A FIELD DATA STUDY OF THE RELATIONSHIPS OF NUTRITIONAL PRACTICES TO MILK YIELD AND COMPOSITION AND THE ESTIMATION OF THEIR GENETIC PARAMETERS

By

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ABSTRACT

Master of Science

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Alan Kwai Wah Tong

A field data study of the relationships of nutritional practices to milk yield and composition and the estimation of their genetic parameters

A total of 17,259 Ayrshire and 139,720 Holstein 305-day lactation records constituted data for this study. The responses of yields of milk, fat and protein to net energy intake from silage, hay, pasture and concentrates were curvilinear and significant, but responses of percentage traits were apparently not affected by feeding levels. Higher silage to hay ratios and higher energy concentration had positive, while higher roughage to concentrate ratios had negative, significant ($P < 0.01$) effects on all yield traits and fat percent. Correcting records for feeding levels reduced repeatabilities of yield traits but had no effect on percentage traits. Genetic variability and heritability increased with levels of concentrate feeding for fat yield and percentage constituents. Repeatabilities increased with levels of concentrate feeding for all traits. Sire x herd interactions were higher in environments with higher levels of nutrition for yield traits.

RESUME

Matière de Science

Science Animale
(Reproduction)

Alan Kwai Wah Tong

Une étude basée sur des données du rapport entre des méthodes de nutrition et la production et composition du lait et aussi l'estimation de leurs paramètres génétiques

Un total de 17,259 records de production d'Ayrshire et de 139,720 d'Holstein étant depuis 305 jours en lactation a constitué des données pour cette étude. Les résultats de productions de lait, gras et protéine comparés à la consommation nette d'énergie provenant d'ensilage, de foin, de pâturage et de concentrés furent proportionnels et significtifs, mais les résultats de caractères en pourcentage ne furent pas apparemment affectés par les niveaux de nutrition. Une plus grande proportion d'ensilage que de foin et une plus grande concentration d'énergie furent positifs, par conséquent une plus grande proportion de fourrage que de concentrés furent négatifs, présentant des effects significatifs ($P < 0.01$) sur tous caractères productifs et pourcentage de gras. La rectification de records pour les niveaux de nutrition réduit les répétabilités de caractères productifs, mais n'affecte pas les caractères en pourcentage. La variation génétique et l'héritabilité ont augmenté avec des niveaux de nutrition de concentrés pour la production de gras et pour les éléments en pourcentage. Les répétabilités on augmenté avec des niveaux de nutrition de concentrés pour tous les caractères. Les changements de composant père x troupeau furent plus élevés dans les effects du milieu avec de plus hauts niveaux de nutrition pour les caractères productifs.

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I. INTRODUCTION

Feed is one of the major dairy inputs accounting for 45 to 60% of the cost of milk production. Its cost in dairy rations can be minimized either by reducing unit costs, by increasing forage quality, which may result in higher production of milk, reducing protein supplementation or by feeding more forage and less concentrate. Input-output studies have appeared in literature to examine feed-yield relationships based on yearly herd summaries. However, inferences from these studies can only be used to explain how levels of feeding affect production on a herd basis. On the other hand, nutritional studies have contributed much to our understanding of feed-yield response in individual cows. The evaluation of this relationship under field conditions and accounting for individual cow variation undoubtedly has important practical significance.

The present dairy record information system is one of the most complete and advanced. Making the best use of all available information could contribute much to improve the efficiency of dairy production. One category of such important information generally neglected is feeding. Studies which examine feed-yield relationships by making use of available feeding information to characterize the nutrition status of individual cows under field condition are apparently limited. Conceivably to acquire such information is laborous. The implications of such information to animal breeding are also lacking. For example, the relationships between plane of nutrition and the evaluation of sires and the estimation of genetic parameters are of particular interest.

The objectives of this study were to create lactation records containing complete feeding information and to examine the following:

1) The linear and quadratic effects of net energy intake from silage, hay, pasture and meal on milk yield and composition.
2) The effects of ratios of silage:hay, roughage: concentrate and energy concentration on lactation traits.
3) Correction for levels of feeding on estimates of genetic parameters.
4) Sire x herd interactions and genetic parameters in stratified environments classified according to the plane of nutrition.

II. LITERATURE REVIEW

1. Age of cow

The importance of age-yield relationships in dairy records have been recognized for years. Yields of milk, fat, protein and solids-not-fat (SNF) generally increase over the first four lactations (Gravir and Hickman 1966, Loganathan and Thompson 1968, and Miller 1973), then slowly decline. There is little change in the production after the fifth lactation (Blanchard et al. 1966). On the contrary, percentage composition slowly and consistently declines in lactations of cows calving from 2 to 10 years of age (Blanchard et al. 1966, and Gacula et al. 1968).

Age at calving affects lactation yields to a considerable extent. Lush and Shrode (1950) reported 14 to 16% of the total variance in milk yield was due to effects of age at calving. Other estimates were 27% of Robertson et al. (1956), 12 to 25% of Gacula et al. (1968), and 22% of Sargent et al. (1967) for yields of fat, protein, SNF and total solids. It is traditional to adjust records to a mature basis to compare genetic merit of cows of different ages. To make such an adjustment, it is necessary to know the average rate of increase expected, either by adding the average increase to the yields of the young cows or by multiplying these yields by the average proportionate increase. Searle and Henderson (1960) have considered three existing methods of age-correcting dairy records; (i) multiplicative factors, (ii) herd-level factors, and (iii) additive factors. They concluded that no difference existed between (i) and (ii), however (i) have been preferred over (iii) because the former was not affected by production level of the herd (Miller 1973). Nevertheless, Freeman (1973) pointed out that no single satisfactory method to adjust both complete and incomplete records for age differences has been resolved.

The decline in milk fat percent with age is progressive, but appears to be statistically not significant (Gravir and Hickman 1966, Blanchard et al. 1966, Loganathan and Thompson 1968). Percent of total variance accounted for age effects ranged from 0 to 4% for five breeds of dairy cattles were reported (Gacula et al. 1968).

SNF percent declines significantly with age in a curvilinear manner (Wilcox et al. 1959), and accounts for approximately 12 to 14% of the total variations in Holsteins (Gacula et al. 1968, and Loganathan and Thompson 1968). The decline in SNF content is largely due to a decrease in lactose. The change in total protein content is small. However, Waite et al. (1956) noted a drop in the casein fraction, but presumably a compensatory increase in the noncasein fractions. Gacula et al. (1968) reported significant age effects on percent protein and accounted for 6.2 and 2.2% of the total variance for Ayrshires and Holsteins respectively, and Von Krosigk et al. (1960) noted 3% of the total variance in percent protein was due to significant age effects for Holsteins.

As discussed by Legates (1960), the changes in yields and composition with successive lactations reflect effects due to physiological changes in the cow, particularly the udder. Aging of the udder is a series of complicated processes associated with the animal's reduced efficiency to replace mammary tissues for milk secretion, as well as damage to the supporting tissues and the teats through normal usage. Since milk secretion is known to be under hormonal control, this is further complicated by the changes in the amount of relative proportions of hormones secreted for lactation. This creates another class of problems with respect to considering age-yield relationships,that is,correcting lactation records by age differences is biologically real and not just age dependent.

2. Year, season and month of calving

Year of calving is historically considered to be a significant source of variation in dairy records. Yearly trends in production observed in a population may be partly due to genetic improvement and partly due to improved feeding practices and management. Statistical procedures have been developed to estimate the genetic or environmental changes with respect to time (Henderson et al. 1959, Van Vleck and Henderson 1961, and Henderson 1972).

The influence of season of calving on lactation yields is well recognised. Generally, winter or spring calvings are more favorable than other seasons of the year. Annis et al. (1959) reported lactation milk yields were highest for cows freshened in March and April and lowest in July and August for Washington herds, and Gacula et al. (1968) reported similar significant seasonal trends of yields of milk, fat and SNF yield for five major breeds of Massachusetts dairy cattles. Reports of Bereskin and Freeman (1965), and Parkhie et al. (1966) showed cows calved in late autumn and winter produced more milk and with significantly higher fat content. Percentages are usually high in winter and low in summer.

3. Effects of feeding

Feed is one of the major dairy inputs accounting for 45 to 60% of the cost of milk production. Feed cost in the dairy ration can be minimized either by reducing unit costs, by increasing forage quality which may result higher production of milk or reducing protein supplement, or by feeding more forage and less concentrate. Several reviews have been published concerning various aspects of widely varying levels of forage and concentrate feeding for dairy cows (Huffman 1961, Kesler and Spahr 1964, Coppock 1969, Hillman 1969, Miller and O'Dell 1969, and Broster 1972), and of the interrelationships between feeding and milk composition (Legates 1960, Rook 1961, Laben 1963, Van Soest 1963, Huber and Boman 1966, and Storry 1970).

(i) Forage feeding: Miller and O'Dell (1969) pointed out that the key problem of forage feeding is whether the cow could obtain sufficient energy intake to meet her requirement. Ways in which energy deficiency can be overcome are (1) increasing forage digestibility, (2) increasing efficiency of utilization of digested nutrients, (3) increasing forage intake, and (4) increasing concentrate supplementation.

Pasture grazing is a traditional practice to feed fresh forages to dairy cows. Various studies (Castle et al. 1960, Castle et al. 1964, and McCullough and Shell 1955) have indicated either little or no effect on milk production when extra concentrates were fed to cows grazing on high quality pasture. McCullough and Shell (1955) showed that milk production was maintained above 40 lb daily with no concentrate supplement, provided the digestibility of the forage dry-matter remained above 70%. Donker et al. (1968) have shown that most cows producing at levels up to 50 lb of milk daily could obtain nutritional support for production from excellent pasture alone, but beyond this level of daily milk production, supplementation with concentrates was required. In a few instances, concentrate supplementation to grazing cows increased milk yields about 1 lb of milk per 1 lb of concentrate added and percentages composition were slightly affected. Halley and Dougall (1962) noticed that higher milk yield, lower fat percent and slightly higher SNF percent were associated with cows which received concentrate supplements rather than cows just on pasture alone. Hancock (1958) fed cows at three levels of nutrition; (1) one cow per acre and 1 lb of concentrate per each 5 lb of milk, (2) one cow per acre with no concentrate, and (3) one cow per 6/10 of acre with no concentrate. The results indicated that group (1) cows produced 45% and group (2) cows 16% more FCM than group (3) cows, and the milk of group (1) cows had a slightly higher fat and casein percent than other groups of cows. They concluded that the greater yields of group (1) cows over group (2) cows were due mainly to their capacity to maintain a similar grass intake level despite concentrate supplements so that the total net energy intake was at a higher level. The transfer of cows from winter feeding to spring grazing is usually associated with a rise in SNF content and a slight fall in fat percent (Waite et al. 1959, and Rook et al. 1960). This seasonal phenomenon has been attributed to a considerable improvement in the plane of energy nutrition as a result of the high quality spring pasture. The changes in milk composition are caused by an increase in the relative proportion of propionate to acetate (Annison et al. 1959, Rook and Balch 1961, Bath et al. 1962, and Van Soest 1963).

Dry storage of roughage is undoubtedly the most permanent form of storage. But, due to the limitations such as the amount of labour, mechanical handling and weather, hay making is less frequently used in intensive dairy operations. Greater proportions of silage in dairy rations are expected. All silage feeding programs offer a means of circumventing the problem of hay curing and can adapt well to automation of feeding. Various aspects of silage feeding have been reviewed extensively (Hemken and Vandersall 1967, Coppock 1969, and Hillman 1969). Equally high levels of milk were produced from cows fed varying rations ranging from all corn silage to all alfalfa hay when properly supplemented with grain. Milk composition was apparently not affected by the source of roughage in the ration (Brown et al. 1965, Brown et al. 1966, and Hemken and Vandersall 1967). However when Waugh et al. (1955) fed cows four levels of hay (0.0, 0.25, 0.50 and 1.00 kg per 100 kg of body weight), plus corn silage free choice, and reported slightly higher fat content for cows fed higher levels of hay. Murdock and Rook (1963) compared cows fed hay or silage free choice, indicating certain silages could depress

SNF content. The basic problem in replacing hay with silage is the increased moisture content of the silage which could limit cows' consumption of sufficient dry-matter to supply their energy requirements (Hardison 1959). It is generally felt that in feeding practices, the adequacy of energy supply should receive primary consideration. Thus sufficient information on the forage and proper concentrate supplementation are necessary if maximum production is to be maintained.

(ii) Concentrate feeding: Much greater emphasis has been placed on maximum concentrate feeding for fattening beef cattle than for dairy cows. The primary objective of concentrate feeding in dairy rations is to supplement energy deficiency from forage feeding. Many studies have shown that high-concentrate feeding resulted in increased milk production (Hotchkiss et al. 1960, Brown et al. 1962, Ronning and Laben 1966, Opstvedt and Ronning 1967, Fosgate et al. 1968, and Bath et al. 1974), whereas other research indicated no advantage in that respect (Putnam and Loosli 1959, Hooven and Plowman 1963, Olson et al. 1966, Davis 1967, and Swanson et al. 1967). Changes in fat, protein and SNF percent and shifts in volatile fatty acid ratios may or may not develop, depending on the particular concentrate gradients, nature of the forages, and methods of feeding (Elliot and Loosli 1959, Huffman 1961, Brwon et al. 1962, Bishop et al. 1963, Van Soest 1963, and Ronning and Laben 1966).

Brown et al. (1962) showed drastic increases in milk production at higher levels of grain feeding, especially at the free choice level. Ronning and Laben (1966) fed cows four milled diets having hay-to-concentrate ratios of 90:10, 60:40, 30:70 and 0:100. They observed milk yield was significantly depressed in the 90:10 treatment groups, and over-conditioning was noted in the two higher concentrate groups. Most of the increased production was accounted for by the greater energy intake of the diets. If energy intake is held constant, different ratios of hay-to-concentrate rations seem to have little effects on production. For example, Elliot and Loosli (1959) fed diets in which the level of Estimated Net Energy (ENE) intake above maintenance was held constant. Production of FCM milk was not different on diets containing 40, 60 or 80% of the ENE in the form of concentrates. Similarly, feeding grains of relatively high fibre content (oats and barley) to increase the plane of nutrition of a ration (hay plus grass silage plus concentrate) had only small increase in milk yield (Burt 1957, and Huber et al. 1965).

There is evidence indicating that liberal grain feeding is of little advantage. Hooven and Plowman (1963) paired two groups of 19 cows fed grain, hay and silage free choice, whereas the control group was fed 110% of Morrison's Standard. No difference in FCM milk was observed other than an increase in cow body weight. Olson et al. (1966) showed that cows fed concentrates free choice produced more milk than cows fed restricted concentrates, but the difference in milk yield became not significant when converted from actual yield to FCM milk. Other problems associated with high-level concentrate feeding centre around to maintain normal metabolism and health. Excellent reviews have dealt with such problems (Huffman 1961, Kesler and Spahr 1964, Van Soest 1963, and Miller and O'Dell 1969).

A frequent observation resulting from high-concentrate, restricted-roughage diet feeding is the depression of the milk fat percentage (Ronning and Laben 1966, Olson _et al_. 1966, Opstvedt and Ronning 1967, Swanson _et al_. 1967 and Bath _et al_. 1974). But it is not inevitably so, for instance, Brown _et al_. (1962) reported fat percent was not affected when cows were fed free choice grain. If forage-to-concentrate ratio was not greater than 65:35, fat depression would not occur (Ronning 1960). Furthermore, the fibre in some forages appears to be a much more effective fibre source than that in others (Van Soest 1963) and the effect of fibre on rumen metabolism would be largely eliminated when forages are finely ground and pelleted (Rodrigue and Allen 1960, and Moore 1964). Therefore diets producing changes in the relative proportions of ruminal acetate, propionate and butyrate ratios play an important role in the energy metabolism of dairy cattle.

Varied ratios of roughage-to-concentrate have varying effects on milk protein and SNF. Higher planes of energy nutrition have been shown to increase the proportion of propionate in the rumen which has resulted in an increased protein content of the milk (Rook and Balch 1961, Huber and Boman 1966, and Schingoethe et al. 1973). Ronning and Laben (1966) fed cows four hay-to-concentrate diets, and reported protein and SNF content not to be affected. Olson et al. (1966) and Swanson et al. (1967) reported that while fat depression was associated with cows fed liberal concentrates, SNF content was not significantly affected. However, Opstvedt and Ronning (1967) fed cows only concentrates and noticed a high concentration and yield of SNF than cows fed only alfalfa hay. Lower energy intake was evident with the alfalfa hay ration group. In general, reduction of energy intake below the recommended standard causes a reduction in milk SNF content (Flux and Patchell 1957). Small increases in SNF have resulted from increased energy intake well above the standard (Burt 1957, Holmes et al. 1957, Castle et al. 1959, Bishop et al. 1963, Huber and Boman 1966, and Yousef et al. 1970). After Hoogendoorn and Grieve (1970) fed 27 Holstein cows at 90, 100 and 120% of the National Research Council requirements for digestible energy, they reported the SNF content was significant higher (8.83, 9.04 and 9.06% respectively) for cows which received higher energy rations. Increases in SNF percentage at high energy intake levels have generally occurred in the protein fraction, mainly the alpha-casein and beta-lactoglobulin fractions (Yousef et al. 1970). However, Gardner (1969) compared two levels of feeding, the lower level equalled NRC (1958) standard, and the higher one was intended to be adequate to maintain live weight through the lactation. He reported increases in yields of milk and protein without significantly affecting percentages of milk composition.

