Use of Sire Evaluations for First, All, and Later Lactations to Predict Lifetime Profit Functions of Individual Daughters

by

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(ABSTRACT)

Sire evaluations from first, all, and later lactations for Predicted Difference milk, fat, and dollars on 226 sires were used to predict deviated relative net income. Eleven different relative net incomes were calculated on 176,902 individual cows. Low, medium and high values were used for lifetime product value and feed price. Lifetime product value was actual milk and fat production. Individual relative net income was deviated from contemporaries in the same herd and calving in the same year of first freshening.

Progeny group average estimates of deviated relative net income could be predicted with reasonable accuracy. Coefficients of determination for progeny group average lifetime DRNI ranged from .152, from the model using Predicted Difference fat from first lactation evaluations, to .587 from the model including first and later lactation evaluations from Predicted Difference dollars. Accuracy of prediction of sire group average deviated relative net income per day was less. Coefficients of determination ranged from .062, from the model using Predicted Difference milk from later lactation evaluations to .224 from the model including Predicted Difference dollars from first and later lactation evaluations. In all models, Predicted Difference dollars with first and later lactation evaluations accounted for an equivalent or greater amount of variation when compared to other models on both a lifetime and per day basis. In the prediction of

individual deviated relative net income, for lifetime and per day, the variation accounted for by the models examined was very small, though statistically significant.

Later lactation sire evaluations were more useful than evaluations based on first lactations in the prediction of lifetime profit. Later lactation evaluations were as important as evaluations from all lactations and as useful as a combination of evaluations from first and later records for lifetime profit measures. Profit on a per day basis placed more emphasis on first lactation evaluations than evaluations based on later lactations. The predictive ability of first lactation evaluations was as good as first and later lactation evaluations combined in predicting profit. However, overall accuracy of prediction was reduced relative to lifetime profit and differences between evaluations from different lactations were not large.

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Introduction

The primary objective in a breeding program is to increase cow profitability. The traditional approach has been through increased milk production. Norman et. al. (25) developed a lifetime profit function, relative net income (RNI), using Dairy Herd Improvement (DHI) variables. Studies (25,35) have demonstrated that lifetime and per day profit can be accurately estimated using RNI.

Profit measures require herdlife variables to be accurately calculated. Time required for profitability to be expressed prohibits direct selection on the trait. Tigges (35) and Balaine et al. (1) have shown that milk production was the most important variable in the prediction of RNI. Lin and Allaire (21) determined that selection on total milk produced to 41 months of age was more efficient than selection on milk produced to 305 days in first lactation for genetic gain in milk produced up to 48 months, 72 months, or lifetime. Using records to this age accounts for some of the inherent variability between consecutive lactations due to days open, days dry, length of lactation, and udder health.

Thus far studies have primarily focused on information available on the individual cow to predict RNI. Relationships between selected variables from sire evaluations and RNI have not been examined. The majority of genetic gain in production traits is made through sire selection. True genetic merit of a sire can be estimated more accurately than the true genetic merit of a cow and higher reproductive rates allow for a higher selection intensity of the sire population.

Published sire evaluations from the Modified Contemporary Comparison are derived from two separate summaries. A summary is calculated from first lactation records only. A second summary is calculated from all lactation records beyond firsts. The two summaries are then combined to calculate the published progeny evaluations based on all lactations. The question of which evaluation, first, all, or later, would better predict RNI has not been examined. Research to determine the relationship between sire evaluations based on different lactations and profit returned to dairymen appears warranted.

Objectives of this study were :

1. To determine relationships between sire evaluations calculated using first, all, or later lactation records and profit estimates of individual daughters.

2. To determine what function of sire evaluations from first and later records provide the best predictor of lifetime profit for individual daughters, and to compare such functions to evaluations based on all records.

3. To evaluate the importance of later records in sire evaluations for the prediction of lifetime and per day profitability.

Review of Literature

Presently there are two methods of calculating sire Predicted Differences (PD) in the United States. The first method, Modified Contemporary Comparison (MCC), is calculated by the Animal Improvement and Programs Laboratory (AIPL), a branch of the United States Department of Agriculture (USDA). The second method, Northeast A.I. Sire Comparison (NEAISC), uses Best Linear Unbiased Prediction methodology. Fundamental differences exist between the two methods. Modified Contemporary Comparisons use first and later lactations from which published progeny evaluations for all lactations are derived, and are calculated for both A.I. and non-A.I. sires. The NEAISC publishes progeny evaluations solely for A.I. sires used in the northeast from first lactation records only.

Inclusion of only first lactation yield in progeny evaluations offers several advantages. First records are available earlier than later records and measurements exist for more cows than for later records. Sources of variation due to days dry, injury, disease, reproductive difficulties, and preferential treatment are less likely to influence yield of first lactation. Perhaps most importantly, direct selection for milk yield does not occur before first lactation, although pedigree selection could occur. Computational expenses and complexity of programming for proofs based on first lactations only are less than for evaluations based on later or all lactations.

