61-90 months was the mature age for peak yield for the purebred Zebus.

Although age was very important in this study for milk yield, factors for age adjustments were not derived. Like other studies on tropical cattle, deriving age factors from such limited data is not justifiable because the factors so derived are reliable only when applied to the original data. In studies involving "small" samples, typically, the best way to take care of age effect is to incorporate it in the model instead of developing age-factors for purposes of prior adjustment.

The relationships of calving interval and lactation length with milk yield were determined by fitting different combinations of linear and quadratic terms to determine the amount of variation in milk yield explained, while holding other fixed effects constant.

Fixed effects and their interactions accounted for 45% of the total variation in milk yield. A combination of linear, quadratic and cross product terms of calving interval and lactation length accounted for 29% of the total variation in milk yield. Lactation length alone accounted for 28% and calving interval alone accounted for 8% of total variation in milk yield. Since lactation length along accounted for almost the same variation in milk yield as a combination of lactation length and calving interval, it was concluded that calving interval was not important in presence of lactation length.

Estimates of heritability and repeatability were obtained for each breed group from the variance components for sires and cows. Estimates from data with both sire and dam identified (6,963 records) were .11, .12, and .30 for Tharpakar, Sahiwal and Red Sindhi, respectively, whereas estimates from data with or without dam identified (8,293 records) were .29, .22, and .25 for Tharpakar, Sahiwal and Red Sindhi, respectively. The reason for the discrepancies in the estimates from the two sets of data was unclear. The speculation is that records without dam identification might involve some recording error, such as misidentification, or the sires mated to those dams may have been collectively inferior. Similarly, the estimates of repeatability obtained by using 6,962 records with dam identification were .20, .24, and .12 for Tharpakar, Sahiwal and Red Sindhi, respectively. Using 8,293 records the estimates of repeatability were .22, .27, and .14 for Tharpakar, Sahiwal and Red Sindhi, respectively. These estimates were much lower than those reported in literature. Of noteworthy particularly is the low cow variance, which accounted for less than 25% of the total phenotypic variance for milk yield in the present study.

Estimates of heritability within each breed group within lactation showed similar discrepancies for the two data sets. The estimates of heritability obtained by using 6,962 records for first, second, and third lactations were, respectively, .10, .15, and .20 for Tharpakar; .05, .24, and .13 for Sahiwal; and .03, .18, and .69 for Red Sindhi.

Estimates obtained by using 8,293 records for first, second, and third lactations were, respectively, .48, .49, and .44 for Tharpakar; .22, .32, and .19 for Sahiwal; and .01, .03, and .64 for Red Sindhi. Considering only estimates obtained from 500 or more records, there was little change in estimates from lactation to lactation.

BIBLIOGRAPHY

BIBLIOGRAPHY

Alim, K. A. 1960. Reproductive rates and milk yield of Kenana cattle in Sudan. J. Agr. Sci. 55: 183-188.

Alim, K. A. 1962. Environmental and genetic factors affecting milk production of Butana cattle in the Sudan. J. Dairy Sci. 45: 242-247.

Amble, V. N., & J. P. Jain. 1967. Comparative performance of different grades of crossbred cows on military farms in India. J. Dairy Sci. 50: 1695-1701.

Amble, V. N., K. S. Krishnan, & J. S. Srivastava. 1958. Statistical studies of breeding data of Indian herds of dairy cattle. I. Red Sindhi herds at Hosur and Bangalore. Indian J. Vet. Sci. 28: 33-82.

Ansell, R. H. 1976. Maintaining European dairy cattle in the Near East. World Animal Review. 20: 1-7.

Armour, J., R. P. Lee, & J. G. Ross. 1961. Observation on a crossbreeding experiment with cattle in Nigeria. Trop. Agri. 38: 319-323.

Asker, A. A., A. A. El-Itriby, & L. H. Bedeir. 1958. Environmental factors affecting milk production in Egyptian cows. Indian J. Dairy Sci. 11: 113-124.

Asker, A. A., K. H. Juma, & S. A. Kasir. 1966. Factors affecting milk production in crossbred cattle in Iraq. Ann. Agric. Sci. Univ. A' in Shams. 10: 47-63.

Barr, A. J., J. H. Goodnight, J. Sall, & J. Selwig. 1979. A User's Guide to SAS 79. Sparks Press, Raleigh, N.C.