4. Breed differences

The evidence for genetic variation in milk yield and composition has been established (Butcher et al. 1967, Butcher and Freeman 1968, Thompson and Loganathan 1968, Gacula et al. 1968, Batra et al. 1969, and Wilcox et al. 1971). Armstrong (1958), in a comprehensive review of the literature since 1900 from Canada and the United States on breed differences in milk composition, published average values for fat and SNF percentages for different breeds. The largest study was the interregional project (Wilcox et al. 1971) involving data of five breeds from 22 states, including 22,382 records on cows in 298 herds. The average milk yield and composition based on age adjusted records are presented in the following table. Holsteins are highest in milk yield and lowest in all percentages, and Jersey are lowest in milk yield and highest in all percentages. Generally, breeds with the higher milk fat test are also higher in SNF and protein test.

Table 1: Average milk yield and composition for five breeds of dairy cows

Breed	Milk	Fat %	SNF %	Protein %
Ayrshire	11,567	3.99	8.52	3.34
Brown Swiss	12,814	4.16	8.99	3.53
Guernsey	10,601	4.87	9.01	3.62
Holstein	15,594	3.70	8.45	3.11
Jersey	9,798	5.13	9.21	3.80

5. Herd differences

Bailey (1952) and Overman et al. (1953) noted significant differences among herds and concluded that herd variation was influenced by both genetic and environmental factors. The relative proportion of variations expressed as per cent of the total variations associated with herd effects ranged from 25 to 33% for yields of milk, fat and protein and approximately 7 to 16% for constituent percentages (Burdick and McGillard 1963, Bereskin and Freeman 1965, Fairchild et al. 1966, Van Vleck 1966, and Gacula et al. 1968). The estimates of herd effects tend to vary with the type of data and the statistical models used. Genetic causes in herd variations are small. Pirchner and Lush (1959) and Morillo and Legates (1970) reported genetic differences made up approximately 10% of the between-herd variation in milk yield and the remaining 90% was caused by differing environments. Pirchner and Lush (1959) also pointed out that utilization of A.I. sevice would enventually erase nearly all the between-herd genetic differences. Thus, herd components of variance reflect largely permanent, or long-term differences among herds. Many input-output type of studies, based on the relationships between yearly herd average records and some measureable management practices, have been made to characterize the relative importance of these herd differences. For the purpose of this discussion, the influences of feeding practices upon variations in herd production are primarily considered.

Bayley and Heizer (1952) analysed herd data on 967 cows in 47 Holstein herds in Wisconsin to determine the effects of nine environmental influences on average herd milk production. They reported the rate of TDN (Total Digestible Nutrients) fed daily and the nutritive ratio of the rations were two of the five significant dependent variables affecting yields of milk and fat. For an increase of 1 lb of TDN per 1000 lb of body weight, there was an average increase of 551 lb of milk and 18 lb of fat, but a decrease of 0.02% in fat test.

McKinney _et_ _al_. (1965) related 13 environmental factors to monthly herd average production in 305 Georgia DHIA herds. They found feeding practices, management of breeding program, per cent A.I., grain feeding and type of milking machines were statistically significant sources of variation. The 13 variables studied accounted for 31% of the total variation in monthly milk production.

Stone et al. (1966)reported that changes in grain feeding and changes in per cent days in milk were closely related to changes in yearly herd average milk production in New York DHIA herds. From a multiple regression analysis using 6 independent variables, they reported that a 1 kg change in grain feeding resulted in a change of 0.84 kg of milk. In a similar study, Miller et al. (1968) also reported that concentrates fed was the only feed measure which contributed significantly to yearly production averages.

Stone et al. (1966) failed to find any substantial relationships between changes in milk yield and changes in DHIA estimates of hay, silage and pasture consumed. Miller (1968) studied the effects of levels of feeding at different levels of milk production. He concluded that grain estimates were the most reliable and useful DHIA feeding estimates, whereas silage fed estimates were relatively more useful than hay and pasture estimates. These results could be caused by large errors in estimating forages. The reliability of these estimates relies heavily on the ability of the farmers or the field supervisors to report the quality and quantity of forages fed. Corley et al. (1960) attempted to study the reliability of these estimates. They found the correlations between the project fieldman and the project personnel were in all cases higher than between a DHIA supervisor and the project fieldman.

Brown and White (1973) studied the possible linear and quadratic effects of nine independent variables on yearly herd average records consisting of three breeds of dairy cows from eight eastern and southeastern states. Significant linear and quadratic effects of concentrate feeding were reported for Guernseys and Holsteins, but the estimates of these quadratic effects were inconsistent for the two breeds. Varying significance of linear and quadratic effects of pasture, hay and silage feeding were also reported.

6. Genetic-environmental interactions

Bowman (1970) defined a genotype x environmental interaction as a change in the relative performance of a 'character' of two or more genotypes measured in two or more environments. McBride (1958) and Dickerson (1962) have discussed problems of genotype by environmental interactions in animal breeding. Its practical implication lies on the proper ranking of phenotype of a series of genotypes in different environments. Two methods are generally used to determine genotype by environment interactions, (1) analysis of variance method, and (2) product moment correlation method. Falconer (1952, 1960) has proposed the concept of genetic correlation between two traits be extended to the genetic correlation between phenotypes of the same genotype expressed in two different environments, as the appropriate measure of genetic by environment interaction.

This method has been used to examine sire by herd interactions (Mason and Robertson 1956, Robertson et al. 1960, and Van Vleck 1963) and sire by region interactions (Lytton and Legates 1966) in dairy records. For the situation involving more than two environments, Dickerson (1962) extended this method by calculating the intra-class genetic correlation (r) from components of variance for genotype (σ_G^2) and for genotype x environment interaction (σ_{GE}^2) such that $r = \sigma_G^2 / \sigma_G^2 + \sigma_{GE}^2$. This expression indicates that the intra-class correlation approaches 1.0 when genetic by environment interactions are absent.

(i) Sire by production interaction: One of the most frequent ways to examine sire by production interaction is to classify herds in accordance to their production levels. Changes in rank order and variance for genotypes in different levels of production would indicate the presence of interaction. Mason and Robertson (1956) reported that the genetic variance of yield within herds increased as the average yield increased and correspondingly the heritability from low, medium and high-yield herds were 0.05, 0.15 and 0.22 for milk yield and 0.27, 0.47 and 0.49 for fat test respectively. Van Vleck (1963) also reported that higher genetic variability and heritability were associated with higher production levels for milk yield and fat yield. However, no evidence of sire by herd interaction within or between levels of production has been reported, as they found the correlations between sires in different environments were approximately 1.0. Burnside and Rennie (1961) and Legates (1962) agreed that,although total variability and genetic variability increased with levels of production, the fraction of genetic variance remained relatively constant over all herd levels. Their results failed to establish any significant relationship between heritability values and the herd production levels.

(ii)Sire by ration interaction: Sire by ration interaction appears to have varying degrees of significance. Mao and Burnside (1969) studied interactions of sire proofs (expressed as BCA) by three levels of grain feeding in summer. They reported significant interactions which accounted for 17% of the total variance in sire proofs. Richardson et al. (1971) fed cows of 13 sires at two levels of feeding (all forage or forage plus grain). Sire by ration interactions were significant for milk and FCM but contributed less than 4% of the total variation. Other estimates of sire by ration interactions were small and considered negligible (Lamb et al. 1973, and Rindsig and Freeman 1973).

(iii)Sire by herd interaction: Most estimates of sire by herd components of variance have been small or negative (Legates et al. 1956, Wadell and McGillard 1959, Van Vleck et al. 1961, and Van Vleck 1966). Pirchner and Lush (1959) reported about 6% of the total variation within year to be interaction between sires and herds. Specht and McGillard (1960) attributed about 9% of the total variation in milk and fat to interaction. Burdick and McGillard (1963) also concluded that no interactions of practical importance were found between sires and herd environments classified by levels of production. However, this evidence does not necessarily preclude the possibility of genetic by environmental interactions for production being found when the environmental conditions are defined more precisely than by herds.

III. SOURCE AND PROCESSING OF DATA

1. Source of data

Test day data collected by the Macdonald College Dairy Herd Analysis Service (DHAS) from May 1966 to April 1973 inclusive were used to estimate 305-day lactation records used in this study.

The DHAS program is an owner sampler program. Each month the milk produced by each cow over a 24-hour period was weighed and sampled for a milk composition test by the farmer. A DHAS field supervisor checked and collected the milk samples and sent them to the milk testing laboratory at Macdonald College. From May 1966 to October 1968, milk samples were tested for fat and protein content on an Infra-red Milk Analyser. After this period, Milko Tester Automatic equipment was used to analyze fat content and the integrated unit (Milko Tester Automatic & Pro-Milk Automatic) was used to determine fat and protein content in alternate months. The milk composition test results were then forwarded to the data processing centre, where herd and cow test day information were checked and punched on cards and verified. The test day data were edited and DHAS reports were produced on a IBM 360 Model 22 computer with two 2311 disk drives, two 9 track 800 BPI (Bytes per inch) tape drives, a 2501 card reader and a 1443 printer.

2. Description of data

The test day data required to create lactation records were on IBM cards and were stored by month of test from May 1966 to April 1973. Four types of data cards were concerned with this study:

(i)Herd identification cards: two cards for each herd to identify the farmer's name and address.

(ii)Cow identification cards: two cards containing herd number, registration date, her identification, sire and dam identification, date of birth and her body weight for each cow when she came on the testing service.

(iii)Herd test day data cards: one card containing the amount, quality, dry-matter content and per cent net energy for both succulent feeds and dry feeds for each herd on every test day.

(iv)Cow test day data cards: one for each cow on each test day indicating the current status of the cow (i.e. whether she was calved, bred, dry or in milk etc.), the amount of meal fed and milk produced, fat and protein content of her milk.

3. Data processing methods

Due to the tremendous volume of data cards, tape files were created from cards to facilitate data manipulation.

Data cards were sorted manually by herd. Then they were read by a Cobol program to create tape files with each herd as a file and each block contained 20 records with 84 bytes per record. Approximately 3.6 million data cards were processed and the information was stored on 14 reels of 2400-feet 800 BPI magnetic tapes.

Limitations in the computer configuration (32K main storage and Basic Fortran Compiler) required the following procedures to process each reel of test day data to calculate the lactation records.

(i)Each reel was merged with the misplaced data cards and then were sorted within each file by type of data cards (i.e. herd test day data card, or cow test day data card, etc.), cow number and test day. The resultant files constituted the permanent test day data master files.

(ii)Each herd was edited for correct cow numbers and other valid fields and was deblocked (i.e. each block contained one record, so that records could be processed by Fortran programs) into 8 reels of 2400-feet magnetic tapes.

(iii)Each deblocked data tape was processed separately by Fortran programs to estimate lactation records. Combining all lactation records produced by the 14 reels of test day data master files constituted the master files of lactation records. Subsets of lactation records for Ayrshire and Holstein cows were obtained from these master files.

4. Defining lactation records

Only complete lactation records were estimated,i.e. cows having date calved and date dry identified. Lactations with cows started 90 days after calving and cows dried before 183 days were discarded. For 305-day productions, cows in milk for more than 305 days were credited up to the 305th day and cows dried before 305 days were credited to the dry date. Lactation records with few protein tests would tend to make the lactation protein yield estimates unreliable. Therefore a restriction was set on the lactation protein yield such that only lactations with four or more protein tests were included, otherwise the lactation record was not given a protein yield value.

5. Editing test day protein observations

To insure that only valid protein tests were used to calculate lactation protein yield, conditions were imposed so as to minimize errors contributed by the Pro-Milk Tester. Test day protein observations were discarded: (i) if a protein test was less than the corresponding fat test in the same test month and was also less than 2%, or (ii) if a protein test was greater than the corresponding fat test and was also greater than 4%.

In some instances, the test day protein observations were missing. This might have been due to (i) farmers failed to sample the cow, or ~~(ii)~~ Pro-Milk Tester failed to produce bimonthly protein test. Missing values within the first and the last test day did not contribute a serious problem, because averaging the previous and the succeeding test generally gave satisfactory estimates for the missing tests. However it is known that protein tests drop drastically from the date of calving to the 45th day after calving. Esan (1971) reported Holstein cows in this population had an average protein test of 4% in the 7th day after calving which dropped to 2.9% by the 45th day. Furthermore, the Test Interval Method was used to calculate lactation yields, and this method is known to be affected by the time of first test and the time of last test. For example, Everett and Carter (1968) reported first tests on the 4th day of lactation resulted in a -40 kg bias of milk while a +140 kg bias of milk occurred when the first test day was on the 29th day of lactation. Some linear equations were developed to predict the first and the last missing protein tests.

The procedures used to estimate the first missing protein tests were based on projections from succeeding tests and to estimate the last missing tests were based on projections from the previous tests. If the lactation curve for protein test is divided into two periods, then the curve could be approximately represented by two linear equations. Least squares estimates for the stage of lactation on protein percent were obtained for this population (Esan 1971). The relative change in protein percent with respect to days after calving was estimated from these least squares estimates. A general linear equation was set up to predict the missing tests:

$$\hat{y} = y + bX$$

where:

$\hat{y}$ = the first or last missing tests to be estimated.

y = the second test when we want to estimate the first missing value, or the second last test when we want to estimate the last test.

b = slope of protein percent on days after calving.

X = the days after calving.

To test the accuracy of the prediction equations established, a set of first and second tests and another set of last and second to last tests were collected for both Holsteins and Ayrshires to test the hypothesis, $H_0 : E_1 - E_2 = 0$, where E_1 was the average protein tests estimated by the prediction equations, and E_2 was the average actual protein tests. These equations underestimated the tests by an average of approximately 0.14% for both start and end of lactation for both breeds (Table 2). The paired t-test statistics were all significant ($P < 0.01$). The significant deviations that resulted from the prediction equations might have been due to a bias

Table 2: Paired t-test for the mean differences between the estimated and the actual tests[a)]

Test	No of paired Observation	E_1	E_2	S_d	t
Before correcting for bias					
Ayrshire					
First test	187	332.88	344.32	3.79	-3.02**
Last test	77	381.64	397.03	5.55	-2.77**
Holstein					
First test	1128	306.05	322.21	1.47	-10.97**
Last test	528	352.93	367.98	1.94	-7.76**
After correcting for bias					
Ayrshire					
First test	151	342.00	337.07	4.52	1.09
Last test	64	380.90	380.76	5.46	0.26
Holstein					
First test	1420	322.18	321.33	1.40	0.61
Last test	553	368.74	372.09	1.86	-1.80

a) protein values coded by times 100

** significant at 0.01 level

attributable to a nonlinear relationships between protein test and the stage of lactation. A correction factor was introduced into the equations, and another set of first and second tests and last and second to last tests were collected from a different subset of herds to test if $\hat{y} = y\ bX + 0.14$ gave better estimates. In all cases H_0 was accepted (Table 2), indicating the equations were adequate to provide estimates for missing tests. The prediction equations used to estimate missing tests were as follows (protein tests were coded by x 100):

(i) For Ayrshires

$\hat{y} = y - 3.28927X + 14$, for X less than or equal to 45 days.

$\hat{y} = y + 0.34693X + 14$, for X greater than 45 days.

(ii) For Holsteins

$\hat{y} = y - 2.92105X + 14$, for X less than or equal to 45 days.

$\hat{y} = y + 0.29795X + 14$, for X greater than 45 days.

6. Computing 305-day feed intake

305-day feed consumption and net energy intake from silage, hay and meal and 305-day net energy intake from pasture were computed. Any succulent feeds with dry-matter content less than 89% were classified as silage, and the minimum net energy content of meal was set to equal to 70%.

Test day net energy intake from roughages (i.e. silage and hay) was calculated as: amount(lb) x dry-matter content(%) x % net energy (therm/100 lb of feed). The amount fed in pounds was based on the herd average cow body weight. Net energy intake from pasture was given in units of therms of energy intake from pasture per day per herd average cow body weight. Therefore a cow's actual feed intake was multiplied by her body weight. Thus, feed intakes from roughages and pasture were subjected to errors if changes in cow body weight were not reported. Test day net energy intake from meal was equal to the amount fed(lb) x % net energy. The test interval intakes were computed as: 1/2(first test day intake + second test day intake) x test interval. The 305-day amount fed and energy intake would be the summation over a 305 days period.

7. Computing 305-day productions

Lactation yields were estimated by Test Interval Method. Previous studies (Dickinson and McDaniel 1970, Everett *et al*. 1968, and Sargent *et al*. 1968) have indicated the effectiveness of this method. For a particular test interval, milk yield was estimated as: 1/2(first test day milk yield + second test day milk yield) x test interval. The first test day observations were used to estimate the yields in the period from the day of calving to the first test day. If a cow was in milk for more than 305 days, the last test day observations prior to the 305th day were used to terminate the records, and if a cow was in milk for less than 305 days but greater than 183 days, the last test day observations were used to project the records to the dry date. Fat and protein yields were computed similarly by averaging the per cent composition of two tests and multiplying by the average milk yield in that test interval. The percentages of fat and protein in the subsequent analyses were obtained by dividing the lactation composition yields by the milk yield.