Basing all decisions relative to genetic merit for yield on first lactation may have several disadvantages. Yield measurements of the dairy cow occur throughout her productive life. If first lactation yield had a genetic correlation of unity with later lactation yield, use of first lactation yield alone in progeny evaluations would be justified. Estimates of the genetic and phenotypic correlations between first lactation and subsequent lactation yields are given in Tables 1 and 2. Estimates range from .75 to .92 for the genetic correlation between first and second lactation. The genetic correlation decreases as lactations become further separated from first. Genetic correlations between second and third, or later lactation yield are generally higher than for first and second. The correlation also remains relatively constant as lactations become further separated from second lactation (4,23,32)

Although every animal must have a first lactation, first lactations do not make up the majority of total records available. Therefore a large portion of relevant information remains unused in sire selection based on first lactation evaluations.

Use of records beyond first may broaden the aggregate genotype under selection. Inclusion of later lactation information in sire evaluations accounts for some of the inherent variability between daughters. Some sources of variation, days dry and length of lactation, are under management influences to some extent and may be used to bias actual genetic values upwards. Other variation, disease and mastitis resistence, accounted for by using records beyond firsts may help to define the true genotype of the sire.

Table 1. Estimates of genetic correlations among different lactation yields.

References	First x Second	First x Third	Second x Third
Bar-Anan (2)	.84		
Barker & Robertson (4)	.75	.81	.95
Hoque & Hodges (19)			.83
Maijala & Hanna (23)	.81-.87	.80-.85	.91-1.0
Meyer (24)	.91	.91	.95
Powell et al. (31)	.75	.76	.92
Rothschild & Henderson (34)	.92		
Tong et al. (37)	.89	.85	.89
Van Vleck (39)	.90		

Table 2. Estimates of phenotypic correlations among different lactation yields

References	First x Second	First x Third	Second x Third
Barker & Robertson (4)	.40	.40	.43
Butcher & Freeman (ABS) (6)	.56	.50	.63
Butcher & Freeman (DHIA) (6)	.49	.46	.54
Maijala & Hanna (23)	.49	.46	
Meyer (24)	.54	.54	.58
Rendell & Robertson (32)	.50	.43	.56
Rothschild & Henderson (34)	.56		

Several studies (7,24,38) have shown that inclusion of later lactations may introduce bias to sire evaluations. Ufford et al. (38) lists possible sources of bias as:

1. Incorrect mature equivalent conversion factors.
2. Sires differing in ratio of first lactation records to all records.
3. Culling based on production.
4. Preferential treatment.

Cassell et al. (7) studied the impact of culling on MCC evaluations for second lactations. All records on daughters on the lowest 0, 10, 20, or 30% of Modified Contemporary Deviations were eliminated, and sire evaluations for second records were calculated by MCC procedures. Adjusted second lactation sire evaluations from the culled data set produced a rank correlation of .98 with evaluations from unculled records (personal communication). Similar results were found by Van Vleck and Henderson (40). These results suggested that the effects of culling on later lactation evaluations have been overstated. Differences between bulls were suppressed by culling, but no dramatic shifts in rank resulted.

Another disadvantage of using later lactations to evaluate sires is the time required to collect data. Various researchers (2,7) have suggested the benefits of a two-stage selection program for selecting sires. An initial decision would be made on the basis of first lactation progeny tests as to whether a bull should be brought back into general A.I. service as a sire of replacement females. Matings to produce sons for the next generation would also be made on the basis of first lactation evaluations. However, the final decision to sample sons of a bull should also consider second lactations of his daughters and the change in yield from first to second lactation. Such an approach makes use of the additional accuracy gained through use of later records. It may allow genetic improvement for lifetime profit traits to proceed at a faster rate than from evaluations based on first lactation records (7), while not increasing the generation interval for sires.

Correlation of First and Later Records

Traditionally investigations concerning degree of genetic control of milk yield, correlations with other traits, and responce to selection have used first lactations. Objectives of breeding programs should be to maximize genetic gains in some trait or traits. Questions concerning which traits to maximize remain.

Genetic correlations between first and second, or later lactations are not 1.0. However, there is difference of opinion among researchers as to whether estimates of .85 to .90 are "clearly not unity" or "essentially unity". Interpretation of the genetic correlation between first and second records defines the benefit of later lactations for sire evaluation.

Two groups (23,31) have postulated reasons for the genetic correlation less than unity between first and second lactation. Maijala and Hanna (23) and others (4,31) have concluded that yields in later lactations are partly caused by different genes than first lactation. Butcher and Freeman (6) suggesed that if all genes have equal effects, first lactation is controlled by more pairs of genes than second lactation, or, if the same number of genes control both lactations, they have larger effects on first lactation.

Barker and Robertson (4) conducted a study from the progeny test records of Friesian bulls available at the Milk Marketing Board of England and Wales in April 1961. Bulls selected were required to have been used in A.I., and to have had at least 150 daughters with first lactation records. Variance-covariance analysis procedures were used to estimate genetic and phenotypic parameters for the first three lactations in Friesian cows. Barker and Robertson (4) concluded that their estimate of the genetic correlation between first and second lactation was significantly different from unity. These workers stated that although there is a general agreement between the ranking of sires on first and second lactations, bulls will be found whose daughters will increase in yield with age more or less than the average value.