Barr, G. R., & L. D. Van Vleck. 1963. Regressions and correlations among consecutive and nonconsecutive lactation records. J. Dairy Sci. 46: 628.

Bereskin, B., & R. W. Touchberry. 1966. Crossbreeding dairy cattle III. First Lactation production. J. Dairy Sci. 49: 659-667.

Bhasin, N. R., & R. N. Desai. 1967. Influence of crossbreeding on the performance of Indian cattle. Indian Vet. J. 44: 405-412.

Bhatnagar, D. S., M. Gurnani, & D. Sundaresan. 1970. Performance of Brown Swiss bulls on the crossbreds at National Dairy Research Institute (NDRI), Karnal, India. Annual Report, NDRI, Karnal, India. 63-67.

Bhatnagar, D. S., M. Gurnani, M. R. Bhosrekar, & R. Nagarcenkar. 1971. Crossbreeding of Zebu (Red Sindhi and Sahiwal) with Brown Swiss. Annual Report, National Dairy Research Institute (NDRI), Karnal, India. 39-40.

Blanchard, R. D., A. E. Freeman, & P. W. Spike. 1966. Variation in lactation yield. J. Dairy Sci. 49: 953-956.

Bradford, G. E., & L. D. Van Vleck. 1964. Heritability in relation to selection differential in cattle. Genetics. 49: 819-827.

Branton, C., R. E. McDowell, & M. A. Brown. 1966. Zebu-European crossbreeding as a basis of dairy cattle improvement in the U.S.A. South Coop. Sev. Bull. 114. Louisiana Agr. Exp. Sta., Baton.

Branton, G., G. Rios, D. L. Evans, B. R. Farthing, & K. L. Koonce. 1974. Genotype-climatic and other interaction effects for productive responses in Holsteins. J. Dairy Sci. 57: 833-841.

Butcher, D. F., & A. F. Freeman. 1968. Heritabilities and repeatabilities of milk and milk fat production by lactations. J. Dairy Sci. 51: 1387-1391.

Butcher, D. F., & A. F. Freeman. 1969. Estimation of heritability and repeatability of milk and milk fat production with selection effects removed. J. Dairy Sci. 52: 1259-1267.

Camoens, J. K., R. E. McDowell, L. D. Van Vleck, & J. D. Rivera Anaya. 1976. Holsteins in Puerto Rico: I. Influence of herd, year, age, and season on performance. J. Agric. Univ. of Puerto Rico. 60: 526-539.

Camoens, J. K., R. E. McDowell, L. D. Van Vleck, & J. D. Rivera Anaya. 1976. Holsteins in Puerto Rico: II. Influence of lactation length, days dry, days open, and calving interval on production traits. J. Agric. Univ. of Puerto Rico. 60: 540-550.

Camoens, J. K., R. E. McDowell, L. D. Van Vleck, & J. D. Rivera Anaya. 1976. Holsteins in Puerto Rico: III. Components of variance associated with production and estimates of heritability. J. Agric. Univ. of Puerto Rico. 60: 551-558.

Chhabra, A. D., R. M. Acharya, & D. S. Sundaresan. 1970. Effect of age and body weight at freshening on milk production in Hariana cattle. I. Relative importance of age and body weight of freshening on milk production in Hariana cattle. Indian J. Dairy Sci. 23: 1-6.

Dickerson, G. E., & A. B. Chapman. 1939. The effect of age and dry period on production at different levels of producing ability. Proc. Am. Soc. Anim. Prod., 32nd. Ann. Meet. 73-76.

Duran, C. V. 1976. Genetic and environmental parameters in the Lucerna herd of cattle in Colombia. M. S. Thesis, North Carolina State University, Raleigh.

Eltriby, A. A., & A. A. Asker. 1958. Some production characteristics of Native cattle, Friesian, Shorthorn and their crosses in Egypt. Emp. J. Expt. Agric. 26: 314-322.

Farthing, B. R., & J. R. Steele. 1967. Biased estimates of heritability resulting from incorrect methods of estimating components of variance. J. Dairy Sci. 50: 105-107.

Fimland, E. A., R. Bar-Anan, & W. R. Harvey. 1972. Studies on dairy records from Israeli-Friesian cattle. I. Influence of some environmental effects. Acta. Agric. Scand. 22: 34-48.

Fosgate, O. T., & H. K. Welch. 1960. Effect of certain environmental factors upon milk production in Georgia. J. Dairy Sci. 43: 442.