8. Description of lactation records

Lactation records were stored in tape files. Each record contained the following information: herd number, cow number, body weight(lb), date of birth, calved and dry, lactation number, sire and dam identification, 305-day milk, fat and protein yield(lb), 305-day amount fed(lb) from silage, hay and meal, and 305-day net energy intake(therm) from silage, hay, pasture and meal.

9. Classification of data

All lactation records created for Ayrshires and Holstein cows were used for milk yield, fat yield and percent fat analyses. These records are referred to as All Records. A subset of the records with lactation protein yield values, which are referred to as the Protein Subset, was used for protein yield and per cent protein analyses.

Holstein cow records with their sires identified constituted lactation records for the estimation of genetic parameters. Similarly, within this sire identified Holstein cow subset, All Records and the Protein Subset were collected for the appropriate lactation trait analyses. Genetic and phenotypic correlations between protein or percent protein and the rest of the lactation traits were based on the Protein Subset records.

Lactation records were classified by age of cow (5 classes), year of calving (7 classes) and season of calving (3 classes) as follows.

(i)Age of cow

Class	Age of cow (years old)
1	less or equal to 3
2	3-4
3	4-5
4	5-6
5	greater than 6

(ii)Year of calving

Class	Year of calving
1	1966
2	1967
3	1968
4	1969
5	1970
6	1971
7	1972

Preliminary examination of the data indicated that the Protein Subset only had a few observations in the 7th year of calving class, because the integrated fat and protein test unit was out of service for a considerable period of time during that year. This resulted in the majority of the records having three or fewer protein tests and those records were not given lactation protein yield values. Therefore, the 7th class of the Protein Subset was eliminated and the effects of year of calving were reduced to 6 classes.

(iii)Season of calving

Class	Season of calving
1	Nov-Feb
2	Mar-Jun
3	Jul-Oct

In a subsequent analysis to study the interaction of sire by herd environment, records were classified into three levels of net energy intake from meal as follows.

Level of net energy intake from meal	Lactation net energy intake(therm) from meal
Meal 1 (Low)	less or equal to 2200
Meal 2 (Medium)	greater than 2200, less or equal to 2900
Meal 3 (High)	greater than 2900

IV. METHOD OF ANALYSIS

As indicated in the previous section (Source and Processing of Data), in addition to the usual cow production information, the lactation records created also contained lactation feed intake from various feeds. This additional information makes the study of the effects of nutrition on field data and its relationship to animal breeding possible in dairy cattle. Five different models were used in the present study. Their brief considerations, descriptions, their underlying assumptions and computations are presented in the following sections.

1. Model I

Henderson's Method II (Henderson 1953) was used to simultaneously estimate the fixed effects of levels of net energy intake from silage, hay, pasture and meal, and herd, cow within herd and error components of variance. Fortran programs based on the procedures described by Harvey (1960), were available to carry out the analyses on a IBM 360 Model 22 computer. The following model was assumed to describe the lactation records.

$$Y_{ijklmn} = u + H_i + C_{ij} + A_k + R_l + S_m + \sum_{f=1}^{8} B_f X_{fijklmn} + E_{ijklmn}$$

for $i = 1,2,\ldots\ldots p$

$j = 1,2,\ldots\ldots q$

$k = 1,2,\ldots\ldots r$

$l = 1,2,\ldots\ldots s$

$m = 1,2,\ldots\ldots t$

$n = 0,1,2,\ldots\ldots N_{ijklm}$

where

Y_{ijklmn} = n-th lactation record of j-th cow in i-th herd for k-th age of cow, l-th year and m-th season of calving.

u = the population mean.

H_i = the effects common to i-th herd.

C_{ij} = the effects common to j-th cow in i-th herd.

A_k = the effects common to k-th age of cow.

R_l = the effects common to l-th year of calving.

S_m = the effects common to m-th season of calving.

$X_{fijklmn}$ = linear and quadratic net energy intake from silage, hay, pasture and meal respectively, and $f = 1,2,\ldots\ldots 8$.

B_f = linear and quadratic partial regression coefficients of Y_{ijklmn} on $X_{fijklmn}$ for $f = 1,2,\ldots\ldots 8$.

E_{ijklmn} = random error.

It was assumed that the random effects of herd, cow within herd and the error term were identically and independently distributed with mean zero and variance σ_H^2, σ_c^2 and σ_E^2 respectively. For hypothesis testing purposes, the random errors were assumed to be normally distributed. Interactions were assumed to be absent. Age of cow, year and season of calving effects and the covariates were considered to be fixed. Sire and dam effects were not included in the above model because there were only a limited number of records for which the sire and dam could be identified. This could inflate the herd component estimates. The failure to consider the joint effects of year and season of calving could also produce some bias in the estimates.

The analyses can be described in two steps: Step 1 - computing least squares estimates; and Step 2 - Estimating the variance components. For convenience to develop the theories involved, the above model is generalized in terms of matrix notation and the notations used are largely after Searle (1968) and Henderson (1971). The model can be rewritten as:

$$y = Xb + Zu + e$$

where y = a vector of observation of order $n \times 1$.
X = a fixed and known matrix of order $n \times p$.
Z = a fixed and known matrix of order $n \times q$.
b = a vector of unknown fixed effects of order $p \times 1$.
u = a vector of random variables of order $q \times 1$.

e = a vector of random errors of order n x 1, and is distributed with zero vector mean and variance-covariance $\sigma_e^2 I$, and Cov(ue')=0.

The vector b can be partitioned into p subvectors corresponding to the effects of age of cow, year and season of calving and the regression effects. Least squares procedures can be used to estimate the vector b in Step 1 temporarily regarding u as fixed. Similarly vector u can be partitioned into q subvectors corresponding to the herd effects and cow within herd effects. The vector of random effects, u, is distributed with mean null vector of order q x 1 and variance-covariance matrix D, where $D = \begin{bmatrix} I\sigma_H^2 & 0 \\ 0 & I\sigma_c^2 \end{bmatrix}$. Estimation of herd and cow within herd variance components is carried out in Step 2.

Step 1 - Computing least squares estimates: Least squares procedures involves minimizing the sums of squares of deviations of observed y's from their expected values, i.e. minimizing e'e. The normal equations after differentiating with respect to $\hat{b}$ and $\hat{u}$ are:

$$\begin{bmatrix} X'X & X'Z \\ Z'X & Z'Z \end{bmatrix} \begin{bmatrix} \hat{b} \\ \hat{u} \end{bmatrix} = \begin{bmatrix} X'y \\ Z'y \end{bmatrix}$$

Due to the large matrix size of random effects (Z), X'Z, Z'X and Z'Z must be absorbed into X'X. After multiplying and expanding the above normal equations, then the following equations are obtained,

$$X'X\hat{b} + X'Z\hat{u} = X'y \qquad (1)$$

$$Z'X\hat{b} + Z'Z\hat{u} = Z'y \qquad (2)$$

Solving for $\hat{u}$ from (2), $\hat{u} = (Z'Z)^{-1}Z'y - (Z'Z)^{-1}Z'y\hat{b}$, and substituting $\hat{u}$ in (1) produces the least squares estimates of the fixed effects, i.e. $\hat{b} = (X'X - X'Z(Z'Z)^{-1}Z'X)^{-1}(X'y - X'Z(Z'Z)^{-1}Z'y)$. Since Z'Z is a diagonal matrix, even if its order is large, it can be calculated in stages with each random equation. This is generally referred to as the absorption process. A solution to $\hat{b}$ is based on the constraint that $\hat{b}_p = 0$ and amended to satisfy $\sum_{i=1}^{p} b_i = 0$, so the solutions are directly expressed as deviations from a mean of zero.

The residual sum of squares is $SSE = y'y - \hat{b}'X'y - \hat{u}'Z'y$ with an unbiased estimate of the error variance being $\hat{\sigma}_e^2 = SSE/N - r$, where r is the rank of matrix XZ. The sums of squares due to fitting the i-th fixed effect are computed directly as, $SSi = \hat{b}_i'Gi^{-1}\hat{b}_i$, where $\hat{b}_i$ is the vector of least squares estimates of SSi effect, and Gi is the segment of inverse matrix corresponding to $\hat{b}_i$ (Harvey 1960). Normality is assumed to test hypothesis $H_o : b_{i_1} = b_{i_2} = \ldots\ldots b_{is}$, (i.e. to test the equality of b's), for all i, and s is the last level in i-th fixed effect. Then the F-test statistics is given by: $F(H_o) = SSi/(s - 1)\hat{\sigma}_e^2$, and $F(H_o)$ has a F-distribution with (s - 1) and (N - r) degrees of freedom.

Step 2 - Estimating variance components: The model used in this analysis contains both random and fixed effects, frequently referred to as a mixed model. Generally in a mixed model, expected values of the random effects contain functions of the fixed effects that can not be eliminated by considering linear combinations of the random effects. However, the bias in estimating variance components due to the presence of fixed effects in the mixed model is eliminated by using Henderson's Method II (Henderson 1953). This method involves estimating the fixed effects by least squares procedures, correcting the data in accordance with these estimates, equating the corrected sums of squares to their corresponding expectations and solving for the variance components. A generalized Method II was considered by Searle (1968), and he showed that Henderson's Method II was a special case of his generalized Method II which could be applied, provided that certain conditions were met to obtain the generalized inverse used to estimate the fixed effects and that no interactions existed between the fixed and random effects in the model.

From the normal equations decribed in the previous section, a solution to the normal equations is given by:

$$\begin{bmatrix} \hat{b} \\ \hat{u} \end{bmatrix} = \begin{bmatrix} X'X & X'Z \\ Z'X & Z'Z \end{bmatrix}^{-} \begin{bmatrix} X'y \\ Z'y \end{bmatrix}$$

where $\begin{bmatrix} X'X & X'Z \\ Z'X & Z'Z \end{bmatrix}^{-} = \begin{bmatrix} P & Q \\ Q' & S \end{bmatrix}$ is the generalized inverse.

Then $\hat{b} = PX'y + QZ'y$. If we let $L = PX' + QZ'$, then $\hat{b} = Ly$. If $\hat{b}$ is used to correct the observed y vector for the fixed effects, then the corrected y observations, designated as w, can be expressed as: $w = y - X\hat{b}$. Substituting Ly for $\hat{b}$ and $Xb + Zu + e$ for y, the model for w becomes:

$w = (X - XLX)b + (Z - XLZ)u + (I - XL)e$. Henderson (1971) has shown that w reduces to, $w = \alpha 1 + Zu + Te$, where α is a scalar and $T = (I - XL)$ if the following conditions are met, (i) $(X - XLX)$ has all rows the same, and (ii) $XLZ = 0$. Therefore, appropriate procedures (Searle 1968) to obtain a full rank subset of normal equations are necessary to satisfy the above conditions. The reduced model for w becomes a simple random model (Model II of Eisenhart, 1947), but the constant α contains a linear function of the fixed effects and the variance-covariance matrix of e becomes a complicated set of linear functions of $TT'\sigma_e^2$. In terms of the mathematical model in this analysis, the reduced model would become a simple two-way nested random model, $Y_{ijk}^* = u^* + H_i + C_{ij} + E_{ijk}^*$.

The corrected lactation records Y_{ijk}^* are obtained by:

$Y_{ijk}^* = Y_{ijklmn} - \tilde{A}_k - \tilde{R}_l - \tilde{S}_m + \sum_{f=1}^{8} \hat{B}_f(\bar{B}_f - X_{fijklmn})$, where:

$\tilde{A}_k$, $\tilde{R}_l$, $\tilde{S}_m$ are the least squares estimates for k-th age of cow, l-th year and m-th season of calving. $\hat{B}_f$ and $\bar{B}_f$ are the linear and quadratic partial regressions and means respectively. $X_{fijklmn}$ is the linear and quadratic net energy intake from silage, hay, pasture and meal respectively and Yijklmn is an observed record before correcting for the fixed effects.

The sum of squares of r-th random effect can be expressed as $w'Zr(Zr'Zr)^{-1}Zr'w$, and its expectation is

$$E(w'Zr(Zr'Zr)^{-1}Zr'w) = \alpha^2 1'Zr(Zr'Zr)^{-1}Zr'1 + \sum_{i=1}^{s} \sigma_i^2 tr(Zr(Zr(Zr'Zr)^{-1}Zr'ZiZi') + \sigma_e^2 tr((I-XL)'Zr(Zr'Zr)^{-1}Zr'(I-XL)).$$

This is identical to the expectation arrived at for the completely random model using Henderson's Method I except for the coefficient of σ_e^2. The coefficient of σ_e^2 reduces to $\sigma_e^2 r(Zr) + \sigma_e^2 tr(X'Zr(Zr'Zr)^{-1}Zr'XP)$, where $r(Zr)$ is the rank of Zr, and P is defined earlier and it is the portion of the generalized inverse corresponding to the fixed effects (Henderson 1971). Therefore, the coefficient of σ_e^2 is augmented by $tr(X'Zr(Zr'Zr)^{-1}Zr'XP)$, which is the only difference compared to Method I. The expression $(X'Zr(Zr'Zr)^{-1}Zr'X)$ is the quantity obtained when r-th random effects are absorbed into X'X and it can be calculated by subtracting the matrix after r-th random effects are absorbed from the original X'X matrix. In order to be conformable with P, it is necessary to impose the same constraints on $(X'Zr(Zr'Zr)^{-1}Zr'X)$ as were imposed on P. In this analysis, three augmented portions by three separate passes to absorb the mean, herd and cow within herd equations respectively are required.

The best unbiased estimate of σ_e^2 as given by Henderson (1953) is, $\hat{\sigma}_e^2 = (y'y-R(b)-R(u))/N-r(XZ)$, where R(b) and R(u) are the reduction sums of squares due to fitting all fixed and random effects respectively and r(XZ) is the rank of the full model. The variance components for herd and cow within herd effects can be solved by equating their corrected sums of squares to their expectations. The following expressions are used for the actual calculation.

$$K = \begin{bmatrix} K1 & K2 & K3 \\ K4 & K5 & 0 \\ 1 & 0 & 0 \end{bmatrix}, \text{ and } \hat{\sigma}^2 = \begin{bmatrix} \hat{\sigma}_E^2 \\ \hat{\sigma}_c^2 \\ \hat{\sigma}_H^2 \end{bmatrix}, \text{ then } \hat{\sigma}^2 = K^{-1} \begin{bmatrix} Th - Tu \\ Tc - Th \\ \hat{\sigma}_E^2 \end{bmatrix}.$$

where $K1 = H + tr(X'Zh(Zh'Zh)^{-1}Zh'XP) - 1 - tr(X'1(1'1)^{-1}1'XP)$

$$K2 = \sum_i \frac{\sum_j Nij^2}{Ni.} - \frac{\sum_{ij} Nij^2}{N}$$

$$K3 = N - \frac{\sum_i Ni.^2}{N}$$

$$K4 = C + tr(X'Zc(Zc'Zc)^{-1}Zc'XP) - H - tr(X'Zh(Zh'Zh)^{-1}Zh'XP)$$

$$K5 = N - \sum_i \frac{\sum_j Nij^2}{Ni.}$$

and N = total number of records.

H = number of herds.

C = number of cow within herd.

Tu = Correction for the mean.

Th = Herd sum of squares

Tc = Cow within herd sum of squares

The total variance is estimated as: $\hat{\sigma}_P^2 = \hat{\sigma}_H^2 + \hat{\sigma}_C^2 + \hat{\sigma}_E^2$, where, $\hat{\sigma}_H^2$ is the estimated herd variance component, $\hat{\sigma}_C^2$ is the estimated cow within herd variance component and $\hat{\sigma}_E^2$ is the estimated error (within cow) variance component. Intra-herd repeatability (on a between and within cow basis) is estimated as $r = \hat{\sigma}_C^2/(\hat{\sigma}_C^2 + \hat{\sigma}_E^2)$.

2. Model II

This was a reduced Model I, with identical terms to Model I except the covariates of feed intake were not considered. It is given as follows with all definitions and assumptions similar to those in Model I:

$$Y_{ijklmn} = u + H_i + A_k + R_l + S_m + E_{ijklmn}.$$

The primary function of this model was to evaluate the relative changes in herd and cow variance components for milk yield and composition contributed by accounting for feeding practices. This was obtained by the differences between the variance components estimated from Model I and Model II.

3. Model III

This model was used to estimate the effects of feed ratios of silage:hay, roughage:concentrate and energy concentration of all feed on milk yield and composition. All difinitions and assumptions were the same as in Model I except for the covariates:

$$Yijklmn = u + Hi + Cij + Ak + Rl + Sm + \sum_{f=1}^{3} Bf\ Xfijklmn + Eijklmn$$

where $X_1ijklmn$ = the ratio of net energy intake from silage to net energy intake from hay.

$X_2ijklmn$ = the ratio of net energy intake from silage, hay and pasture to that of net energy intake from meal.