Meyer (24) used restricted maximum liklihood (REML) procedures on records from the Milk Marketing Board of England and Wales to estimate genetic parameters for milk and fat yield for the first three lactations. Analytical procedure required that many subsets of the data be created. Results are reported in Table 1. Meyer (24) used a prior value for genetic correlation of .90, and calculated genetic correlations of .91, .91, and .95 between first and second, first and third, and second and third lactations. Meyer (24) concluded that heifer yield was an efficient selection criteria for lifetime production, and that including later records would improve the precision of sire evaluation only to a limited extent.

A recent study (Tong et al. (37)) used 90 Quebec Holstein A.I. sires to estimate genetic parameters of the first three lactations for milk, fat, and protein yield and percent of fat and protein. Restricted maximum liklihood procedures were used. Genetic correlations of .80 were assumed for all lactations. Results were slightly lower than those found by Meyer (24). Tong et al. (37) calculated genetic correlations of .89, .85, and .89 between first and second, first and third, and second and third lactations. Correlations resulting from the study were interpreted as close to unity, leading to the conclusion that different lactations were in essence genetically the same trait, with possible differences in error variance structure.

Research conducted by Powell et al. (31) examined the value of different lactations for estimating the genetic merit of dairy cows. Data consisted of Holstein lactation records and sire summaries at USDA. Heritabilities and genetic correlations were calculated from cow-daughter data when both had three or five lactations. The measure of production was the Modified Contemporary Deviation for milk. Correlations were computed within sire of daughter or son to control those sources of variation. Estimates of .75 between first and second lactations were lower than those found by Tong et al. (31) and Meyer (24).

Powell et al. (31) suggested possible sources of differences. First lactation animals in the study by Tong et al. (37) tended to be older than those in the study by Powell et al. (31). Thus correlations between the first two lactations of older cows might be expected to be higher than for younger animals (31). Results suggested that those lactations are controlled by some different genes. Powell et al. (31) concluded that the importance of first lactation data may be overestimated and that performance in each lactation is more of a separate trait than has been appreciated.

Most studies (4,6,19,23,31,32,36) suggest that, as lactations become further separated from first, genetic and phenotypic correlations with first lactation decrease. Second and subsequent lactations are more highly correlated, and the decrease in correlation for second and later records is less than with firsts. Heritability estimates (4,16,19,23,27,37) also tend to decrease with later lactations. Results may be a consequence of additional error variance affecting later lactations or a decrease in additive genetic variation in later lactations.

Use of Later Records in Sire Evaluations.

Estimates of genetic correlations among progeny evaluations are given in Table 3. Correlation estimates between first and later lactation evaluations range from .77 (43) to .85 (36), while estimates of first with all, or all with later lactation evaluations are all greater than .94. The higher correlation is a consequence of the part-whole nature of the relationship of first and all, and all and later lactation evaluations.

A study by Cassell et al. (8) examined 200 Holstein sires, each with more than 500 daughters from the Summer 1981 MCC sire summary. Some results are in Table 3. The average PD milk (all lactations) for these bulls was 286 kg. The average difference, PD from later lactations minus PD from first lactations, was 47 kg. For most bulls, proofs of later lactations for milk exceeded proofs of first lactations. More importantly, the standard deviation (149 kg) of the difference indicated considerable variation among bulls.

Bar-Anan (2) reported that dairymen are primarily interested in lifetime yield of daughters of the small group of bulls selected for extensive use by their evaluations of first lactations. Therefore, changes in yield from first to later lactations in this small group of bulls should be of primary concern. This change could yield resulting changes in the rank of sires. Cassell et al. (8) found that high PD bulls had a standard deviation of difference between PD's of later and first lactations of 124 kg, versus 149 kg for all sires in the study. This suggested that the elite sires varied nearly as much in difference as did all sires.

Cassell et al. (8) performed truncation selection on PD of first lactation, to the sample of sires in their study, retaining the best 25% for further use. Seventy-two percent of sires in the top quartile of proofs on first lactation remained in the top quartile,

Table 3. Estimates of genetic correlations among progeny evaluations based on first, all, or later lactations.

References	First x All	First x Later	All x Later
Bar-Anan & Ron (3)		.82	.94
Cassell et al. (8)	.95	.84	.97
Tomaszewski et al. (36)		.85	
Wickham & Henderson (43)		.77	

18% appeared in the second quartile, and 10% appeared in the third quartile of proofs based on later lactations. Thus selection of sires based on first lactation evaluations would lead to some incorrect decisions with respect to later records and might not achieve maximum progress in genetic improvement (8).

Wickham and Henderson (43) developed a model to describe the selection of cows to have a second lactation. A procedure to estimate the biases in BLUP was also presented. The procedure was used to obtain estimates of biases in evaluations for 1109 Holstein sires in AI in the northeastern United States. It was found that estimated biases from the assumed selection models were small relative to the changes in ranking of bulls from evaluations calculated from first or second lactations of daughters. A rank correlation of .77 was found between bulls based on first and second lactations of daughters where selection is ignored.