Freeman, A. E. 1973. Age adjustment of production records: History and basic problems. J. Dairy Sci. 56: 941-946.

Freeman, A. E. 1979. Breeding structure of the dairy industry in the U.S.A. Holstein-Friesian World. May 25: 206-209.

Frick, G. E., A. I. Mann, & S. Johnson. 1947. The relation of season of freshening to milk production. J. Dairy Sci. 30: 631-640.

Gacula, M. C., Jr., S. N. Gaunt, & R. A. Damon, Jr. 1968. Genetic and environmental parameters of milk constituents for five breeds. I. Effects of herd, year, season, and age of cow. J. Dairy Sci. 51: 428-437.

Galukande, E. B., P. Mahadevan, & J. G. Black. 1962. Milk production in East African Zebu cattle. Anim. Prod. 4: 329-336.

Gahlon, M. S., & D. D. Malik. 1967. Effect and relationship of dry period with economic milk traits of Sahiwal cows. Indian J. Dairy Sci. 20: 161-164.

Gill, J. L. 1978. Design and Analysis of Experiments in the Animal and Medical Sciences. Volume 1. The Iowa State Univ. Press, Ames, Iowa.

Gill, J. L. 1978. Design and Analysis of Experiments in the Animal and Medical Sciences. Volume 3, Appendices. The Iowa State Univ. Press, Ames, Iowa.

Gill, J. L., & E. L. Jensen. 1968. Probability of obtaining negative estimates of heritability. Biometrics 24: 517-526.

Gopal, D., & D. S. Bhatnagar. 1969. Effect of age at first calving and first lactation yield on life time production of Sahiwal cattle. Annual report, National Dairy Research Institute (NDRI), Karnal, India. 57-58.

Gowen, J. N. 1920. Studies on milk secretion. V. On the variation and correlations of milk secretion with age in Jersey cattle. Genetics 5: 249-324.

Gravir, K., & C. G. Hickman. 1966. Importance of lactation number, age and season of calving for dairy cattle breed improvement. Canadian Dept. Agr. Publ. 1239.

Gurnani, M., & D. S. Bhatnagar. 1974. Association of preceeding dry period and lactation yield in crossbred cows. Indian J. Dairy Sci. 27: 130-133.

Gurnani, M., D. S. Bhatnagar, & D. Sundaresan. 1976. Estimates of heritability, genetic and phenotypic correlation coefficients amongst economic traits in Tharpakar and Sahiwal cows. Indian J. Dairy Sci. 29: 233-235.

Hardie, A. R., E. L. Jensen, & W. J. Tyler. 1972. Genetic, phenotypic, and economic relationships among yields of milk and its components. J. Dairy Sci. 55: 690.

Hayman, R. H. 1974. The development of the Australian Milking Zebu. Wld. Anim. Rev. (FAO) 11: 31-35.

Henderson, C. R. 1949. Estimation of changes in herd environment. J. Dairy Sci. 32: 706.

Hickman, C. G. 1962. Effects of level of herd environment I. Relationship between yield and age. J. Dairy Sci. 45: 861-864.

Hickman, C. G., & C. R. Henderson. 1955. Components of the relationship between levels of production and rate of maturity of dairy cattle. J. Dairy Sci. 38: 883-890.

Hillers, J. K., & D. O. Everson. 1972. Effects of various discrete distributions on magnitude of heritability. J. Dairy Sci. 55: 682.

Hollon, B. F., C. Branton, & R. E. McDowell, 1969. Performance of Holstein and crossbred dairy cattle in Louisiana. I. First lactation production. J. Dairy Sci. 52: 498-506.

Hooven, N. W., Jr., R. H. Miller, & R. D. Plowman. 1968. Genetic and environmental relationships among efficiency, yield, consumption, and weight of Holstein cows. J. Dairy Sci. 51: 1409-1419.

Jha, B. N., & S. C. Biswas. 1964. Effect of the length of dry period on the successive lactation yield in Tharpakar cows. Indian Vet. J. 41: 404-409.

Johansson, I., & A. Hansson. 1940. Causes of variation in milk and butterfat yield of dairy cows. Kgl. Lantbruksakad Tidsrk. Nr. 6 1/2: 1-127.

Johansson, I., & J. Rendel. 1968. Genetics and Animal Breeding. W. H. Freeman and Co., San Francisco.