$X_3ijklmn$ = the ratio of total net energy intake to the total amount fed from silage, hay and meal.

B_1, B_2, B_3 = partial regression coefficients of Yijklmn on Xfijklmn, for f = 1,2,3 respectively.

4. Model IV

Eisenhart's Model II (Eisenhart 1947) was assumed to describe both sets of records corrected by the least squares estimates from Model I and Model II to estimate variance and covariance components for estimation of genetic parameters. This model is as follows.

$$Yijkl = u + Si + Hj + (SH)ij + Cijk + Eijkl$$

for i = 1,2,......s

j = 1,2,......h, and total number of ij subclasses is t.

k = 1,2,......c

l = 1,2,......Nijk

where

Yijkl = l-th lactation record of k-th cow in ij-th sire-herd subclass.

Si = the effects common to i-th sire.

Hj = the effects common to j-th herd.

(SH)ij = the interaction effects common to the i-th sire and j-th herd.

Cijk = the effects common to the k-th cow in ij-th sire-herd subclass.

Eijkl = within cow random error.

Sires, herds, sire x herds, cows and errors were assumed to constitute independently and identically distributed random variables with mean zero and respective variances σ_S^2, σ_H^2, σ_{SH}^2, σ_C^2 and σ_E^2. A dam component was not included in the model due to limitations of the data that there were few records for which the dam could be identified. Consequently the sire and herd variance components in the above model could be inflated.

If inbreeding coefficients are assumed to be zero (i.e. random mating population), then the genetic and environmental interpretations of the components underlying the above model can be considered. The sire component of variance, σ_S^2, is due to sire groups being different. These groups consist of paternal half sibs, so that σ_S^2 is the covariance of half sibs. It estimates 1/4 of the additive genetic variance. The cow component of variance, σ_C^2 and herd variance component, σ_H^2 are due to differences between animals and between herds. They contain both genetic and permanent environmental portions. The within cow variance component, σ_E^2 , measures the variance of repeated records within a cow, therefore it contains the temporary environmental portion.

Since it is a completely random model, Henderson's Method I (Henderson 1953) was used to estimate the variance and covariance components. This method involves collecting the sums of squares or cross-products and equating these to their expectations and solving for the variance and covariance components. The following expressions were used to obtain solutions.

$$\text{Let } K = \begin{bmatrix} N-K6 & K1-K7 & K1-K8 & K2-K9 & s-1 \\ K3-K6 & N-K7 & K3-K8 & K4-K9 & h-1 \\ K6-K3 & K7-K1 & \begin{matrix} N+K8- \\ K1-K3 \end{matrix} & \begin{matrix} K5+K9- \\ K2-K4 \end{matrix} & \begin{matrix} t-s- \\ h+1 \end{matrix} \\ 0 & 0 & 0 & N-K5 & c-t \\ 0 & 0 & 0 & 0 & N-c \end{bmatrix}$$

$$K1 = \sum_i \frac{\sum_j N_{ij.}^2}{N_{i..}}, \quad K2 = \sum_i \frac{\sum_{jk} N_{ijk}^2}{N_{i..}}, \quad K3 = \sum_j \frac{\sum_i N_{ij.}^2}{N_{.j.}},$$

$$K4 = \sum_j \frac{\sum_{ik} N_{ijk}^2}{N_{.j.}}; \quad K5 = \sum_{ij} \frac{\sum_k N_{ijk}^2}{N_{ij.}}, \quad K6 = \frac{\sum_i N_{i..}^2}{N},$$

$$K7 = \frac{\sum_j N_{.j.}^2}{N}, \quad K8 = \frac{\sum_{ij} N_{ij.}^2}{N}, \quad K9 = \frac{\sum_{ijk} N_{ijk}^2}{N}.$$

$$\text{and } \hat{\sigma}^2 = \begin{bmatrix} \hat{\sigma}^2_S \\ \hat{\sigma}^2_H \\ \hat{\sigma}^2_{SH} \\ \hat{\sigma}^2_C \\ \hat{\sigma}^2_E \end{bmatrix}, \quad \text{then } \hat{\sigma}^2 = K^{-1} \begin{bmatrix} Ts - Tu \\ Th - Tu \\ Tsh - Ts - Th + Tu \\ Tc - Tsh \\ To - Tc \end{bmatrix}$$

where To = total sum of squares or cross products.

Tu = correction to the mean.

Ts = sire sum of squares or cross products.

Th = herd sum of squares or cross products.

Tsh = sire-herd subclasses sum of squares or cross products.

Tc = cow in sire-herd subclasses sum of squares or cross-products.

Repeatability, heritability, genetic and phenotypic correlations for milk yield and composition were estimated on a within herd basis by taking ratios of appropriate variance ~~and~~ covariance components.

(i) Repeatability

$$r = \frac{\hat{\sigma}^2_S + \hat{\sigma}^2_C}{\hat{\sigma}^2_S + \hat{\sigma}^2_{SH} + \hat{\sigma}^2_C + \hat{\sigma}^2_E}$$

(ii) Heritability

$$h^2 = \frac{4\hat{\sigma}^2_S}{\hat{\sigma}^2_S + \hat{\sigma}^2_{SH} + \hat{\sigma}^2_C + \hat{\sigma}^2_E}$$

(iii) Genetic and phenotypic correlations between trait x and trait y are given by Hazel (1943);

Genetic correlation, $r_g = \hat{\sigma}_{SxSY} / \sqrt{\hat{\sigma}^2_{SX} \, \hat{\sigma}^2_{SY}}$

Phenotypic correlation, $r_p = \hat{\sigma}_{PxPY} / \sqrt{\hat{\sigma}^2_{PX} \, \hat{\sigma}^2_{PY}}$

where

$\hat{\sigma}_{SxSY}$ = sire covariance component between trait x and trait y.

$\hat{\sigma}^2_{SX}$ and $\hat{\sigma}^2_{SY}$ = sire variance components for trait x and trait y respectively.

$\hat{\sigma}^2_{PX}$ and $\hat{\sigma}^2_{PY}$ = total phenotypic variance (sum of sire, herd, cow and error) for trait x and y respectively.

$\hat{\sigma}_{PxPY}$ = total phenotypic covariance between trait x and trait y.

5. Model V

This is a reduced Model IV, by which the sire-herd interaction term is neglected. The purpose of this design is primarily to examine changes in herd and sire variance or covariance components and consequently the effects on genetic parameters when interactions are not included in the model. Model V is assumed to be a random model and it is given as follows:

$$Yijkl = u + Si + Hj + Cijk + Eijkl$$

Definitions and assumptions underlying this model are the same as in Model IV. The procedures used to estimate the variance and covariance components are similar to Model IV except that Ki's in K matrix and sums of squares or cross products corresponding to the interaction term are deleted. Examining the expectations in K matrix, it is evident that $\hat{\sigma}_c^2$ and $\hat{\sigma}_E^2$ would be expected the same as in Model IV. However, $\hat{\sigma}_S^2$ and $\hat{\sigma}_H^2$ would change as (K2 - K9) is deleted from the sire equations and (K4 - K9) is deleted from the herd equations. Consequently, positive sire x herd interactions in Model IV would result in underestimating the sire and herd components.

V. RESULTS AND DISCUSSION

1. Distribution of data

A total of 161,833 lactation records were created from DHAS test day data files from the period of May 1966 to April 1973 inclusive. Of these records, 86.34% were Holstein, 10.66% were Ayrshire and the remaining 3% accounting for records of Brown Swiss, Canadienne, Guernsey, Jersey and Shorthorn cows. In view of the limited number of observations in the minor breeds, only records of Holsteins and Ayrshires were used in this investigation. For studies estimating genetic parameters, only Holstein records with sires identified were used. Distribution of these subsets of lactation records for Holsteins and Ayrshires is given in Table 3.

Table 3: Subsets of lactation records

			Sire identified subset	
Breed	All Records	Protein Subset	All Records	Protein Subset
Ayrshire	17,259	6,841		
Holstein	139,720	61,300	13,561	7,506

Distribution of lactation records by age of cow is given in Table 4. Number of cows decreased with age from 3 to 6 years, as might be expected if low producers were culled with increasing lactation numbers.

Table 4: Population distribution of lactation records by age of cow

Class	Age of cow (year-old)	All Records		Protein Subset	
		Ayrshire	Holstein	Ayrshire	Holstein
1	<3	3,334	29,750	1,559	14,477
2	3-4	2,845	23,101	1,157	9,906
3	4-5	2,463	19,936	941	8,581
4	5-6	2,122	17,370	778	7,541
5	>6	6,495	49,563	2,406	20,795
	Total	17,259	139,720	6,841	61,300

Number of lactation records (Table 5) increased steadily from 1966 to 1971 reflecting the expansion of the DHAS program. The relatively small number of observations in 1972 is due to the fact that the test day data used in this study were terminated in April 1973 and cows that calved after late summer of 1972 had not completed their lactations by the following April.

Table 5: Population distribution of lactation records by year of calving

Class	Year of calving	All Records		Protein Subset	
		Ayrshire	Holstein	Ayrshire	Holstein
1	1966	188	1,607	188	1,607
2	1967	610	6,214	524	5,373
3	1968	1,830	13,664	535	5,141
4	1969	2,928	23,703	2,342	20,307
5	1970	3,899	32,114	2,059	18,230
6	1971	4,577	38,555	1,193	10,642
7	1972	3,227	23,863		
	Total	17,259	139,720	6,850	61,300

Distribution of lactation records by season of of calving (Table 6) consistently indicated more cows freshened in spring (i.e. class Mar-Jun) than other seasons for Ayrshires and Holsteins. This implies that Quebec dairymen are aware that, as reported in the literature, spring and winter calvings are more favourable than other seasons.

Means, phenotypic standard deviations and coefficients of variation for milk yield and composition of Ayrshires and Holsteins are shown in Table 7. These data were not adjusted for age differences. Approximately 70% of the cows were less

Table 6: Population distribution of lactation records by season of calving

Class	Season of calving	All Records		Protein Subset	
		Ayrshire	Holstein	Ayrshire	Holstein
1	Nov-Feb	4,366	43,056	1,908	18,795
2	Mar-Jun	10,053	64,592	3,334	24,246
3	Jul-Oct	2,840	32,072	1,599	18,259
	Total	17,259	139,720	6,841	61,300

Table 7: Means, phenotypic standard deviations and coefficients of variation for milk yield and composition

Trait	Ayrshire			Holstein		
	Mean	S.D.	C.V.	Mean	S.D.	C.V.
Milk(lb)	8,703	2,014	0.23	10,569	2,979	0.28
Fat(lb)	330	79	0.24	371	114	0.31
Protein(lb)	297	66	0.22	339	86	0.25
Fat %	3.79	0.39	0.10	3.50	0.57	0.16
Protein %	3.27	0.25	0.08	3.07	0.43	0.14

than 4 years-old, thus lower yields are expected when compared to mature equivalent records (Wilcox et al. 1971). Nevertheless, these results confirm two established facts, (i) Holsteins have higher yields but lower percentages than Ayrshires, and (ii) Percentage traits show less variability than yield traits.

Average net energy intake in therms from silage, hay, pasture and meal are shown in Table 8. The exact distribution of these feed variables was not examined in this study and has apparently not been studied elsewhere. Since estimation of least squares effects does not require normality (Searle 1971), the consequences, if these variables are not normal, might not be too serious except in testing hypotheses where normality has to be assumed. Net energy intake from meal feeding had the lowest values of coefficient of variation among these four feed intake variables for both breeds. Miller et al. (1968) reported values of coefficient of variation being 0.15 and 0.19 for meal and dry forage respectively from yearly herd average records. Later, Miller (1968) concluded that meal estimates were the most reliable DHIA feed estimates.

Table 8: Means, standard deviations and coefficients of variation for 305-day net energy intake from feeds

	Ayrshire			Holstein		
Feed	Mean	S.D.	C.V.	Mean	S.D.	C.V.
Silage	303	397	1.31	551	584	1.06
Hay	1,264	454	0.36	1,335	546	0.41
Pasture	1,089	378	0.35	1,023	442	0.43
Meal	1,812	608	0.34	2,210	825	0.37

2. Effects of age, year and season of calving

Effects of age, year and season of calving on milk yield and composition have been well established. The main purpose for including these effects in the model was primarily to account for known sources of variation and secondly to use these estimates to correct lactation records. Therefore, estimates of effects of age, year and season of calving from Model I (model including levels of feeding) and Model II (model not including levels of feeding) are discussed concurrently. Estimates of these effects from Model III were similar to those from Model II and are not discussed.

Significant age effects at calving on yields of milk, fat and protein were found for Ayrshires and Holsteins with both models (Table 9; Appendix Tables 1 to 8). However,

Table 9: Least squares estimates of the effects of age of cow on milk yield and composition for Ayrshires and Holsteins from Model I and Model II[a]

Trait	Model	Age of cow (year-old) <3	3-4	4-5	5-6	>6
Milk(lb)	Ayr Model I **	-558.7663	-102.7355	156.6976	239.6797	265.1244
	Model II**	-980.9994	-321.7972	243.1650	482.2357	577.3960
	Hol Model I **	-789.7683	-166.3144	184.7779	357.7964	413.5083
	Model II**	-1537.7183	427.2739	332.3025	732.9807	899.7090
Fat(lb)	Ayr Model I **	-18.9395	-3.2215	5.8178	8.7563	7.5870
	Model II**	-35.6907	-11.8409	9.3140	18.3268	19.8909
	Hol Model I **	-28.2647	-6.1392	6.7319	13.0686	14.6033
	Model II**	-55.6134	-15.7003	12.1429	26.7928	32.3778
Protein(lb)	Ayr Model I **	-18.7082	-2.6789	6.0456	7.0457	8.2957
	Model II**	-36.8126	-10.4325	7.7705	16.4232	23.0514
	Hol Model I **	-26.3711	-4.1059	6.2358	10.8732	13.3680
	Model II**	-50.2407	-12.3679	10.5316	23.3088	28.7684
Fat %	Ayr Model I *	0.0373	0.0077	-0.0053	-0.0117	-0.0279
	Model II	0.0273	0.0031	-0.0028	-0.0065	-0.0211
	Hol Model I	0.0024	-0.0017	0.0007	0.0007	-0.0022
	Model II	-0.0062	-0.0048	0.0026	0.0051	0.0033
Protein %	Ayr Model I	-0.0088	0.0144	0.0028	-0.0074	-0.0010
	Model II	-0.0045	0.0160	0.0023	-0.0094	-0.0043
	Hol Model I **	0.0006	0.0160	0.0002	-0.0081	-0.0087
	Model II**	0.0039	0.0173	-0.0003	-0.0099	-0.0110

a) expressed as deviations from the mean
* significant at 0.05 level
** significant at 0.01 level

age of cow had varying effects on percentage traits for the two breeds. Significant age effects were observed on protein percent for Holsteins with both models, while only fat percent from Ayrshire Model I was significantly affected by age at calving. Studies elsewhere showed disagreement regarding the effects of age on fat percent. For example, Gravir and Hickman (1966) reported no significant age effects on fat percent, but Gacula et al. (1968) showed significant effects. Different results for age at calving on percentage composition of the two breeds could be due to the small sample size for the Ayrshire population or breed differences. In general, effects of age of cow on milk yield and composition were in agreement with Gravir and Hickman (1966), Gacula et al. (1968) and Loganathan and Thompson (1968). Yields of milk fat and protein increase with age, while percentages decline steadily with age.

Effects due to year of calving on milk yield and composition were significant for both breeds with the two models (Table 10; Appendix Tables 1 to 8). The 1972 year class was eliminated in the Protein Subset analyses due to a limited number of records with protein values. Except in the first (1966) and the last (1971 and 1972) year classes, milk yield was relatively constant for both breeds over the period from 1967 to 1970, but some trends of decline in percentage of fat and protein were noticed. The drastically high and low values of estimates for 1966 and 1972 classes were presumably due to

Table 10: Least squares estimates of the effects of year of calving on milk yield and composition for Ayrshires and Holsteins from Model I and Model II[a]

Trait	Model	1966	1967	1968	1969	1970	1971	1972
		Year of calving						
Milk(lb)	Ayr Model I	365.9041	-91.6370	-85.6586	46.4148	-64.8101	-13.4226	-156.7906
	Model II	-343.4224	-441.6917	32.9486	290.8587	56.6438	226.5933	178.0698
	Hol Model I	-48.7950	50.9466	-17.2012	91.3347	73.8949	99.9475	-250.1275
	Model II	-924.1577	-518.1648	-30.0197	319.9468	324.4639	523.4639	304.4673
Fat(lb)	Ayr Model I	21.0545	3.2526	-2.8800	5.1243	-5.4066	-4.2896	-16.8552
	Model II	-7.6514	-10.9445	1.7478	14.8324	-0.4392	5.5290	-3.0739
	Hol Model I	-0.6507	4.1382	-0.1504	7.0359	2.8858	3.7393	-16.9979
	Model II	-32.7421	-16.4500	-0.3677	15.4377	12.1281	19.1909	2.8030
Protein(lb)	Ayr Model I	4.8173	-6.0140	-1.2649	2.1450	0.5620	-0.2454	
	Model II	-17.0013	-14.5850	7.8157	8.5639	7.1576	8.0491	
	Hol Model I	-12.8914	-3.2463	1.2211	5.4719	5.8037	3.6410	
	Model II	-38.0403	-18.9757	5.7143	13.8194	17.2639	20.2184	
Fat %	Ayr Model I	0.0752	0.0798	0.0082	0.0374	-0.0327	-0.0416	-0.1263
	Model II	0.0543	0.0694	0.0097	0.0426	-0.0289	-0.0331	-0.1139
	Hol Model I	0.0090	0.0196	0.0044	0.0380	0.0044	0.0019	-0.0773
	Model II	-0.0018	0.0148	0.0064	0.0411	0.0079	0.0065	-0.0749
Protein %	Ayr Model I	-0.0315	0.0046	0.0134	0.0212	0.0178	-0.0285	
	Model II	-0.0302	0.0048	0.0129	0.0244	0.0175	-0.0293	
	Hol Model I	-0.0762	-0.0202	0.0184	0.0385	0.0386	0.0009	
	Model II	-0.0738	-0.0178	0.0182	0.0376	0.0371	-0.0013	

a) expressed as deviations from the mean sampling variation since few observations were associated with these classes.