Nicholson et al. (25) used first, second, and third lactation Ontario Record of Performance 305-day milk records to evaluate the use of later records in dairy sire evaluation. Each lactation evaluation was analyzed separately, and second and third lactation records were analyzed with and without adjustment for selection. Magnitude of adjustment for selection was small, but adjustment did result in sire proofs for second and third lactations that had a variance similar to proofs based on first lactation records. Of the 246 sires, only six were expected to have significantly different proofs, due to chance alone. However, Nicholson et al. (25) reported that 41 sires were found to be significantly different in either their second or third lactation proof compared to their first. For one bull in six the later lactation proof was either significantly higher or lower than the first lactation proof.

These results (25) are in close agreement with those of Wickham and Henderson (43) presented above. Both studies (25,43) are supported by the work of Cassell et al.

(8) in showing that first lactation sire evaluations can lead to a possible misranking of sires when later or all lactations are considered.

Cassell et al. (7) looked at effects of culling on MCC sire evaluations, mentioned previously. Results showed that as culling intensity increased correlations between PD milk from first and second lactations declined from .85 to .73. The effects of culling had very limited effect on sire ranks when comparing culled versus unculled second lactation datasets. A similar study was conducted by Lofgren et al. (22) on the same data used by (7). Best linear unbiased prediction evaluations of sires were obtained separately for both records, and second records only for culled and unculled groups and for all first records. Correlations between first and second milk evaluations declined from .84 to .70 as culling increased.

Both studies (7,22) showed that culling on second records reduced standard deviations of milk as culling increased from 0 to 30%. Cassell et al. (7) found the standard deviation decreased from 274 to 228 kg. Lofgren et al. (22) found a 58 kg decrease in standard deviation of sire evaluations for milk as culling increased from 0 to 30%. The all lactation MCC evaluation produced means and standard deviations for milk similar to models adjusted for selection of second lactation records subject to culling. Lofgren et al. (22) also found that BLUP and MCC evaluations based on the same daughters showed similar effects of culling and ranked bulls nearly identically.

Eriksson (11) examined the effects of selection on different mixed model procedures. He used a simulation technique where selection intensities varied between 30 and 100%. Genetic values were estimated by single- and multiple-trait mixed model (MM) procedures, and a combination of single-trait MM sire solutions using selection index theory.

Eriksson (11) found that selection bias within practicable selection intensities resulted in quite small effects in single-trait MM estimates of transmitting abilities as well as sire-group differences. At increased selection intensities, selection bias was quite obvious when single-trait MM procedures were used. Multiple-trait MM evaluations gave the best results of all methods of evaluations compared in the study, both within and across sire groups. The combined index procedure using single-trait MM solutions were comparable in results to the multiple-trait MM procedure for within sire groups. Eriksson (11) recommended use of evaluation methods using all available information, especially at higher selection intensities. Under present Swedish conditions, single-trait MM procedures were recommended for use in sire evaluations of second lactation milk yield (11). To increase the accuracy of second lactation evaluations Eriksson (11) suggested the combination of single-trait MM procedures with index procedures.

Ufford et al. (38) examined the variances of errors of prediction for sire evaluations using BLUP methodology. Sire evaluations which included only first records were compared with records of all lactations for bulls of the Ayrshire, Guernsey, Jersey, and Brown Swiss breeds. Only sires used in AI with daughters having DHI records processed at the New York Dairy Processing Laboratory were included in the study. Ufford et al. (38) determined that using all lactation records reduced variances of group solutions by 7 to 14% for groups of sires used artificially and by 20 to 24% for groups used in natural service. Use of all lactation records also decreased the variance of prediction error. Results showed that 15 daughters per sire with all lactations gave accuracy equivalent to 25 daughters with first lactation records only. Ufford et al. (38) calculated that genetic progress per year from selection of bulls to sire daughters would be expected to be 10 to 15% greater with use of all lactation records than with use of only first lactation records. The comparable increase from selection of sires of sons would be 3 to 10%. As the number of daughters per sire increases, the accuracy of prediction of the sires genetic value increases, and the value of including later lactation records decreases (38).

However with the current trend of decline in cow numbers, future sampling resources may become limited.

Bar-Anan (2) simulated two sire selection models differing in selection criterion. Data consisted of 106 Israeli sires with complete second lactation tests in 1970 to 1974. Each sire was required to have at least 60 effective daughters in each lactation group. Model 1 consisted of first lactation tests. For model 2 a tandem selection system was simulated, using first and second lactation tests. Bar-Anan (2) found the contribution of proven sires to the rate of genetic improvement in lifetime production was greater from model 2 than from model 1 by about 15%. This would result in an estimated yield increase of 7.5 kg milk per cow/year in daughters of proven bulls.

Several researchers (8,25,41) have stated that a sire by age of daughter interaction, i.e. sire differences in rate of maturity, may exist. Evidence indicates possible differences in genetic trend for first and later progeny tests of sires. Studies have been conducted looking at the rate of maturity in dairy cows, and at the relationship of first lactation milk production and longevity. Hickman and Henderson (17) examined 3,912 cows on DHI test in 1,094 New York herds from 126 AI sires to determine the heritability of the rate of maturity. Rate of maturity was measured as the increase in production from first to second lactation. Hickman and Henderson (17) found the rate of maturity to be from one-fourth to one-third as heritable as first lactation production. Herd production had far more influence on increase from first to second lactation than did production of sire's progeny groups.