Johar, K. S., & C. M. Taylor. 1970. Variation in calving interval in Tharpakar, Hariana and Mahi cows. Indian Vet. J. 74: 223-227.

Johnston, J. E., R. E. McDowell, R. R. Shrode, & J. E. Legates. 1960. Summer climate and its effects on dairy cattle in the southern region. 1960. South. Coop. Serv. Bull. 240.

Kartha, K. P. R. 1934. A study of the data of milk yields of various types of cattle obtained from the records of the government military farms. Indian J. Vet. Sci. 4: 116-162.

Kendall, M. G., & A. Stuart. 1969. The Advanced Theory of Statistics. Vol. 1. Distribution Theory, 3d ed. London: Griffin.

Kendrick, J. F. 1953. Standardizing dairy-herd-improvement association records in proving sires. U.S. Dept. Agric. Res. Serv. BDI-INF. 162.

Klein, J. W., & T. E. Woodward. 1943. Influence of length of dry period upon the quantity of milk produced in the subsequent lactation. J. Dairy Sci. 26: 705-713.

Kohli, M. L. 1962. Study of some economic characters in the Hariana herd at Hissar. Animal Breeding Abstracts. 30: 3.

Kohli, M. L., & K. R. Suri. 1960. Breeding season in Hariana cattle. Indian J. Vet Sci. 30: 219-223.

Kushwaha, N. S. 1964. Heritability and repeatability of calving interval in Sahiwal dairy cattle. Kanpur Agric. Coll. J. 24: 23-26.

Kushwaha, N. S., & Misra. 1962. Study of some economic characters in dairy cattle as influenced by age at first calving. Indian J. Dairy Sci. 22: 81-84.

Lecky, T. P. 1962. The development of Jamaica Hope as tropical--adapted dairy breed. U.N. Conf. on the application of science and technology for the benefit of the less developed areas. Agenda Item C.5.2: 18 pp.

Lee, A. J. 1974. Month, year, herd effects on age adjustments of first lactation milk yield. J. Dairy Sci. 57: 332-338.

Lee, J. E., O. T. Fosgate, & J. L. Carmon. 1961. Some effects of certain environmental and inherited influence upon milk and fat production in dairy cattle. J. Dairy Sci. 44: 296-299.

Lee, J. J., & C. G. Hickman. 1967. Yield-age regression in age corrected records. J. Dairy Sci. 50: 987.

Lindström, U. B., & H. Solbu. 1977. Studies on milk records from Kenya. II. Systematic effects on production traits. Z. Tierzuchtg. Zuchtgsbiol. 94: 33-42.

Lush, J. L. 1940. Intra-sire correlations or regressions of offspring on dam as a method of estimating heritability of characteristics. Proc. Am. Soc. Anim. Prod. 33rd Ann. Meet: 293-301.

Lush, J. L., & R. R. Shrode. 1950. Changes in milk production with age and milking frequency. J. Dairy Sci. 33: 338-358.

Lytton, V. H., & J. E. Legates. 1966. Sire by herd environment interaction for milk production. J. Dairy Sci. 49: 874-878.

Mahadevan, P. 1953. The general life and production statistics of the Sinhala cattle of Ceylon. Emp. J. Exp. Agric. 21: 55-60.

Mahadevan, P. 1954. Repeatability and heritability of milk yield in crosses between Indian and European breeds of dairy cattle. Emp. J. Expt. Agric. 22: 93-96.

Mahadevan, P. 1955. Population and production characteristics of Red Sindhi cattle in Ceylon. J. Dairy Sci. 38: 1231-1241.

Mahadevan, P. 1956. Variation in performance of European dairy cattle in Ceylon. J. Agric. Sci. 48: 164-170.

Mahadevan, P. 1966. Breeding for milk production in tropical cattle. Commonwealth Agr. Bur. Farnham Royal, Bucks. England.

Mahadevan, P., & H. G. Hutchison. 1964. The performance of crosses of Bos taurus and Bos indicus cattle for milk production in the coastal region of Tanzania. Anim. Prod. 6: 331-336.

Mahadevan, P., & H. J. S. Marples. 1961. An analysis of the Entebbe herd of Nganda cattle in Uganda. Animal Prod. 3: 39-39.

Mao, I. L., E. B. Burnside, J. W. Wilton, & M. G. Freeman. 1974. Age-month adjustment of Canadian dairy production records. Can. J. Anim. Sci. 54: 533-541.