Effects of season of calving on milk yield and composition (Table 11) were significant with both models for the two breeds (Appendix Tables 1 to 8), except for fat percent and protein percent with Model I for the Ayrshires and fat percent with Ayrshire Model II. Estimates of seasonal effects on fat and protein percent were similar with Model I and Model II and closely followed the trends reported by other studies (Wilcox et al. 1959, Johnson et al. 1961, and Esan 1971). Percentages of fat and protein were highest for cows calving in the spring (Mar-Jun class). Rook et al. (1960) attributed increased SNF content to the increased plane of energy nutrition when cows were placed on spring pasture. The high percentage of protein observed in this study for cows calving in spring in the province of Quebec are closely related to the high quality of forages found during this period. No noticeable differences were found between a model accounting for and a model not accounting for levels of feeding indicating that feeding practices exert little effect on seasonal variation in milk percentages. However, for yield traits, results from Model II consistently indicated that winter calving (Nov-Feb)was the most favorable. These trends were comparable to those reported in the literature (Bereskin and Freeman 1965, Parkhie et al. 1968, and Gacula et al. 1968). But, estimates of seasonal effect from

Table 11: Least squares estimates of the effects of season of calving on milk yield and composition for Ayrshires and Holsteins from Model I and Model II[a]

Trait	Model	Season of calving		
		Nov-Feb	Mar-Jun	Jul-Oct
Milk(lb)	Ayr Model I **	43.3.83	74.8062	-118.1245
	Model II**	280.1240	-144.0795	-136.0445
	Hol Model I **	51.8456	81.8287	-133.6742
	Model II**	345.6065	-218.8621	-126.7444
Fat(lb)	Ayr Model I **	0.6572	3.9148	-4.5720
	Model II**	10.1957	-4.7931	-5.4026
	Hol Model I **	0.5185	5.2246	-5.7431
	Model II**	11.4652	-5.0626	-6.4027
Protein(lb)	Ayr Model I *	1.4428	2.9415	-4.3844
	Model II**	7.4262	-5.8120	-1.6142
	Hol Model I **	0.3010	4.0586	-4.3596
	Model II	8.2637	-4.8643	-3.3994
Fat %	Ayr Model I	-0.0089	0.0126	-0.0036
	Model II	-0.0028	0.0053	-0.0025
	Hol Model I **	-0.0111	0.0214	-0.0103
	Model II**	-0.0059	0.0239	-0.0179
Protein %	Ayr Model I	-0.0092	-0.0099	0.0192
	Model II*	-0.0102	-0.0112	0.0214
	Hol Model I **	-0.0185	0.0082	0.0103
	Model II**	-0.0189	0.0101	0.0088

a) expressed as deviations from the mean
* significant at 0.05 level
** significant at 0.01 level

a model which accounted for levels of feeding indicated spring calving (Mar-Jun) to be more favorable than winter calving.

3. Linear and quadratic effects of levels of net energy intake from silage, hay, pasture and meal on milk yield and composition

A total of 17,259 Ayrshire and 139,720 Holstein records described by Model I were subjected to least squares analyses. The resultant least squares estimates of linear and quadratic partial regression coefficients for net energy intake from silage, hay, pasture and meal for Ayrshires and Holsteins are shown in Table 12 and analyses of variance are presented in Appendix Tables 1 to 8.

Linear effects of net energy intake from silage, hay, pasture and meal feeding were all positive and significant ($P < 0.01$) for yields of milk, fat and protein in both breeds. Linear partial regression coefficients in Holsteins indicated that an increase of 1 therm of net energy fed resulted in yield increases ranging from 1.3 to 1.9 pounds for milk, 0.04 to 0.07 pounds for fat and 0.04 to 0.05 pounds for protein, depending on the source of net energy. The magnitude of effects of a fixed quantity change of net energy were in increasing order from silage, hay and pasture to meal. The feed-yield relation has been investigated extensively in

Table 12: Least squares estimates of linear and quadratic partial regression coefficients of milk yield and composition on net energy intakes for Ayrshires and Holsteins

		Partial regression coefficient							
Trait	Breed	Silage	Silage^2	Hay	Hay^2	Pasture	Pasture^2	Meal	Meal^2
Milk(lb)[a]	Ayrshire	1304.08**	-0.07	1124.49**	-0.02	1797.35**	-0.17**	1644.36**	0.10**
	Holstein	1392.61**	-0.05**	1340.05**	-0.07**	1880.55**	-0.07**	1944.79**	0.04**
Fat(lb)[b]	Ayrshire	6209.52**	-0.95**	5186.74**	-0.37*	6733.60**	-0.52*	5892.20**	0.56**
	Holstein	4839.75**	-0.05	4918.26**	-0.30**	7120.68**	-0.28**	6650.15**	0.25**
Protein(lb)[b]	Ayrshire	3908.61**	-0.04	3244.98**	0.00	5904.05**	-0.08	6339.49**	-0.00
	Holstein	4234.47**	-0.23*	4280.80**	-0.21*	5581.33**	-0.21	5375.54**	0.17**
Fat %[c]	Ayrshire	1461.96**	-0.69**	1149.30**	-0.33*	-104.66	0.15	-110.13	0.15*
	Holstein	-62.56	0.11**	117.36	-0.04	505.87**	-0.05	-107.94	0.07*
Protein %[c]	Ayrshire	258.83	-0.39	-76.46	-0.01	-538.09	0.12	352.92	-0.09
	Holstein	193.34	-0.11*	132.69	-0.06	-45.46	0.01	117.14	-0.04*

a) coded by times 10^3, b) coded by times 10^5, and c) coded by times 10^7
* significant at 0.05 level
** significant at 0.01 level

nutritional studies (Burt 1957, Huffman 1961, Kesler and Spahr 1964, Coppock 1969, Hillman 1969, Miller and O'Dell 1969, and Broster 1972) and from yearly herd average production records (Bayley and Heizer 1952, McKinney et al. 1965, Stone et al. 1966, Miller 1968, Miller et al. 1968, and Brown and White 1973). Positive relationships observed in this study between net energy intake from various sources of feed and lactation yields indicated yields were independent from the source of net energy whether from forages or concentrates. Many studies (McCullough and Shell 1955, Castle et al. 1960, Castle et al. 1964, and Donker et al. 1968) have indicated either little or no effect on milk production when extra concentrates were fed to cows grazing on high-quality pasture. Equally high milk production levels have been maintained when cows were fed varying forage proportions ranging from all silage to all hay when properly supplemented with concentrates (Brown et al. 1965, Brown et al. 1966, Hemken and Vandersall 1967, Coppock 1969, and Hillman 1969). From studies on yearly herd average records, milk yield responses to feeding 1 kg of concentrates ranged from 0.74 to 0.84 (Stone et al. 1966, and Brown and White 1973). Brown and White (1973) reported positive and significant linear effects of concentrates, hay and pasture feeding on yearly herd average milk production. Most of the studies on herd average production records were based on the relationship between quantity fed and response of milk production. The measure of levels of feeding in the present study was the estimated lactation net energy intake from the respective source of feeds. Apparently, this is a better estimator of feed intake than that used in input-output types of studies because this estimator accounts for (1) individual cow differences and (2) variations in feed quality. The linear effects of net energy intake from silage, hay, pasture and meal on yields of milk, fat and protein for both breeds were in agreement with the results of above literature cited. Higher levels of net energy intake generally resulted in increased production.

For the Holstein population, quadratic effects of net energy intake from silage, hay, pasture and meal feeding were all significant for yields of milk, fat and protein except the effects of silage on fat yield and pasture on protein yield. Fewer significant quadratic effects were observed in Ayrshires, either because of sample size or breed differences. Significant quadratic effects of concentrates but varying effects of silage and hay on yearly herd average milk production for Guernsey, Holstein and Jersey were reported by Brown and White (1973). It is evident from this study (Table 12) that, although the quadratic effects for yield traits were statistically significant, the values were relatively small and of minor practical importance. Brown and White (1973) compared a full regression model which included both linear and quadratic effects of concentrates, silage, hay and pasture and the reduced model which included only linear effects. They reported that the full model accounted for no more than a 1% increase in the amount of variation which could be accounted for by only the linear model.

In Holsteins, linear effects of feed intake did not significantly affect percentages of fat and protein, except for the linear effects of pasture on fat percent. Quadratic effects of silage and meal on fat percent and meal on protein percent in Holsteins were significant. Fat percent of Ayrshires was apparently more affected by feeding levels as significant results were observed for linear silage and hay effects and quadratic silage, hay and meal effects. Protein percent was not affected by levels of feeding in Ayrshires and only quadratic effects of silage and meal were significant for Holsteins. Conclusively, net energy intake from silage, hay, pasture and meal had little effect on milk composition.

4. Effects of feed ratios on milk yield and composition

The effects of the ratios of silage:hay, roughage: concentrate and energy concentration were estimated from Model III for Ayrshires and Holsteins. Results are shown in Table 13 and analyses of variance are presented in Appendix

Table 13: Least squares estimates of effects of feed ratios on milk yield and composition for Ayrshires and Holsteins

	Partial regression coefficient					
	Silage:Hay		Roughage:Concentrate		Energy Concentration	
Trait	Ayrshire	Holstein	Ayrshire	Holstein	Ayrshire	Holstein
Milk(lb)	9.7518	17.1199**	-322.5810**	-1064.6011**	3178.8141**	3274.7093**
Fat(lb)	-2.0412	0.7469**	-14.1612**	-38.7079**	113.0272**	127.8431**
Protein(lb)	9.5414**	0.5501**	-26.8488**	-30.6964**	169.5680**	131.0015**
Fat %	-0.0291**	0.0014**	-0.0223**	-0.0123**	-0.1757	0.1117**
Protein %	-0.0122	-0.0025**	0.0097	-0.0003	0.1468	-0.0700

** significant at 0.01 level

Tables 9 to 12. Since there were almost eight times as many Holsteins as Ayrshires, the Holstein results were used as the basis for interpreting the results.

An all silage feeding program offers means of circumventing the problem of hay curing and can adapt well to automated feeding. Various aspects of silage feeding have been extensively reviewed (Hemken and Vandersall 1967, Coppock 1969, Hillman 1969). The results have generally indicated that, for cows fed varying forage proportions ranging from all corn silage to all hay, milk yield and composition has not been affected by the source of roughage in the ration (Brown _et al_. 1965, Brown _et al_. 1966, and Hemken and Vandersall 1967). Results from the present study support the above view. Holstein results indicated that if the ratio of silage:hay fed was doubled, it would result in increases of 17 pounds of milk, 0.75 pounds of fat and 0.55 pounds of protein. Fat percent was slightly increased whereas protein percent was decreased when more silage in relation to hay was fed. However, the effects of silage: hay ratio were small and probably contributed little practical significance.

Higher roughage:concentrate ratio significantly ($P < 0.01$) depressed yields of milk, fat and protein and percent fat for both Ayrshires and Holsteins (Table 13). Protein percent in Holsteins was lowered when a higher proportion of the ration was composed of roughage, but it was statistically not significant. The key problem generally expressed in high levels of roughage feeding is that cows usually can not obtain sufficient energy intake to meet their requirement, so that proper supplementation with concentrate is necessary. Previous studies have indicated that high-concentrate feeding results in increased milk production (Hotchkiss et al. 1960, Brown et al. 1962, Ronning and Laben 1966, Forgate et al. 1968, and Bath et al. 1974). The decreased production observed with high roughage rations in the present study supports those results reported elsewhere. However, fat depression with high concentrate rations was not observed in this study. Changes in fat and protein percent resulting from changes in ruminal acid ratios may or may not develop, depending on the particular concentrate, nature of the forages and methods of feeding (Rook 1961, Van Soest 1963, and Ronning and Laben 1966).

Energy concentration is a measure of nutritive value of the feed (i.e. higher energy concentration indicates more net energy available in a pound of feed consumed). Highly significant ($P < 0.01$) increased yields of milk, fat and protein and fat percent were observed with increased energy concentration (Table 13). Fat depression was not observed in Holsteins, presumably because a considerable portion of the ration was roughage. Elliot and Loosli (1959) reported that if energy intake were held constant, different ratios of hay:concentrate (60:40, 40:60, and 80:20) seemed to have little effect on production. On the contrary, feeding grains of relatively high fibre content to increase the plane of nutrition results in only small increases in milk production (Huber et al. 1965). Bayley and Heizer (1952) reported that for an increase of 1 pound of TDN per 1000 pounds of body weight, an average increase of 551 pounds of milk and 18 pounds of fat was produced. In this study, the large and significant increases of yields of milk, fat and protein resulting from increased energy concentration in the feed support the view that adequate energy should receive primary consideration in practical dairy cattle feeding.

5. Effects of levels of feeding on estimates of intra-herd repeatability

Henderson's Method II was used to estimate herd, cow within herd and within cow variance components based on Model I and Model II. This method requires correcting the lactation records for the fixed effects in the model. Records of Model I were corrected by levels of feeding in addition to other fixed effects in Model II, and were referred to as Corrected Records. Analyses of variance and expected sums of squares of Model I and Model II required for the estimation of variance are shown in Appendix Tables 13 and 14 for Ayrshires and 15 and 16 for Holsteins. The estimated components of variance from Corrected and Uncorrected Records for Ayrshires and Holsteins were summarized in Appendix Tables 17 and 18.

One of the consequences when lactation records were corrected for levels of net energy intakes in addition to correcting for age, year and season of calving was the tremendous reduction in the components of variance for yields of milk, fat and protein, but those of percentages were scarcely affected. Hence it is difficult to interpret changes in the components of variance when expressed as absolute values. In order to examine the relative reduction in the various components of variance due to different levels of feeding, components of variance were expressed as a percentage of total variance in each model (Table 14). Percent changes in the total variation for yields of milk, fat and protein ranging from 1 to 3% for Ayrshires and 7 to 9% for Holsteins were attributed to differences in feeding practices among herds, and 6 to 8% for Ayrshires and 2 to 6% for Holsteins were accounted for by levels of feeding among cows. There were slight increases in the percent of total variance for herd effects of protein percent in both Ayrshires and Holsteins after accounting for levels of feeding. Table 12 indicated that most of the regressions of feed intakes on protein percent were statistically not significant, thus presumably the resulting

Table 14: Variance components expressed as a percent of total variance and repeatability estimates from Corrected and Uncorrected Records

		Percent of total variance							
		Herd		Cow		Within cow		repeatability[a]	
Trait	Record	Ayr	Hol	Ayr	Hol	Ayr	Hol	Ayr	Hol
Milk(lb)	Corrected	40	34	20	24	40	42	0.34	0.36
	Uncorrected	41	41	27	28	32	31	0.45	0.47
Fat(lb)	Corrected	38	30	18	25	44	45	0.30	0.35
	Uncorrected	41	40	24	26	35	34	0.40	0.43
Protein(lb)	Corrected	40	36	15	16	45	48	0.27	0.25
	Uncorrected	43	44	23	23	34	33	0.41	0.40
Fat %	Corrected	21	14	40	54	39	32	0.51	0.62
	Uncorrected	21	14	40	53	39	33	0.51	0.62
Protein %	Corrected	21	17	33	34	46	49	0.42	0.41
	Uncorrected	20	15	34	35	46	50	0.43	0.41

a) intra-herd repeatability, r = cow/cow + within cow.

herd component of variance should not differ much from component estimates from Uncorrected Records. The reason for the inflated herd component of protein percent is not known. This might have been due to rounding errors in the computation procedures or the relative changes in cow and within cow components resulting in the change in the herd component. The herd component of variance after accounting for levels of feeding might have magnified other environmental and genetic influences upon the cows in the herd. Griffiths and Featherstone (1957) studied seven herds of cows with low SNF content, and after accounting for season, stage of lactation, age, mastitis and feeding practices as factors involved, they concluded that genetics constituted a major factor. No essential differences existed in the percent of total variance components for percent fat between Corrected and Uncorrected Records (Table 14). These results favour the generally expressed view that the fat test is least affected by feeding practices among percentage traits.