Hillers and Freeman (18) investigated the differences between sires in the rate of maturity of their daughters. Data were collected in 76 herds in central California by American Breeders Service, Inc. A total of 110,084 records representing daughters of 28 sires was included. They used within-sire regression of actual production on age at calving in first lactation as the measure of rate of maturity. This measure ignores second lactation information. Regressions of production on age differed significantly on 28 sires, and ranged from -9 to +258 lb. of milk per month of age. Hillers and Freeman (18) also found, in agreement with Hickman and Henderson (17), that the effect of herd on rate of maturity was more important than the effect of sires. Herd effect was estimated to be from two to three times as important as sire effect (18).

Hargrove (16) conducted a study using deviated mature equivalent lactation yields of 18,869 Pennsylvania Holstein cows to determine rate of maturity. The difference between a later lactation deviation and the first lactation deviation was used to measure rate of maturity. Five definitions of maturity, approximating changes to 3, 4, 5, 6, and 7 year-old cows were analyzed for milk and fat. Of the 10 analysis, 9 showed a significant sire effect. Heritability of rate of maturity in the first four maturities was approximately one-third to one-half as large as heritibility of first lactation yield (16). These estimates were slightly higher than the one-fourth to one-third reported by Hickman and Henderson (17).

The previous studies (16,17,18) show that sires do differ in rate of maturity of their daughters for lactation yields. However, magnitude of heritability of rate of maturity in comparison to milk yield, suggested continuation of selection of breeding stock having high first lactation production (16). This may result in a slow change toward a more rapid rate of maturity under this selection technique as selection on first lactation would tend to favor those animals that matured earlier (16).

Van Vleck (39) looked at first lactation performance and herd life for records in the New York Dairy Records Processing Laboratory of cows first freshening before 1957 and sired by AI bulls. Cows were divided into four groups based on deviations from herd-mate averages of their 305 day mature equivalent first lactation records. Results showed that high producers in the first lactation not only continued to outproduce their lower producing first lactation mates but also had a substantialy longer herd life.

Eighty-two percent of the high production group had second records versus 61% of the low producers. More than twice as many high producers had at least five lactations, 32% versus 15%. Van Vleck (39) concluded that the longer productive herd life tends to refute the claims that high producers in the first lactation leave the herd at an early age and do not live up to productive potential, expressed in first lactation.

Robertson and Barker (33) studied three separate sire groups to determine the correlation between first lactation milk production and longevity in dairy cattle. The first group was a sample of Friesian bulls used in England and Wales, the second group was 15 Ayrshire bulls used in the same area in AI in Scotland, the third sample was the data of Van Vleck (39) on Holstein-Friesians in the USA. Results of Robertson and Barker (33) were similar to Van Vleck's (39). The survival of heifers to have a second lactation was directly related to their yield in first lactation. In the Holstein-Friesian data, the correlation between first lactation yield and survival to have a fifth lactation was .71. Each culling process, assumed performed at the end of each lactation that an animal survived, was estimated to require an increase in the genetic potential of yield in the first lactation by roughly 10 gallons. Robertson and Barker (33) concluded that the probable effect on total length of life was 1.2 lactations per 100 gallons difference in heifer progeny test.

White and Nichols (42) studied the relationship between first lactation, later performance, and length of herdlife in Holstein-Friesian cattle. Their results agreed with others (12,33,39) that heifer yield in higher groups produced significantly more milk and fat in later life than heifers in lower first record groups. However they also found a decline in number of lactations completed after the level of first lactation milk and fat production reached 16,000 lb. and 650 lb. respectively.

First lactation evaluations have gained in popularity for research and genetic evaluation purposes. First lactations are expressed early in the animals life and direct selection for yield has not occurred. First lactation yield has a high correlation with herdlife (33,39) and later lactation yield (Table 1). Analysis using first lactation alone are both less complex and less expensive than when later lactations are included. However, addition of later lactations to studies and evaluations adds valuable information in addition to first lactation information.

Profit Functions

Studies of lifetime and total profit estimates (1,5,13,28,29,35) have examined different variables. These functions differ mainly in completeness and estimation method. A recent review by Pearson and Miller (30), found that most investigators used the linear difference, income minus expenses, with some consideration of time to measure profit.

Gill and Allaire (13) examined the relationship of age at first calving, days open, days dry, and herdlife to a profit function for dairy cattle. Profit was a function of income and expenses associated with maintenance and production from birth to last calving. Functions used were:

Income = [7.00 + (0.8)(fat differential)](milk;kg)/45.5
+ 75*(number of calvings)
+ 390

Expense = .045*(Estimated Net Energy (Mcal) for
maintenance, growth, pregnancy, and lactation)
+ 15*(number of breeding services)
+ rearing cost
+ (basic expenses per day)(herdlife;days).

where fat differential = (actual fat% - 3.5)/.1.