Markos, H. G., & R. W. Touchberry. 1970. Distribution of estimates of heritability and genetic correlation from random samples from a large population of herd improvement registry records. J. Dairy Sci. 53: 656.

Mason, I. L. 1974. Maintaining crossbred populations of dairy cattle in the tropics. Wld Anim. Review (FAO). 11: 36-43.

McDaniel, B. T. 1973. Merits and problems of adjusting to other than mature age. J. Dairy Sci. 56: 959-967.

McDaniel, B. T., R. H. Miller, E. L. Corley, & R. D. Plowman. 1967. DHIA age adjustment factors for standardizing lactation to a mature basis. Dairy Herd Improvement Letter, ARS-44-188.

McDaniel, B. T., & E. L. Corley. 1966. Environmental influences on age correction factors. J. Dairy Sci. 49: 736.

McDowell, R. E. 1959. Adaptability and performance of cattle under the climatic conditions existing in the Southern United States. International Dairy Congress XVI, 1: 333-339.

McDowell, R. E. 1971. Feasibility of commercial dairying with cattle indigenous to the tropics. Cornell Int. Agric. Dev. Bull. 21, Cornell University (22 pp).

McDowell, R. E. 1972. Improvement of Livestock Production in Warm Climates. W. H. Freeman and Co., San Francisco, California.

McDowell, R. E., N. W. Hooven, & J. K. Camoens. 1976. Effect of climate on performance of Holsteins in first lactation. J. Dairy Sci. 59: 965-973.

McDowell, R. E., & B. T. McDaniel. 1968. Interbreed matings in dairy cattle. III. Economic aspects. J. Dairy Sci. 51: 1649-1658.

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

Miller, P. D. 1973. A recent study of age adjustment. J. Dairy Sci. 56: 952-958.

Miller, P. D., & R. C. Henderson. 1968. Seasonal age correction factors by maximum likelihood. J. Dairy Sci. 51: 958.

Miller R. H., W. R. Harvey, K. A. Tabler, B. T. McDaniel, & E. L. Corley. 1966. Maximum likelihood estimates of age effects. J. Dairy Sci. 49: 65-73.

Miller R. H., & N. W. Hooven. 1969. Factors affecting whole and part lactation milk yield and fat percentage in a herd of Holstein cattle. J. Dairy Sci. 52: 1588-1600.

Miller, P. D., W. E. Lentz, & C. R. Henderson. 1970. Joint influences of month and age at calving on milk yield of Holstein cows in Northern United States. J. Dairy Sci. 53: 351-357.

Miller R. H., B. T. McDaniel, & R. D. Plowman. 1968. Effects of errors in the age adjustment of first lactations. J. Dairy Sci. 51: 378-384.

Miller, P., L. D. Van Vleck, & C. R. Henderson. 1967. Relationship among herd life, milk production and calving interval. J. Dairy Sci. 50: 1283-1287.

Moulick, S. K., R. E. McDowell, L. D. Van Vleck, & H. Guha. 1972. Potential of Deshi cattle of India for dairy production. J. Dairy Sci. 55: 1148-1155.

Nagarcenkar, R. 1969. Progress of Jersey-Tharpakar crossbreeding project at the National Dairy Research Institute, Bangalore. New Delhi: Indian Council of Agricultural Research, pp. 96-100.

Nagpaul, P. K. 1971. Lactation yield as affected by month of calving, intercalving and dry period, order of lactation and lactation length in Tharpakar. Indian Council of Agric. Research, pp. 54-55.

Nagpaul, P. K., & D. S. Bhatnagar. 1971. Effect of age at first calving on milk production in Tharpakar cattle. Indian Vet. J. 48: 44-49.

Nagpaul, P. K., & D. S. Bhatnagar. 1972. Effect of preceeding dry period on lactation yield in Tharpakar cattle. Indian Vet. J. 49: 783-788.

Ngere, L. O., R. E. McDowell, S. Bhattacharya, & H. Guha. 1973. Factors influencing milk yield of Hariana cattle. J. Anim. Sci. 36: 457-465.

Norman, D. H. 1967. Genetic and environmental relationships between calving interval and milk and fat production of Holstein-Friesian cattle in Pennsylvania. Unpublished M.S. thesis, Pennsylvania State University. Pennsylvania.