Repeatabilities (Table 14) for Holsteins from Uncorrected Records were within the range of those reported by Butcher <u>et al</u>. (1967) and Gacula <u>et al</u>. (1968), but slightly lower than those reported by Bereskin and Freeman (1965), Gaunt <u>et al</u>. (1968) and Wilcox <u>et al</u>. (1971). Repeatability of fat percent was comparable to that of Butcher <u>et al</u>. (1967) and the repeatability of protein percent was similar to that of Gaunt et al. (1968). Repeatability estimates of milk yield and composition for Ayrshires agreed with those of Gacula et al. (1968) and were lower than those of Wilcox et al. (1971). The second consequence of major concern is the disproportionate changes in the components of variance resulting from Corrected Records which reduced the repeatability estimates. Intra-herd repeatability estimates were drastically reduced for yields of milk, fat and protein, but those of percentages of fat and protein were not affected (Table 14). Repeatability is a measure of the within herd average correlation between records of the same cow. It estimates the proportion of variation among observations caused by permanent differences among animals. These permanent differences consist of the animal's genotype and some permanent environmental effects determining the animal's real producing aility. Therefore, the genetic and the environmental interpretations of the components underlying the model must be related in order to consider the effects of levels of feeding on estimates of repeatability.

Herd and cow components of variance contain genetic and permanent environmental portions, whereas the within cow component contains the sampling variance of repeated records and temporary environmental effects of the same cow. By correcting records for the levels of feeding, part of the permanent environmental effects, contributed by differences in feeding practices among herds or cows, is removed. The relative percent reduction of the herd variance component between Corrected and Uncorrected Records, as pointed out earlier, represents the percent of the total variation accounting for feeding practices among herds in milk yield and composition. The disproportionate reduction in herd and cow components and the inflation of within cow component consequently reduced the repeatability estimates. Frequently, repeatability estimates are considered as logical upper limits for heritability estimates. If all environmental portions were removed from the cow component, it estimates the heritability in a broad sense. The reduction in repeatability observed in this study when environmental effects due to levels of feeding were removed thus narrowed the gaps between estimates of repeatability and heritability. For example, repeatability from Corrected Records for Holsteins in milk yield was close to heritability estimates of 0.35 reported by Gacula _et al_. (1968) and 0.37 of Thompson and Loganathan (1968). As indicated earlier, fat percent was known to be least affected by changes in feeding practices. This corresponds well to the least reduction in repeatability in fat yield, being reduced by 0.10 for Ayrshires and by 0.08 for Holsteins. Repeatability for milk yield was reduced by 0.11 for both Ayrshires and Holsteins. The repeatability estimate of protein yield was reduced as much as 0.14 for Ayrshires and 0.20 for Holsteins. This observation favours the view expressed frequently that nutrition may be another way to change protein content of milk (Legates 1960, Rook 1961, Laben 1963, and Huber and Boman 1966). The tremendous reductions in repeatability estimates of protein yield observed from this study indicate feeding practices are a major environmental influence on this trait. The repeatability estimate of protein yield for Holstein from Corrected Records was comparable to most of the heritability estimates of this trait reported elsewhere (Butcher _et al_. 1967, Gacula _et al_. 1968, and Batra _et al_. 1969). Conclusively, most of the permanent environmental influences affecting the value of repeatability appear to be of nutritional origin. However, the repeatability estimates of percentages of fat and protein were apparently not affected by levels of feeding. This observation was partly explained by the relatively high heritability of percentage traits that only small portion of the variation is due to environmental causes.

6. Effects of correcting for feeding levels on estimates of genetic parameters on milk yield and composition

Most studies of genetic parameters of dairy traits have neglected the effects of nutrition, conceivably due to the inavailability of such information on lactation records. Studies from the previous sections have shown the effects of levels of feeding on lactation traits to be significant in most cases. An immediate problem is whether these nutritional effects would alter the estimates of genetic parameters.

The primary objective of the present study was to compare genetic parameters ajusted for levels of feeding to those obtained by the convention way of estimation.

A total of 13,561 305-day Holstein lactation records with sires identified were collected for the subsequent genetic studies. These sires were either A.I. or natural service sires which were used in one or more herds. This subset of records accounted for approximately 10% of the total Holstein lactation records. Distribution of these records by sire, herd, sire-herd subclass and cow within sire-herd subclass is shown in Appendix Table 19. Corrected Records consisted of those records corrected by the estimated least squares effects (from Model I) for age, year and season of calving and net energy intake from silage, Hay, pasture and meal. Records corrected by the least squares estimates from Model II, which were corrected only for effects due to age, year and season of calving, constituted the Uncorrected Records. Since these two sets of least squares estimates were obtained from a large segment of the milk recored Holstein population in Quebec, the corrected subsets of records should not be subject to serious sampling errors. For the purpose of this study, these subsets of cows were assumed to be randomly collected.

A comparison of the phenotypic performance of Holstein cows from Corrected and Uncorrected Records was studied, and the results were presented in Table 15. Means of milk yield and composition of the Uncorrected Records were higher than those without age ajusted population means in Table 7. The coefficients of variation of lactation traits from Table 15 for the Uncorrected Records were within the range of the Holstein estimates reported by Wilcox *et al*. (1971). After records were corrected for least squares estimates of feeding levels, general reductions in the means, standard deviations and coefficients of variation for all yield traits were noted, but percentage traits remained relatively unchanged.

Table 15: Means, standard deviations and coefficients of variation of milk yield and composition for Corrected and Uncorrected Records

	Corrected Records			Uncorrected Records		
Trait	Mean	S.D.	C.V.	Mean	S.D.	C.V.
Milk(lb)	10,745	1,337	0.12	11,561	2,465	0.21
Fat(lb)	383	58	0.15	412	96	0.23
Protein(lb)	343	45	0.13	364	78	0.21
Fat %	3.56	0.36	0.10	3.57	0.36	0.10
Protein %	3.08	0.23	0.07	3.08	0.22	0.07

Simple correlations were made to study the changes of levels of feeding to changes in lactation traits on both sets of records (Table 16). Silage had the lowest and meal the highest value of correlation coefficient with the lactation traits. Stone et al. (1966) reported 0.49 correlation between yearly herd average milk production and the meal feeding but negligible correlation with silage, hay and pasture. As might be expected, correcting for the levels of feeding reduced the correlation between the dependent and the independent variables. The most drastic reductions in the coefficients of correlation were observed between yields and meal. However, the correlation between protein percent and silage and between protein percent and meal was increased by 0.07 and 0.11 respectively. One of the possible explanations was the rounding errors in the computation procedures, since none of the linear and only two quadratic regressions of protein percent on net energy intakes were significant (Table 12).

Henderson's Method I was used on Model IV to estimate sire, herd, sire x herd and cow within sire x herd components of variance and covariance from the Corrected and Uncorrected Records. Repeatability was calculated on a within herd basis and heritability was computed as the ratio of four times the sire component to the total variance component (i.e. the sum of sire, sire x herd, cow and within cow variance components). The estimated components of variance

Table 16: Simple correlations between lactation traits and net energy intakes for Corrected and Uncorrected Records

Trait	Record	Silage	Hay	Pasture	Meal
		Simple correlation coefficient			
Milk(lb)	Corrected	-0.04	0.03	0.03	0.14
	Uncorrected	0.21	0.14	0.01	0.78
Fat(lb)	Corrected	0.01	0.02	-0.03	0.13
	Uncorrected	0.22	0.12	-0.02	0.74
Protein(lb)	Corrected	0.08	-0.05	-0.04	0.20
	Uncorrected	0.22	0.08	-0.02	0.75
Fat %	Corrected	0.07	0.03	-0.05	0.09
	Uncorrected	0.08	0.02	-0.03	0.12
Protein %	Corrected	0.16	-0.04	-0.04	0.21
	Uncorrected	0.09	-0.01	-0.02	0.10

on both sets of records for milk yield and composition are presented in Appendix Table 20. After records were corrected for levels of feeding, components of variance were reduced for yield traits, but some irregular patterns of slight increases or decreases were observed in the variance components of percentage traits. The percent reduction in the magnitude of variance components due to correcting for levels of feeding ranged from 20 to 73% in yield traits. Therefore, for more meaning, these estimates of variance component were converted to relative percent of the total variation in both sets of records (Table 17).

The contribution of sire component to the total variance for yields of milk, fat and protein for Uncorrected Records ranged from 6.11 to 7.71% and those of percentages composition ranged from 6.66 to 13.03 (Table 17). The relative proportion of herd component expressed as percent of total variation accounted for from 32.57 to 39.51 for yields of milk, fat and protein and from 11.38 to 13.52 for percentage traits. These estimated variance components were in the range of those reported in the literature (Hickman and Henderson 1955, Legates _et al_. 1956, Van Vleck _et al_. 1961, Burdick and McGillard 1963, Bereskin and Freeman 1965, Van Vleck 1966, Gacula _et al_. 1968, and Norman _et al_. 1972). Sire by herd interactions accounted for from 0.29% of the total variance for protein yield to 5.60% for protein percent among all

Table 17: Repeatability, heritability and estimated percentages of total variation of Holstein records contributed by sire, herd, sire x herd and cow components of variance

Trait	Record	Percentage of total variation					Total	r	h^2
		Sire	Herd	SH	Cow	Error	variance		
Milk(lb)	Corrected	6.60	32.39	3.39	15.01	42.61	1790582	0.32	0.39
	Uncorrected	6.11	32.57	4.12	21.77	35.43	6088753	0.41	0.36
Fat(lb)	Corrected	8.55	27.69	2.27	17.49	44.00	3396	0.36	0.47
	Uncorrected	7.71	33.68	1.14	21.15	36.32	9328	0.44	0.47
Protein(lb)	Corrected	6.06	30.91	0.42	10.04	52.57	2064	0.23	0.35
	Uncorrected	6.73	39.51	0.29	16.57	36.90	6047	0.39	0.45
Fat %	Corrected	12.97	10.74	3.19	40.82	32.28	0.1329	0.60	0.58
	Uncorrected	13.03	11.38	2.65	40.68	32.26	0.1333	0.61	0.59
Protein %	Corrected	6.88	14.34	5.30	22.20	51.28	0.0509	0.34	0.32
	Uncorrected	6.66	13.52	5.60	22.58	51.64	0.0505	0.34	0.31

lactation traits. These results favour most of the published estimates on sire x herd interactions that this component was generally small or negative (Legates *et al*. 1956, Wadell and McGillard 1959, Van Vleck *et al*. 1961, Van Vleck 1966, and Burdick and McGillard 1963). Repeatability estimates on a within herd basis for yields of milk, fat and protein were slightly lower than reports of Wilcox *et al*. (1971), but comparable to those of Gacula *et al*. (1968). Those of percentages composition were comparable to reports of Von Krosigk *et al*. (1960) and Butcher *et al*. (1967), but slightly lower than reports of Gaunt *et al*. (1968) and Gacula *et al*. (1968). Heritability of milk yield and composition were in general agreement with most of the published estimates, except that of protein percent was low (Sargent and Legates 1964, Blanchard *et al*. 1966, Butcher *et al*. 1967, Gacula *et al*. 1968, Gaunt *et al*. 1968, and Thompson and Loganathan 1968).

Sire components obtained from records corrected for levels of feeding were slightly increased for yields of milk and fat and percent protein, but decreased slightly for protein yield and fat percent. Sire by herd interaction components of variance had varying effects after being corrected for levels of feeding. Percent components of variance for herd and cow effects were reduced in all traits. These results agreed with those observed in Table 14, confirming that correcting records for levels of feeding effectively removed a considerable amount of environmental variation associated with herd and cow components. As might be expected, repeatability was reduced for all traits (Table 17). The changes in heritability in the Corrected Records were small and probably of little practical significance. However, in all cases, slight increases or decreases in heritability were reflected by the similar changes in the percent sire components. Higher heritability than the corresponding repeatability in milk yield and fat yield was due to the large reduction in cow variance component after records were corrected for levels of feeding. This appears that a considerable amount of permanent environmental effects in the cow component is of nutritional origin.

Phenotypic correlations among yields (Table 18) ranged from 0.85 to 0.91 for the Uncorrected Records. The relationships between constituents and yields were smaller and ranged from -0.20 to 0.46. Genetic correlations among yields were high and similar to those of phenotypic values. The remaining genetic correlations, with two exceptions, were also simailar to the corresponding phenotypic correlation values. The two exceptions were the small positive relationship between milk yield-fat percent and the relatively small negative correlation between milk yield-protein percent. These estimates were within the range of reports elsewhere, with only one exception that both phenotypic and genetic

Table 18: Phenotypic and genetic correlations among milk and milk constituents from Corrected and Uncorrected Records

		Genetic correlation				
Trait	Record	Milk	Fat	Protein	Fat %	Protein %
Milk(lb)	Corrected		0.47	0.81	-0.27	-0.42
	Uncorrected		0.81	0.94	0.05	-0.13
Fat(lb)	Corrected	0.59		0.56	0.71	0.10
	Uncorrected	0.85		0.85	0.61	0.16
Protein(lb)	Corrected	0.75	0.66		-0.01	0.17
	Uncorrected	0.91	0.86		0.18	0.21
Fat %	Corrected	-0.24	0.62	0.08		0.53
	Uncorrected	-0.12	0.40	0.06		0.53
Protein %	Corrected	-0.23	0.20	0.45	0.46	
	Uncorrected	-0.20	0.06	0.22	0.46	

Phenotypic correlation

correlations between milk yield-fat percent were high (Sargent and Legates 1964, Blanchard et al. 1966, Butcher et al. 1967, Christensen 1968, Thompson and Loganathan 1968, Batra et al. 1969, and Wilcox et al. 1971).

General reductions in components of covariance were observed from the Corrected Records. Phenotypic correlations between milk yield and constituents were decreased. Slight increases or decreases in phenotypic correlation were noted among other traits, except protein percent-fat percent was not affected. Genetic correlations among milk yield and milk constituents were also generally decreased except that of fat yield-fat percent and protein percent-fat percent. These changes in phenotypic and genetic correlations were brought about by unequal rate of reductions in the components of covariance to the corresponding variances resulting in increases or decreases in the ratios of the product moment correlation coefficients. Relatively greater reductions in genetic correlations than the corresponding phenotypic correlations indicated greater amounts of environmental covariance due to levels of feeding were associated with the sire components. Thus, the corresponding environmental correlations would also be expected to be reduced. Increases observed in phenotypic and genetic correlations were relatively small compared to the decreases in most of the correlations. Both phenotypic and genetic correlations of protein percent-fat percent were unaltered. These two traits can be assumed to have little environmental variance or covariance attributable to levels of feeding.

7. Sire x herd interactions and genetic parameter estimations from herds feeding different levels of concentrates

Sire by herd and sire by herd production levels interactions have generally been reported to be insignificant (Legates 1962, Burdick and McGillard 1963, and Van Vleck 1963). These studies have inevitably classifed herd environments according to levels of milk production. Large scale studies of genotype by environmental interactions and genetic parameter estimations from herd environments defined by different levels of concentrate intake has not been done. This investigation was designed to seek information on the interrelationships between genetics and nutrition in uncontrolled environments.

A total of 13,561 305-day, age, year and season of calving corrected lactation records were divided into three approximately equal subsets according to low (less than 2200 therms), medium (between 2200 and 2900 therms) and high (greater than 2900 therms) level of lactation net energy intake from concentrates (meal). Henderson's Method I was used on Model IV (including sire, herd, sire x herd and cow within sire x herd subclasses)to estimate components of variance and covariance.

Genetic parameters were computed within each subset of records. Distribution of these subsets of records by sire, herd, sire x herd and cow within sire x herd subclass are shown in Appendix Table 19. The number of observations in each subset were considered approximately equal, but no attempt was made to study how sires were represented in the three environments.

The relationships of levels of meal feeding and phenotypic performance of lactation traits were investigated (Table 19). Means of all traits consistently increased, whereas coefficients of variation decreased with higher levels of meal intake. Phenotypic standard deviations were highest in high level. Studies elsewhere (Legates 1962, and Van Vleck 1963) have shown higher mean and total variation in production of milk in records from higher production levels. The close association between different criteria of stratifying lactation records, i.e. by either levels of production or levels of meal intake as used in this study, is probably connected with the high conrrelations between yield traits and meal intake, which ranged from 0.74 to 0.78 (Table 16).