Results showed that profit per day of life was associated more closely with herdlife than was milk per day of life with herdlife. Coefficients of determination were 62.8% and 35.2% respectively. Lifetime milk was more closely related to herdlife than were profit traits. Coefficients of determination were .940 for lifetime milk and herdlife compared to .811 for profit and herdlife. Gill and Allaire (13) concluded that investigation of estimating economic returns from more variables than milk yield was justified.

Further research by Gill and Allaire (15) looked at selection on some function of first lactation performance traits to optimize profit per day of herdlife. Indexes were constructed by incoporating information available at the end of first lactation. Traits were age at first calving, milk per day, profit per day, and first lactation profit. Combinations of these traits were used to define five indexes. Indexes were compared to direct selection on profit per day of life to determine the relative efficiency and responce to selection on each index. Results showed an index of age at first calving and milk per day of first lactation was about equal to the index of profit per day of first lactation in relative efficiency and responce to selection. The expected gain in profit per day of life from selection on profit per day of first lactation was 24% more efficient than milk per day of first lactation.

Balaine et al. (1) used data on 182 cows with from one to three lactations in the Beltsville Holstein herd to examine profit functions and effect of measures of efficiency and prices. Four profit functions were computed from income and expense for each cow. These were:

Total Profit (TP) = Income - Expense.

Profit Per Day (PPD) = (Income - Expense)/Herdlife.

Profit per Unit of Investment = Income (I)/Expense (E).

Cost per Unit of Production = Expense (E)/Income (I).

Profit functions were estimated at 1970, 1980, and 1985 prices. Prices and partial budgets developed by Pearson (28) were used to calculate the unit prices for the base year 1970. Unit prices for 1980, and 1985 were based on predictions of price trends for dairy farm items from 1970 to 1985.

Correlations among TP and PPD for 1970, 1980 and 1985 prices as well as each of these with herdlife are in Table 4. Strong positive correlations among measures of efficiency for different years indicated that change of various unit prices had little effect on rank of cows for gross profit (TP) or profit per day of herdlife (PPD). Correlations of TP with herdlife were high and positive, reflecting both the direct effect of greater longevity and the accumulation of profit over a longer time. Correlations of PPD and herdlife were small because PPD was already adjusted for herdlife.

Information used in calculation of income and expenses and correlations of these variables with measures of profit are in Table 5. Balaine et al. (1) found that correlations between physical variables and TP were generally higher than correlations with PPD. Maximum correlations were for yield variables with TP ($\cong$ .83), showing the importance of yield variables in the calculation of profit functions.

Table 4. Correlations among total profit and profit per day at 1970, 1980, and 1985 prices by Balaine et al. (1).

	TP80	TP85	PPD70	PPD80	PPD85	Herdlife
TP70[1]	1.00	.98	.72	.78	.80	.56
TP80		.97	.68	.76	.79	.59
TP85			.79	.85	.85	.38
PPD70[2]				.98	.98	-.05
PPD80					1.00	.07
PPD85						.12

1) Total Profit.
2) Profit Per Day.

Table 5. Correlation of lifetime physical variables with measures of lifetime economic efficiencies by Balaine et al. (1).

Physical Variable	Correlation TP[1]	PPD[2]	I/E[3]
Income:			
Milk yield (kg)	.84	.48	.61
Fat yield (kg)	.82	.44	.58
Protein yield (kg)	.84	.46	.60
Live calf weight (kg)	.59	.24	.37
Ending weight (kg)	.38	.19	.25
Expenses:			
Age difference (age at 1st calving-730 (days)	.02	-.02	-.02
Weight gain (weight at 1st calving-birth weight) (kg)	-.04	.03	-.02
Feed energy (Mcal)	.68	.27	.41
Mastitis treatment (no.)	-.06	-.21	-.19
Services (no.)	.34	.07	.14
Herdlife (days)	.59	.17	.31

1) Total Profit.
2) Profit Per Day.
3) Income/Expense.

Conclusions of Balaine et al. (1) were that: 1) linear function of income/expense adjusted for herdlife (PPD) was highly correlated with I/E (.98) and appeared to be the best function for evaluating dairy cattle, 2) changes in relative unit prices representing three points over 15 years had little effect on the rank of cows for PPD, 3) milk yield was the most important income trait, and feed intake, mastitis treatment, and herdlife were the most important expense traits in explaining variation among cows in measures of economic efficiency.

Norman et al (26) working with data from 10,139 Jersey cows, introduced relative net income (RNI), a profit function computed from DHI variables. RNI was designed to reflect major differences among cows in income and expense.

Relative net income was calculated as follows:

RNI = (lifetime value of product x net percentage)
+ (number of freshenings x net value)
+ salvage value - value at first calving
- feed cost for growth after first calving
- (days of productive life) x (feed cost for
maintenance + fixed and operating cost/day
of productive life).

Variable prices can be found in Norman et al. (26). Mean lifetime profit (RNI) was \$699 and average profit per day of life was \$.26. Gill and Allaire (13) used a similar profit function and found average lifetime profit of \$689.

Relationships between lifetime variables in (26) are in Table 6.
High correlations were found ($\geq$ .95) between number of lactations, days in milk (DIM), days of productive life (DPL), lifetime actual milk, lifetime actual fat, and lifetime value

Table 6. Phenotypic correlations between lifetime performance traits from Norman et al. (26).