Norman, H. D., B. T. McDaniel, & F. N. Dickinson. 1972. Conflicts between heritability estimates of mature equivalent and herdmate-deviation milk and fat. J. Dairy Sci. 55: 507-517.

Norton, H. W. 1932. Adjusting records for comparison. Holstein Friesian World 29: 799-804.

Olds, D., & D. M. Seath. 1953. Repeatability, heritability and effect of level of milk production on the occurrence of estrus after calving in dairy cattle. J. Anim. Sci. 12: 10-14.

Osman, A. H. 1970. Genetic analysis of daily milk yield in a dairy herd of Northern Sudan Zebu cattle. Trop. Agric., Tinidad 47(3): 205-213.

Pandey, H. S., & R. N. Desai. 1973. Suitability of crossbred cows for economic level of milk production. Indian Vet. J. 50: 409-412.

Pearson, L., R. K. Wangh, S. Bernado, F. M. Botero, & O. Acosta. 1968. Milking performance of Blanco Orejinegro and Jersey crossbred cattle. J. Agri. Sci., Campb. 70: 65-72.

Pirchner, F. 1964. Population Genetics in Animal Breeding. W. H. Freeman and Company, San Francisco.

Plum, M. 1935. Causes of differences in butterfat production of cows in Iowa testing associations. J. Dairy Sci. 18: 811-825.

Prasad, R. J., & R. B. Prasad. 1972. A study on genetic and phenotypic parameters of some economic characters of Tharpakar cattle. Indian Vet. J. 49: 1199-1206.

Ragab, M. T., A. A. Asker, & S. A. Hilmy. 1954. Milk yield in the Egyptian cow as affected by age, dry period and month of calving. Indian J. Dairy Sci. 7: 171-177.

Reddy, C. E., & D. S. Bhatnagar. 1971. Inheritance of breed efficiency and relationship of age of first calving and first lactation yield to breed efficiency in Tharpakar cattle. Indian J. Dairy Sci. 24: 197-201.

Rigor, T. V., & S. M. Nelmida. 1958. A preliminary report on the reproductive efficiency of crossbred Jersey and Red Sindhi cattle. Phillippine J. Animal Ind. 19: 63-67.

Rincon, E. J. 1975. Additive genetic, heterozygotic and maternal effects on first lactation yields of purebred and crossbred dairy cattle. M.S. Thesis, North Carolina State University, Raleigh.

Ripley, R. L., W. L. Tucker, & H. H Voelher. 1970. Effects of days open on lactation production. J. Dairy Sci. 54: 654.

Robertson, A. 1950. A preliminary report on the herd of Fulani cattle at Shika, Nigeria. Conf. on the improvement of livestock under tropical conditions. Edn. Scot. 5 pp. (mimeo).

Robertson, A. 1977. The effect of selection on the estimation of genetic parameters. Z. Tiezuchtg, Zuchtgsbiol. 94: 131-135.

Sanders, H. G. 1928. The variation in milk yields caused by season of the year, service and dry period, and their elimination. Part III. Age. J. Agric. Sci. 18: 46-67.

Schaeffer, L. R., R. W. Everett, & C. R. Henderson. 1973. Lactation records adjusted for days open in sire evaluation. J. Dairy Sci. 56: 602-607.

Schaeffer, L. R., & C. R. Henderson. 1972. Effects of days dry and days open on Holstein milk production. J. Dairy Sci. 55: 107-112.

Searle, S. R. 1962. Age and herd effects on New Zealand Dairy cow records. J. Dairy Sci. 45: 82-85.

Searle, S. R. 1971. Linear Models. John Wiley and Sons, Inc., New York.

Searle, S. R., & C. R. Henderson. 1959. Establishing age-correction factors related to the level of herd production. J. Dairy Sci. 42: 824-835.

Searle, S. R., & C. R. Henderson. 1960. Judging the effectiveness of age correction factors. J. Dairy Sci. 43: 966-974.

Sharma, D. K., & V. B. Singh. 1974. Effect of the month of calving on milk yield, length of lactation and inter-calving period in cows and buffaloes. Indian J. Dairy Sci. 27: 127-129.

Sikka, L. C. 1931. Statistical studies of records of Indian dairy cattle. I. Standardization of lactation period milk records. Indian J. Vet. Sci. 1: 63-98.

Singh, K. P., & S. K. Choudhery. 1961. Influence of age at first calving on first lactation performance on dairy cattle. Indian J. Dairy Sci. 14: 95-101.