Sire components of variance for yields of milk, fat and protein ranged from 4.84 to 10.94% of the total variation (Table 20). The estimated actual components of variance are presented in Appendix Table 21. There was no evidence of increasing sire or total variation with improved environments

Table 19: Phenotypic performance of cows in low, medium and high level of meal intake

Trait	Level of meal intake	Mean	S.D.	C.V.
Milk(lb)	Low	9,602	1,825	0.19
	Medium	11,512	1,608	0.14
	High	13,702	1,953	0.14
Fat(lb)	Low	339	72	0.21
	Medium	411	67	0.21
	High	491	81	0.17
Protein(lb)	Low	303	58	0.19
	Medium	360	54	0.15
	High	427	63	0.15
Fat %	Low	3.54	0.3640	0.10
	Medium	3.58	0.3579	0.10
	High	3.59	0.3706	0.10
Protein %	Low	3.06	0.2289	0.07
	Medium	3.07	0.2209	0.07
	High	3.09	0.2235	0.07

Table 20: Repeatability, heritability and estimated percentages of total variation of Holstein records from three levels of meal intake

Trait	Level of meal intake	Percentage of total variation					Total variance	r	h^2
		Sire	Herd	SH	Cow	Error			
Milk(lb)	Low	5.29	30.01	-0.75	16.57	48.88	3336441	0.31	0.30
	Medium	7.38	32.32	-2.40	18.58	44.12	2588865	0.38	0.44
	High	4.84	25.60	5.56	21.35	42.65	3826156	0.35	0.26
Fat(lb)	Low	5.87	28.57	0.31	15.59	49.66	5197	0.30	0.33
	Medium	6.13	29.66	2.79	15.43	45.99	4471	0.31	0.35
	High	6.13	26.81	2.01	21.22	43.83	6628	0.37	0.34
Protein(lb)	Low	10.94	35.52	-5.95	10.62	48.87	3327	0.33	0.68
	Medium	4.72	33.82	-0.85	15.78	46.53	2882	0.31	0.29
	High	5.98	30.78	1.15	10.57	51.52	4045	0.24	0.35
Fat %	Low	8.88	12.50	7.62	33.97	37.03	0.1326	0.49	0.41
	Medium	13.65	11.26	1.04	43.39	30.66	0.1281	0.64	0.62
	High	14.06	10.82	1.49	40.31	33.32	0.1375	0.61	0.63
Protein %	Low	3.47	13.84	17.89	21.52	43.28	0.0525	0.29	0.16
	Medium	6.73	12.60	4.37	18.88	57.42	0.0488	0.29	0.31
	High	7.47	11.65	5.10	22.37	53.41	0.0499	0.34	0.34

in the yield traits. However, sire components of percent fat and percent protein consistently increased with levels of meal feeding. The inconsistency observed in the sire components may be due to the fact that sires used in this analysis were not necessary equally represented across environments. Relative changes in sire components were reflected in the heritability estimates. There were no specific trends for heritabilities of yield traits, but gradual increases with levels of meal intake for constituent traits were noted. Heritabilities of constituents in the two high level groups were almost double the value of the low level group. Mason and Robertson (1956) and Van Vleck (1963) consistently showed that genetic variance of milk yield within herds increased as the average yield increased and correspondingly the heritabilities were also increased. However, Burside and Rennie (1961) and Legates (1962) agreed that although the total variability and the genetic variability increased with levels of production, yet the heritability remained relatively constant over all levels. The changes in sire components from three environments with low, medium and high level of meal intake indicate a form of sire by ration interaction. The relative changes of percent genetic variance between levels of meal intake within each traits ranged from approximately 1 to 5% of the total variation. Sire by ration interactions in dairy records ranging from negligible amounts to 17% of the total variation have been reported (Mao and Burside 1969, Richardson <u>et</u> <u>al</u>. 1971, Lamb *et al.* 1973, and Rindsig and Freeman 1973).

Sire by herd interactions when daughters of sires were grouped into three environments increased with improved feeding levels for yield traits but decreased for percent constituents (Table 20). Interactions ranged from negative to 5.56% for yield traits from this study were comparable to reports elsewhere (Legates *et al.* 1956, Wadell and McGillard 1959, Van Vleck *et al.* 1961, Burdick and McGillard 1963, and Van Vleck 1966). Hammond(1947) concluded that the character required is best selected for under environmental conditions which favours its fullest expression and that once developed could be used in other environments. Falconer and Latyszewski (1952) pointed out that for Hammond's concept to hold good, there should be no genotype-environmental interaction. The magnitude of sire x herd interaction of milk production at high levels of meal intake was greater than the corresponding sire component (Table 20). This could lead to some serious consequences in sire evaluation. On the other hand, improved feeding practices apparently had little influence on percentage composition (Table 12), the reduction in interaction terms in these traits might have been due to change of the negative correlation with yield traits.

Percentages of total variation attributable to herds were essentially lower at higher levels of meal feeding. If less than 10% of herd differences are of a genetic nature (Pirchner and Lush 1959), then herd components reflected largely environmental variation. Improved feeding practices would undoubtedly removed some of these environmental differences among individual herds. Cow components at higher levels of meal intake were generally increased. If animals under favourable environmental conditions could express their genotypes to the fullest extent, increases in variation between genotypes are to be expected. Studies have shown that genetic variability increased with levels of production (Mason and Robertson 1956, Burnside and Rennie 1961, Legates 1962, and Van Vleck 1963). Changes of sire components with levels of meal feeding also partially supported this view. Therefore, it is reasonable to expect cow components would increase with improved environments. Increases in sire and cow component resulted in increased repeatabilities. Results consistently indicated repeatabilities of all traits increased with increasing levels of meal feeding, except for protein yield (Table 20). Shrode <u>et al</u>. (1960) reported that changes of repeatabilities from 0.37, 0.32 and 0.70 to 0.49, 0.44 and 0.71 for milk, fat and fat percent respectively after some known definite improvements in various aspects of herd management were made.

Phenotypic and genetic correlations among milk and milk constituents from three levels of meal intake are presented in Table 21. Both phenotypic and genetic correlations decreased with improved environments, except the phenotypic values of fat percent-fat yield, protein percent-fat yield and protein percent-protein yield, and the genetic value of fat yield-fat percent were increased with higher levels of meal intake. Increases or decreases in the product moment correlations are brought about by changes in the ratios of the covariance to those of the variances. Much of the discussion in interpreting the changes of variance components in different environments could also be used to explain the changes in covariances. Improved environments removed some temporary einvironmental covariances associated with the joint function of the two traits and thus reflected the true correlations of these traits.

It is interesting to observe the relationship between milk and fat percent. A majority of the reports found that the phenotypic correlations ranged from -0.05 to -0.66 and the genetic correlations ranged from -0.17 to -0.44 (Sargent and Legates [illegible]1964, Blanchard <u>et</u> <u>al</u>. 1966, Thompson and Loganathan 1968, Batra <u>et</u> <u>al</u>. 1969, and Wilcox <u>et</u> <u>al</u>. 1971). The estimates of correlation for milk yield-fat percent in three environments fell within these ranges, but with decreasing magnitude from low to high level. These results indicated that environmental effects due to nutrition could be one of the sources of variation contributing to differences in estimates of correlations appearing in the literature.

Table 21: Phenotypic and genetic correlations among milk and milk constituents from three levels of meal intake

Trait	Level of meal intake	Genetic correlation				
		Milk	Fat	Protein	Fat %	Protein %
Milk(lb)	Low		0.81	0.97	-0.02	0.58
	Medium		0.55	0.84	-0.38	-0.46
	High		0.42	0.87	-0.36	-0.50
Fat(lb)	Low	0.84		0.99	0.56	0.87
	Medium	0.72		0.45	0.55	0.00
	High	0.72		0.68	0.69	0.03
Protein(lb)	Low	0.89	0.85		0.37	0.77
	Medium	0.83	0.76		-0.19	0.07
	High	0.83	0.75		0.04	-0.01
Fat %	Low	-0.08	0.45	0.13		0.88
	Medium	-0.18	0.55	0.11		0.45
	High	-0.21	0.52	0.04		0.47
Protein %	Low	-0.19	0.10	0.27	0.47	
	Medium	-0.17	0.17	0.39	0.46	
	High	-0.23	0.13	0.35	0.46	

Phenotypic correlation

Reductions in phenotypic correlations were not too large, ranging from 0.02 to 0.13 for all traits. But the decreases in genetic correlations with improved environments were much larger and have significant implications. One of these implications is that the expected selection response could be serious biased if no consideration is made regarding the environment upon which the genetic correlation value is obtained.

8. Consequence in genetic parameter estimates neglecting sire x herd interaction

Most estimates of genetic parameters using paternal half sib correlation methods from mature equivalent records were based on models ignoring sire x herd interaction (for example, Gacula et al. 1968, and Wilcox et al. 1971). Results from the previous section indicated that sire x herd interactions for yield traits were larger in better environments. From the existing data, this follow-up study used a model ignoring sire x herd iteraction (i.e. Model V) to reestimate the genetic parameters.

Repeatability, heritability and estimated percentages of total variation from Model V (including sire, herd and cow within sire-herd subclasses) for records of three levels of meal intake are presented in Table 22, and the actual estimated components of variance are shown in Appendix 22. Before

Table 22: Repeatability, heritability and estimated percentages of total variation from an interaction ignored model

Trait	Level of meal intake	Percentage of total variation				Total variance	r	h^2
		Sire	Herd	Cow	Error			
Milk(lb)	Low	4.92	29.81	16.52	48.75	3345431	0.31	0.28
	Medium	6.11	31.72	18.42	43.75	2610848	0.36	0.36
	High	8.04	26.74	21.76	43.46	3754540	0.41	0.44
Fat(lb)	Low	6.03	28.65	15.61	49.71	5192	0.30	0.34
	Medium	7.61	30.35	15.58	46.46	4426	0.33	0.44
	High	7.29	27.22	21.37	44.12	6584	0.39	0.40
Protein(lb)	Low	7.59	33.99	10.43	47.99	3388	0.27	0.46
	Medium	4.25	33.61	15.74	46.40	2890	0.30	0.26
	High	6.69	31.01	10.61	51.69	4031	0.25	0.39
Fat %	Low	12.90	14.10	34.93	38.07	0.1289	0.56	0.60
	Medium	14.23	11.45	43.55	30.77	0.1277	0.65	0.64
	High	14.95	11.05	40.51	33.49	0.1369	0.62	0.67
Protein %	Low	13.90	17.52	22.77	45.81	0.0496	0.44	0.67
	Medium	9.25	13.40	19.14	58.21	0.0483	0.33	0.43
	High	10.64	12.41	22.72	54.23	0.0492	0.38	0.49

comparing the results to those of the previous model which included sire x herd interactions, an examination of the individual expectations was necessary (page 47). Expectations of cow and within cow sums of squares were the same in both models, but (K2 - K9) and (K4 - K9) of the interaction term were taken away from sire and herd equations respectively. Thus the existence of a sire x herd interaction would overestimate these two components in a model which failed to account for this interaction. This statement was examplified by comparing the sire component in milk yield from both models(Table 20 and Table 22). Furthermore, heritability is a ratio of four times the sire to the total variance, positive and negative interaction component estimates changed the absolute magnitude of the total variance. Nevertheless, the differences may be of no practical significance. For example, heritabilities of milk in three environments from the model ignoring interaction still fell within the acceptable range of this estimate. Repeatability was not expected to change greatly because the cow component would not be appreciably affected by the inclusion or deletion of a sire x herd term.

Ignoring interaction apparently did not affect phenotypic and genetic correlations (Table 23), except for the genetic correlations of milk yield-constituents at low levels were underestimated. This might have been an indication that interaction covariances between two traits were approaching zero in most cases, and thus did not affect the ratios of the product moment correlations.

Table 23: Phenotypic and genetic correlations among milk and milk constituents from an interaction ignored model

	Level of meal intake	Genetic correlation				
Trait		Milk	Fat	Protein	Fat %	Protein %
Milk(lb)	Low		0.71	0.85	-0.14	0.15
	Medium		0.54	0.71	-0.25	-0.41
	High		0.54	0.84	-0.38	-0.42
Fat(lb)	Low	0.85		0.84	0.59	0.51
	Medium	0.72		0.73	0.67	0.23
	High	0.71		0.69	0.57	0.15
Protein(lb)	Low	0.90	0.87		0.26	0.64
	Medium	0.84	0.75		0.33	0.33
	High	0.83	0.75		-0.03	0.13
Fat %	Low	-0.07	0.45	0.14		0.60
	Medium	-0.20	0.53	0.06		0.61
	High	-0.21	0.53	0.06		0.60
Protein %	Low	-0.17	0.10	0.25	0.47	
	Medium	-0.19	0.16	0.38	0.44	
	High	-0.23	0.12	0.34	0.44	

Phenotypic correlation

VI. CONCLUSION

Relationships between feeding practices and milk yield and composition were investigated by studying 17,259 Ayrshire and 139,720 Holstein 305-day, age, year and season of calving adjusted records. Positive and signficant ($P < 0.01$) linear effects and generally significant quadratic effects of net energy intake from silage, hay, pasture and meal indicated that yield responses to levels of feeding were curvilinear. Examination of the linear relationships between yields and levels of net energy intake indicated that yields were independent of the source of net energy from either forages or concentrates. Incorporating larger amount of silage in the ration relative to hay slightly increased yields of milk, fat and protein. The magnitudes of change were small, for example, doubling the ratio of silage in the ration resulted in increases of 17 lb of milk, 0.74 lb of fat and 0.55 lb of protein. These results favoured the extensive use of silage in dairy ration and partially substantiated the popular interest in all silage feeding program. Higher roughage in the ration depressed yields, because animals could not obtain enough energy for their production as a result of reduction in dry-matter intake from high forage rations. Increased voluntary intake of the forages or supplementation with concentrates were apparently the only solution to problems of high-level forage feeding programs.

Energy concentration, a measure of the overall nutritive value of the feed, consistently exerted large positive effects on yields of both breeds. The estimators of feeding practices in this series of studies were the net energy intake from any particular feed or some ratios of two categories of feed on a net energy basis. One advantage of using such an estimator in dairy field data was that it accounted for variations in feed quality. Except for the roughage:concentrate ratio, which had a negative effect on lactation yields, other ratios and the net energy intake from silage, hay, pasture and meal were positive. It was therefore concluded that energy in dairy rations should receive primary consideration in practical nutrition. Increasing net energy intake from whatever source of feedstuff generally increased yields. On the other hand, high forage feeding, which would result in a reduction in total net energy intake, would seriously reduce yields of milk, fat and protein. Net energy intake from silage, hay, pasture and meal apparently had little influence on milk composition. However, ratios of feed had varying and inconsistent effects on fat percent between the two breeds. Only silage:hay ratio in Holsteins had any significant effect on protein percent. These inconclusive effects of feeding on milk composition indicated that altering milk composition through nutritional changes was limited. Changes in fat and protein percent are thought to result from changes in ruminal fatty acid ratios. These changes may or may not develop, depending on factors such as the particular concentrates, nature of the forages and method of feeding.

One of the basic assumptions in estimating variance components is that random effects are free from fixed effect influences. Failure to account for important fixed effects could bias the variance component estimates. General reductions in variance components after records were corrected for levels of feeding, as observed in this study, posed a challenge to the validity of this basic assumption. Whether the model which failed to consider levels of feeding biased the component estimates was open to question. Furthermore, the unequal proportion of reduction in variance components of cow and within cow reduced repeatability estimates. Repeatabilities were reduced by a range of 0.10 to 0.25 for yields of milk, fat and protein for both Ayrshires and Holsteins. It was mentioned earlier that milk composition was apparently not affected by levels of feeding. This was demonstrated by the unchanged repeatability of milk composition in the Corrected Records. The decreases in repeatability of yield traits were due to removal of some permanent environmental effects associated with the cow component. Repeatability is a measure of within herd average correlation between records of the same cow. After the influence of feeding was removed, repeatability estimates of the yield traits approached the corresponding heritability estimates indicating that permanent environmental effects are largely of a nutritional nature.

In an attempt to examine the changes in heritability, phenotypic and genetic correlations after correcting records for levels of feeding, sire identified Holstein records were described by a model which included sire, herd, sire x herd, cow and within cow terms. Similar reductions in variance components and repeatabilities were observed in the Corrected Records. Slight increases or decreases of heritability estimates among yield traits and unchanged heritability estimates of milk composition traits indicated that correcting records for levels of feeding did not significantly change heritability estimates. The changes in sire x herd interaction were not consistent among all traits. Varying increases or decreases were observed in the phenotypic and genetic correlations among milk yield and composition traits. A generally greater amount of reduction in genetic correlations than corresponding phenotypic correlations indicated that a greater amount of environmental covariance due to levels of feeding was associated with the sire component. The phenotypic and genetic correlation of major concern was milk-fat percent. However, these estimates fell within the acceptable range irrespective of whether feeding was accounted or not. Therefore, it was concluded that correcting for levels of feeding had no major effect on genetic parameters, except repeatability which was significantly reduced in all cases.

In one study, Holstein records were stratified into three approximately equal subsets according to low, medium and high level of meal intake to study sire x herd interactions and genetic parameters estimated from these three environments. Sire components across different feeding levels were inconsistent for milk and protein yield, but other traits consistently showed higher genetic variability with higher levels of nutrition. The relative changes of percent genetic variance between levels of meal intake within each trait ranged from approximately 1 to 5% of the total variation. Inconsistency in showing higher genetic variability in improved environments for milk and protein yield was thought to be a result of daughters of the sires were not equally represented across all three environments. Correspondingly, heritability estimates in these three environments were reflected by the same changes in sire components. Fat yield and the percentage traits showed increased heritabilities with levels of meal intake. To a certain extent, these results support the view that animals required optimum environmental conditions to express their genotypes to the fullest extent. Sire by herd interactions when daughters of sires were grouped into three environments were observed to increase with improved levels of feeding for yield traits, and decrease for percenatage traits. This implied that more problems in sire evaluation at optimum environments than poor environments were to be expected. Increases in sire and cow component accompanied by decreases in herd components resulted in increased repeatability estimates with improved cow environment. The reduction in herd component was resulted from removal of some environmental differences among individual herds. Phenotypic and genetic correlations were generally decreased with improved environment, but it was concluded that these changes were not particular significant since most estimates in these three environments were within acceptable ranges.