Trait	Lactations	DIM	DPL	LM	LF	LPV	RNI	LPV/DPL
DIM[1]	.99							
DPL[2]	.98	.99						
LM[3]	.95	.97	.96					
LF[4]	.96	.97	.97	.99				
LPV[5]	.98	.97	.97	1.00	1.00			
RNI[6]	.84	.87	.83	.95	.94	.95		
LPV/DPL	.25	.30	.23	.42	.41	.41	.60	
RNIPD[7]	.63	.67	.63	.69	.69	.69	.69	.54

1) DIM = days in milk.
2) DPL = days of productive life.
3) LM = lifetime milk.
4) LF = lifetime fat.
5) LPV = lifetime product value.
6) RNI = relative net income.
7) RNIPD = relative net income per day.

of product. Lifetime RNI was highly correlated (≅.95) with lifetime actual milk and fat and lifetime value of product. Number of lactations, DIM, and DPL were less correlated with lifetime RNI (r = .83 to .87) but had a strong influence on RNI (26).

Expressing lifetime RNI per DPL (RNIPD) placed a premium on rapid return to investment. Correlations of RNIPD with lifetime performance traits were less, since RNIPD was expressed per day, and performance traits were expressed on a lifetime basis (26). Addition of variation due to herdlife resulted in the lower correlations.

Tigges (35) used the RNI function developed by Norman et al. (26) to examine the relationships of official Holstein-Friesian conformation scores with a profit function based on DHI variables. Tigges (35) found that milk production was the most important variable in any profit function, in agreement with others (21,26). The next most important variables were number of calves and herdlife. Milk yield in first lactation accounted for 31.4% of variation in milk per day of life and 62.3% of profit per day of life. Lin and Allaire (21) concluded that the economic evaluation of dairy cows could be accomplished more realistically by including performance variables in addition to milk yield into an estimate of profit to a certain age. Tigges (35) found that adding days of herdlife to milk value formed the best two variable regression model to predict total profit with an R^2 of .94.

Lin and Allaire (21) examined the effects of selection on milk yield on genetic gain in total milk produced to 48 months, 72 months, or lifetime. Selection on total milk produced to 41 months of age was more efficient than selection on milk produced to 305 days of first lactation. Lin and Allaire (21) showed genetic gain in total profit was 13 to 14% greater when selection was on estimated profit to 41 months than on milk yield to 305 days in first lactation. Part of the result was automatic, since measurements to 41 months of age use more of the information involved in total profit than does first 305 day yield for most cows. Using records to this age accounts for some of the variablilty due to days dry, days open, and other factors between consecutive lactations.

Relative net income appears to be a desirable measure to determine profit returned to dairy producers. The ability to predict RNI on progeny of sires from sire evaluation variables can be used to access the utility of such evaluations. Specifically, the accuracy with which variables from first, all, or later lactation evaluations can predict RNI can help determine the usefulness of the different evaluations in predicting profitability.

Materials and Methods

Sources of Data

This study required three data sets: herd DHI test history, sire summaries from first, all, and later records, and individual daughter production information by lactation for Holsteins. Herd and daughter data consisted of DHIA variables. Sire data were MCC sire evaluations calculated in the Summer 1985 run of the USDA-DHIA MCC. All data were from AIPL in Beltsville Md.

The initial herd data set included 102,739 Holstein herds on official DHI test from across the U.S. from January 1, 1966 to April 1, 1985. Information on each herd included state, county, and herd code number, first date herd entered a DHI testing program, last DHI test date, and average milk and fat production for each season the herd was on a testing program.

Herds included in the study were required to have been on test for a continuous period of 72 months or greater. For those herds that entered a DHI testing program prior to January 1966, a period of at least 72 continuous months on DHI test after

January 1966 was required. Last acceptable test date for a herd to start a DHI testing program was April 1, 1979. A total of 68,975 herds remained in the final herd data set.

Initial sire data consisted of 599 Holstein sires each with greater than 150 daughters in their all lactation summary. Information included MCC sire evaluations based on first, all or later records, and selected variables. Sires that remained in the final data set were required to have at least 150 daughters in each of first, all and later lactation evaluations. For imported sires, at least 150 daughters of U.S. origin were required. Only those daughters of U.S. origin were used in the study to insure uniformity of evaluations. Four hundred and fourteen sires survived these edits.

The original daughter data set was made up of approximately 2.9 million DHI production records of Holstein cows with last digit of herd number ending in 3, 5 or 8. This requirement obtained an essentially random sample of approximately 30 percent of the tested, sire identified U.S. dairy cattle population. Variables for each cow included: birth date, sire and dam identification, herd number, number of lactations, and cow registration number. Variables for each lactation were: calving date, actual milk and fat production, days in milk, days carried calf, and days dry previous lactation. Each cow was allowed production information through ten lactations or disposal, whichever came first. Actual milk and fat production records were used rather than mature equivalent records to more accurately calculate RNI for each animal.