Singh, S. B., & R. N. Desai. 1961. Inheritance of some economic characters in Hariana cattle. III. Milk yield. Indian J. Dairy Sci. 14: 141-146.

Singh, S. B., & R. N. Desai. 1961. Inheritance of some economic characters in Hariana cattle. IV. Lactation period. Indian J. Dairy Sci. 14: 147-153.

Singh, S. B., & R. N. Desai. 1962. Inheritance of some economic characters in Hariana cattle. V. Dry period. Indian J. Dairy Sci. 15: 1-8.

Singh, S. B., R. N. Desai. 1962. Inheritance of some economic characters in Hariana cattle. VI. Calving Interval. Indian J. Dairy Sci. 15: 9-12.

Singh, S. B., & M. Dutt. 1963. Effect of the season of calving on milk production, lactation period and service period in Sahiwal cattle. Indian Vet. J. 40: 362-364.

Singh, D., & D. Sundaresan. 1969. Heritability of some economic characteris in Tharpakar cattle. J. Res. Punjab Agric. Univ. 6: 131-137.

Smith, C. 1962. Estimation of genetic changes in farm livestock using field records. Animal Prod. 4: 239-251.

Smith, J. W., & J. E. Legates. 1962. Relation of days open and days dry to lactation milk and fat yields. J. Dairy Sci. 45: 1142-1198.

Soof, M. S. A., & B. D. Singh. 1970. Inheritance of economic traits in Hariana cattle. Indian J. Anim. Sci. 40: 484-488.

Specht, L. W., & L. D. McGilliard. 1960. Rates of improvement by progeny testing in dairy herds of various sizes. J. Dairy Sci. 43: 63-75.

Stonaker, H. H., D. P. Agarwala, & D. Sundaresan. 1953. Production characteristics of crossbred, backcross and purebred Red Sindhi cattle in Gangetic Plain Region. J. Dairy Sci. 36: 678-687.

Sundaresan, D., S. N. Ray, & K. K. Iya. 1965. The performance of the dairy herd at the National Dairy Research Institute, Karnal. Indian J. Dairy Sci. 18: 34-44.

Syrstad, O. 1965. Studies of dairy herd records. III. Effect of age and season of calving. Acta. Agric. Scand. 15: 31-63.

Taneja, V. K., D. N. Bhat, & R. C. Garg. 1978. Estimates of heritability for economic traits in Sahiwal and Sahiwal Holstein crossbred Grades. Indian J. Dairy Sci. 31: 191-197.

Thomson, G. M., & A. E. Freeman. 1970. Environmental correlations in pedigree estimates of breeding value. J. Dairy Sci. 53: 1259-1265.

Tomers, S. P. S., B. P. Singh, H. S. Rai, & R. C. Sharma. 1974. Genetic aspects of age at first calving and first lactation milk yield in Sahiwal cows. Indian Vet. J. 51: 245-248.

Touchberry, R. W. 1970. A comparison of the general merits of purebred and crossbred dairy cattle resulting from twenty years (four generations) of crossbreeding. 19th Annual Session, National Poultry Breeders' Round table, Kansas, Missouri, U.S.A.

Turner, H. T., & S. S. Y. Young. 1969. Quantitative Genetics in Sheep Breeding. Cornell University Press, Ithaca, New York.

Van Vleck, L. D. 1966. Change in various components associated with milk records with time and increase in mean production J. Dairy Sci. 49: 36-40.

Van Vleck, L. D. 1966. Heritability estimates of milk production with different numbers of records per sire by herd subclass. J. Dairy Sci. 49: 53-55.

Van Vleck, L. D. 1966. Correlations among records of unrelated cows in the same herd and the same and different year-seasons. J. Dairy Sci. 49: 61-64.

Van Vleck, L. D., & G. E. Bradford. 1966. Genetic and maternal influences on the first three lactations of Holstein cows. J. Dairy Sci. 49: 45-52.

Van Vleck, L. D., L. H. Wadell, & C. R. Henderson. 1961. Components of variance associated with milk and fat records of artifically sired Holstein daughters. J. Anim. Sci. 20: 812-816.

Venkayya, D., & C. P. Anantakrishnan. 1956. Influence of age at first calving on milk yield, lactation length and calving interval. Indian J. Dairy Sci. 9: 164-172.