The consequences in estimating genetic parameters if the sire x herd interaction was not included in the model appeared to vary, depending on the sign and the magnitude of the interaction estimates. However, it was concluded that failure to include the interaction term would tend to overestimate heritability at high levels of feeding. The effects of ignoring the interaction on estimates of phenotypic and genetic correlation was apparently not serious.

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APPENDIX

Appendix Table 1: Analysis of variance by Model I on yields of milk and fat and fat percent for Ayrshires

		F ratio of mean square		
Source	D.F.	Milk	Fat	Fat %
Age of cow	4	93.82**	56.77**	3.08*
Season of calving	2	11.70**	10.36**	2.59
Year of calving	6	15.78**	37.82**	29.47**
Silage	1	148.76**	160.46**	17.53**
Hay	1	100.34**	101.56**	9.83**
Pasture	1	207.29**	138.42**	0.07
Meal	1	451.73**	275.94**	0.19
Silage^2	1	1.15	10.41**	10.95**
Hay^2	1	0.16	4.01*	6.44*
Pasture^2	1	11.06**	5.28*	0.80
Meal^2	1	28.65**	44.50**	6.61*
Error	7242			

* significant at 0.05 level

** significant at 0.01 level

Appendix Table 2: Analysis of variance by Model I on protein yield and percent for Ayrshires

Source	D.F.	F ratio of mean square	
		Protein	Protein %
Age of cow	4	19.33**	1.29
Season of calving	2	3.43*	1.83
Year of calving	5	3.68**	5.59**
Silage	1	19.27**	0.24
Hay	1	12.11**	0.02
Pasture	1	35.77**	0.84
Meal	1	118.79**	1.04
Silage^2	1	0.57	1.85
Hay^2	1	0.02	0.00
Pasture^2	1	3.82	0.26
Meal^2	1	0.00	1.33
Error	1714		

* significant at 0.05 level

** significant at 0.01 level

Appendix Table 3: Analysis of variance by Model I on yields of milk and fat and fat percent for Holsteins

Source	D.F.	F ratio of mean square		
		Milk	Fat	Fat %
Age of cow	4	992.53**	685.34**	0.78
Season of calving	2	101.87**	125.52**	65.64**
Year of calving	6	194.99**	366.67**	189.76**
Silage	1	1765.83**	1138.95**	0.60
Hay	1	1154.52**	830.52**	1.49
Pasture	1	1852.04**	1418.06**	22.49**
Meal	1	5009.27**	3127.96**	2.59
Silage^2	1	12.67**	0.73	11.41**
Hay^2	1	26.85**	30.21**	1.41
Pasture^2	1	15.96**	12.28**	1.01
Meal^2	1	71.12**	124.42**	30.81**
Error	58630			

** significant at 0.01 level

Appendix Table 4: Analysis of variance by Model I on protein yield and percent for Holsteins

Source	D.F.	F ratio of mean square Protein	 Protein %
Age of cow	4	235.94**	8.22**
Season of calving	2	33.88**	28.35**
Year of calving	5	34.65**	78.95**
Silage	1	328.32**	2.48
Hay	1	234.41**	0.81
Pasture	1	345.42**	0.08
Meal	1	819.29**	1.41
Silage^2	1	6.62*	5.81*
Hay^2	1	6.32*	1.84
Pasture^2	1	2.70	0.04
Meal^2	1	23.74**	4.48*
Error	16549		

* significant at 0.05 level

** significant at 0.01 level

Appendix Table 5: Analysis of variance by Model II on yields of milk and fat and fat percent for Ayrshires

Source	D.F.	F ratio of mean square		
		Milk	Fat	Fat %
Age of cow	4	108.66**	83.93**	1.88
Season of calving	2	54.58**	39.44**	0.43
Year of calving	6	22.30**	30.23**	29.12**
Error	7250			

** significant at 0.01 level

Appendix Table 6: Analysis of variance by Model II on protein yield and percent for Ayrshires

Source	D.F.	F ratio of mean square	
		Protein	Protein %
Age of cow	4	31.09**	1.25
Season of calving	2	9.79**	3.17*
Year of calving	5	9.75**	5.95**
Error	1722		

* significant at 0.05 level

** significant at 0.01 level

Appendix Table 7: Analysis of variance by Model II on yields of milk and fat and fat percent for Holsteins

Source	D.F.	F ratio of mean square		
		Milk	Fat	Fat %
Age of cow	4	1402.68**	1197.59**	2.29
Season of calving	2	519.15**	346.36**	82.97**
Year of calving	6	207.18**	289.98**	211.18**
Error	58638			

* significant at 0.05 level

** significant at 0.01 level

Appendix Table 8: Analysis of variance by Model II on protein yield and percent for Holsteins

Source	D.F.	F ratio of mean square	
		Protein	Protein %
Age of cow	4	413.96**	8.55**
Season of calving	2	84.85**	31.20**
Year of calving	5	147.49**	78.54**
Error	16557		

** significant at 0.01 level

Appendix Table 9: Analysis of variance by Model III on yields of milk and fat and fat percent for Ayrshires

Source	D.F.	F ratio of mean square		
		Milk	Fat	Fat %
Age of cow	4	59.21**	43.99**	2.04
Season of calving	2	23.30**	17.73**	0.25
Year of calving	6	18.13**	20.36**	11.05**
Silage:hay	1	0.04	1.03	7.92**
Roughage:concentrate	1	153.16**	156.75**	14.60**
Energy concentration	1	53.36**	35.83**	3.26
Error	3756			

** significant at 0.01 level

Appendix Table 10: Analysis of variance by Model III on protein yield and percent for Ayrshires

Source	D.F.	F ratio of mean square	
		Protein	Protein %
Age of cow	4	17.01**	1.32
Season of calving	2	5.11**	2.78
Year of calving	5	2.35	2.16
Silage:hay	1	8.40**	0.64
Roughage:concentrate	1	106.62**	0.10
Eenrgy concentration	1	25.28**	0.89
Error	1041		

* significant at 0.05 level

** significant at 0.01 level

Appendix Table 11: Analysis of variance by Model III on yields of milk and fat and fat percent for Holsteins

Source	D.F.	F ratio of mean square		
		Milk	Fat	Fat %
Age of cow	4	866.56**	711.82**	1.00
Season of calving	2	208.64**	132.19**	47.91**
Year of calving	6	182.61**	237.34**	86.19**
Silage:hay	1	30.29**	35.93**	7.44**
Roughage:concentrate	1	4454.10**	3669.05**	21.86**
Energy concentration	1	396.81**	376.84**	17.08**
Error	38629			

** significant at 0.01 level

Appendix Table 12: Analysis of variance by Model III on protein yield and percent for Holsteins

Source	D.F.	F ratio of mean square	
		Protein	Protein %
Age of cow	4	291.32**	5.49**
Season of calving	2	20.04**	27.32**
Year of calving	5	62.76**	54.22**
Silage:hay	1	7.22**	9.20**
Roughage:concentrate	1	1019.82**	0.01
Energy concentration	1	148.38**	2.62
Error	11623		

** significant at 0.01 level

Appendix Table 13: Analysis of variance and expected sums of squares by Model I for milk yield and composition of Ayrshires

(i)For All Records

Source	D.F.	Sum of squares			Expected sum of squares
		Milk[a]	Fat[a]	Fat %	
Herd	785	8605	15	529	$823\,\sigma_E^2 + 1309\,\sigma_C^2 + 17181\,\sigma_H^2$
Cow/herd	9211	8611	17	1378	$9261\,\sigma_E^2 + 15947\,\sigma_C^2$
Error	7242	3599	8	384	$\hat{\sigma}_E^2$

a) coded by times 10^{-6}

(ii)For Protein Subset

Source	D.F.	Sum of squares		Expected sum of squares
		Protein[b]	Protein %	
Herd	468	4243	79	$541\,\sigma_E^2 + 612\,\sigma_C^2 + 6793\,\sigma_H^2$
Cow/herd	4639	4986	240	$4726\,\sigma_E^2 + 6228\,\sigma_C^2$
Error	1714	44		$\hat{\sigma}_E^2$

b) coded by times 10^{-3}

Appendix Table 14: Analysis of variance and expected sums of squares by Model II for milk yield and composition of Ayrshires

(i) For All Records

Source	D.F.	Sum of squares Milk[a]	 Fat[a]	 Fat %	Expected sum of squares
Herd	785	26475	43	533	$797\sigma_E^2 + 1309\sigma_C^2 + 17181\sigma_H^2$
Cow/herd	9211	27175	44	1368	$9247\sigma_E^2 + 15947\sigma_C^2$
Error	7250	8832	15	388	$\hat{\sigma}_E^2$

a) coded by times 10^{-6}

(ii) For Protein Subset

Source	D.F.	Sum of squares Protein[b]	 Protein %	Expected sum of squares
Herd	468	11826	77	$488\sigma_E^2 + 612\sigma_C^2 + 6793\sigma_H^2$
Cow/herd	4639	12478	240	$4699\sigma_E^2 + 6228\sigma_C^2$
Error	1714	2386	44	$\hat{\sigma}_E^2$

b) coded by times 10^{-3}

Appendix Table 15: Analysis of variance and expected sums of squares by Model I for milk yield and composition of Holsteins

(i)For All Records

Source	D.F.	Sum of squares Milk[a]	 Fat[a]	 Fat %	Expected sum of squares
Herd	2626	81148	125	2713	$2665\,\sigma_E^2 + 4575\,\sigma_C^2 + 139623\,\sigma_H^2$
Cow/herd	78448	109694	203	12827	$78502\,\sigma_E^2 + 135143\,\sigma_C^2$
Error	58630	41910	78	2498	$\hat{\sigma}_E^2$

a) coded by times 10^{-6}

(ii)For Protein Subset

Source	D.F.	Sum of squares Protein[b]	 Protein %	Expected sum of squares
Herd	1957	39864	497	$4753\,\sigma_E^2 + 2673\,\sigma_C^2 + 61241\,\sigma_H^2$
Cow/herd	42778	59913	2208	$42717\,\sigma_E^2 + 58625\,\sigma_C^2$
Error	16549	15866	439	$\hat{\sigma}_E^2$

b) coded by times 10^{-3}

Appendix Table 16: Analysis of variance and expected sums of squares by Model II for milk yield and composition of Holsteins

(i)For All Records

Source	D.F.	Sum of squares			Expected sum of squares
		Milk[a]	Fat[a]	Fat %	
Herd	2626	337873	465	2748	$2673\sigma_E^2 + 4575\sigma_c^2 + 139623\sigma_H^2$
Cow/herd	78448	367859	523	12790	$78410\sigma_E^2 + 135143\sigma_c^2$
Error	58630	109494	169	2511	$\hat{\sigma}_E^2$

a) coded by time 10^{-6}

(ii)For Protein Subset

Source	D.F.	Sum of squares		Expected sum of squares
		Protein[b]	Protein %	
Herd	1957	155120	485	$2030\sigma_E^2 + 2673\sigma_c^2 + 61241\sigma_H^2$
Cow/herd	42778	156176	2217	$42719\sigma_E^2 + 58625\sigma_c^2$
Error	16549	31335	440	$\hat{\sigma}_E^2$

b) coded by times 10^{-3}

Appendix Table 17: Analysis of components of variance from Corrected and Uncorrected Records for Ayrshires

Trait	Records	Variance component			
		Herd	Cow	Within cow	Total
Milk(lb)	Corrected	505492	251327	497064	1253883
	Uncorrected	1521334	997683	1218238	3737255
Fat(lb)	Corrected	904	442	1045	2391
	Uncorrected	2516	1483	2190	6189
Protein(lb)	Corrected	660	249	727	1636
	Uncorrected	1754	958	1385	4097
Fat %	Corrected	0.0291	0.0556	0.0530	0.1377
	Uncorrected	0.0293	0.0547	0.0536	0.1376
Protein %	Corrected	0.0119	0.0190	0.0258	0.0567
	Uncorrected	0.0115	0.0191	0.0258	0.0564

Appendix Table 18: Analysis of components of variance from Corrected and Uncorrected Records for Holsteins

Trait	Records	Variance component			
		Herd	Cow	Within cow	Total
Milk(lb)	Corrected	581857	396372	714981	1693210
	Uncorrected	2401973	1638492	1867470	5907935
Fat(lb)	Corrected	898	722	1339	2959
	Uncorrected	3310	2201	2876	8387
Protein(lb)	Corrected	711	313	960	1994
	Uncorrected	2540	1283	1895	5718
Fat %	Corrected	0.0179	0.0701	0.0426	0.1306
	Uncorrected	0.0182	0.0698	0.0428	0.1308
Protein %	Corrected	0.0094	0.0183	0.0265	0.0542
	Uncorrected	0.0080	0.0185	0.0266	0.0531

Appendix Table 19: Distribution of sire identified Holstein records by sire, herd, sire-herd and cow in sire-herd subclasses

	Number of records				
Subset of records	Sire	Herd	Sire-herd	Cow/S-H	Total
Overall					
All Records	1873	779	4402	7432	13561
Protein Subset	1439	571	3121	5134	7506
Meal 1 (Low)					
All Records	1116	619	2260	3389	4724
Protein Subset	770	423	1396	2042	2475
Meal 2 (Medium)					
All Records	1118	542	2251	3389	4414
Protein Subset	800	406	1464	2093	2426
Meal 3 (High)					
All Records	1003	431	1917	2929	4423
Protein Subset	755	323	1343	2038	2605

Appendix Table 20: Analysis of components of variance by Model IV from Corrected and Uncorrected Holstein records

Trait	Records	Variance component					
		Sire	Herd	Sire-herd	Cow	Error	Total
Milk(lb)	Corrected	118163	580065	60624	268694	763036	1790582
	Uncorrected	372040	1983176	250686	1325820	2157031	6088753
Fat(lb)	Corrected	290	941	77	594	1494	3396
	Uncorrected	719	3142	106	1973	3388	9328
Protein(lb)	Corrected	125	638	9	207	1085	2064
	Uncorrected	407	2389	18	1002	2231	6047
Fat %	Corrected	0.0172	0.0143	0.0042	0.0543	0.0429	0.1329
	Uncorrected	0.0174	0.0152	0.0035	0.0542	0.0430	0.1333
Protein %	Corrected	0.0035	0.0073	0.0027	0.0113	0.0261	0.0509
	Uncorrected	0.0034	0.0068	0.0028	0.0114	0.0261	0.0505

Appendix Table 21: Analysis of component of variance by Model IV from records classified by levels of meal intake

Trait	Level of meal intake	Variance component					
		Sire	Herd	Sire-herd	Cow	Error	Total
Milk(lb)	Low	176599	1001105	-24975	552726	1630986	3336441
	Medium	191162	836801	-62227	480885	1142244	2588865
	High	185071	979581	212912	816817	1631775	3826156
Fat(lb)	Low	305	1485	16	810	2581	5197
	Medium	274	1326	125	690	2056	4471
	High	406	1777	133	1407	2905	6628
Protein(lb)	Low	364	1182	-198	353	1626	3327
	Medium	136	975	-25	455	1341	2882
	High	242	1245	47	428	2083	4045
Fat %	Low	0.0118	0.0166	0.0101	0.0450	0.0491	0.1326
	Medium	0.0175	0.0144	0.0013	0.0556	0.0393	0.1281
	High	0.0193	0.0149	0.0020	0.0555	0.0458	0.1375
Protein %	Low	0.0018	0.0073	0.0094	0.0113	0.0227	0.0525
	Medium	0.0033	0.0062	0.0021	0.0092	0.0280	0.0488
	High	0.0037	0.0058	0.0025	0.0112	0.0267	0.0499

Appendix Table 22: Analysis of components of variance by Model V from records classified by levels of meal intake

Trait	Level of meal intake	Variance component				
		Sire	Herd	Cow	Error	Total
Milk(lb)	Low	164570	997149	552726	1630986	3345431
	Medium	159490	828229	480885	1142244	2610848
	High	302035	1003913	816817	1631775	3754540
Fat(lb)	Low	313	1488	810	2581	5192
	Medium	337	1343	690	2056	4426
	High	480	1792	1407	2905	6584
Protein(lb)	Low	257	1152	353	1626	3388
	Medium	123	971	455	1341	2890
	High	270	1250	428	2083	4031
Fat %	Low	0.0166	0.0182	0.0450	0.0491	0.1289
	Medium	0.0182	0.0146	0.0556	0.0393	0.1277
	High	0.0205	0.0151	0.0555	0.0458	0.1369
Protein %	Low	0.0069	0.0087	0.0113	0.0227	0.0496
	Medium	0.0046	0.0065	0.0092	0.0280	0.0483
	High	0.0052	0.0061	0.0112	0.0267	0.0492