Edits placed on cows included:

- Cows were required to be born after the herd began an official DHI testing program and prior to April 1, 1979. For cows from herds with a date of initial test prior to January 1966, a birth date after January 1, 1964 was allowed, if the cow calved for first lactation after January 1, 1966.
- First lactation animals were required to calve between 18 and 36 months of age.
- Cows were required to have been milked two times daily for all lactations.
- Cows were required to have 270 to 600 days, inclusive, between each pair of successive parturitions.
- Cows were required to have remained in the same herd for their entire productive life.
- Cows were required to come from a herd on test for at least 72 consecutive months.
- Cows must have been born at least 72 months before the last test date for the herd.
- Cows were required to have at least five contemporaries in the same herd year of first freshening.
- Cows were required to be sired by one of the 414 sires in the final sire data set.

The above edits provided each cow in the data the opportunity for production through 72 months of age in an officially tested herd. The last allowable date of birth of April 1, 1979 allowed an animal the opportunity for production through 72 months of age and reflected the cutoff date for records included in the Summer 1985 USDA-DHIA MCC of approximately April 1, 1985.

Calculation of RNI and RNIPD

The RNI function was formulated to predict relative cow profitability. Relative cow profitability was net income that a dairy producer would receive after expenses, and was measured relative to other cows in the same herd-year of first freshening. It attempts to account for the major sources of income and expenses incurred during the animal's lifetime. DHI variables used to calculate RNI were lifetime production of milk and fat, number of freshenings, age at first calving, and days of herdlife.

RNI was calculated as follows:

RNI = (lifetime product value * net percentage)
+ (number of freshenings * net value)
- (rearing cost)
- (days of productive life * daily maintainance
feed, fixed and operating costs)
+ (345)

where, lifetime product value = (lifetime milk production * milk price) +(lifetime fat production * fat price), rearing cost = (days from birth to first freshening * per day rearing cost). Prices used were determined at a low, medium and high value to evaluate the effects of price combinations on RNI and the ability of sire evaluations from first all and later records to predict different RNI's.

Eleven separate RNI's were calculated (Table 7). Price assumptions used to calculate each RNI are in Table 8. Two categories of physical variables were defined. The first category included milk and fat, referred to as product value, and consisted of the major income variables. The second category consisted of feed price, the major expense variable. Three levels of product and feed price were computed, low, medium, and high. Nine separate RNI's, RNIA through RNII, were calculated by using each combination of product and feed price. Two additional RNI's were calculated by using the medium product and medium feed price while varying the rearing and fixed and operat-

Table 7. Product and Feed Price Combinations used to calculate RNIA through RNIK. Net percentages reflect the cost of feed to to support gestation and value of discarded milk for each RNI.

Feed Price	Product Price		
	Low	Medium	High
Low	A (.82)	B (.85)	C (.87)
Medium	D (.75)	E (.79)	F (.83)
High	G (.65)	H (.72)	I (.76)

J = medium product and feed price, $1.38 per day rearing, $1.77 per day fixed and operating costs.

K = medium product and feed price, $1.65 per day rearing, $3.77 per day fixed and operating costs.

1) Numbers in brackets ( ) are corresponding net percentages.

Table 8. Range of prices used in calculation of different relative net incomes.

	Variable Prices		
	Low	Medium	High
Milk $/kg (3.5%)	23.15	28.66	35.27
0.0%/kg	.123	.163	.222
Fat $/kg	3.09	3.53	3.75
$/.1%	.31	.35	.38
Feed $/Mcal	.12	.18	.24
Value of discarded milk (%)	2.0	2.0	2.0
Rearing Cost ($)			
feed/day	.75	1.00	1.25
fixed per day	.35	.35	.35
Subtotal	1.10	1.35	1.60
Total[1] ($)	1.21	1.49	1.76
Costs associated with production ($)			
maintenance/day[2]	.53	.77	1.06
fixed & operating	1.75	1.75	1.75
Total ($)	2.28	2.52	2.81
Net Value ($)			
value of calf	70.00	70.00	70.00
cost of 2 inseminations	30.00	30.00	30.00
feed to support gestation	8.00	10.00	12.00
Total ($)	32.00	30.00	28.00
Salvage value ($)	470.00	470.00	470.00
Initial heifer calf price ($)	125.00	125.00	125.00
Constant ($)	345.00	345.00	345.00

1) Increased by 10% to account for heifer mortality.
2) Based on a 590 kg cow.

ing costs per day. Relative net income J (RNIJ) was calculated with a rearing cost of $1.38 per day and a fixed and operating costs of $1.77 per day ($.77 maintenance cost, $1.00 fixed and operating costs). Relative net income K (RNIK) was calculated with higher rearing costs per day ($1.65) and fixed and operating costs per day of $3.77 ($.77 maintenance cost, $3.00 fixed and operating costs).

Net percentage differed for each RNI calculated (Table 7). For the RNI using medium feed and product prices a net percentage of 79% was derived from 19% of product value to purchase feed to support production plus 2% of product value for value of discarded milk. Net value was initial calf value minus the cost of insemination and the cost of feed to support gestation. Initial calf value of $70 was used, this assumed a 50:50 sex ratio and was the average price of a bull and heifer calf at 1986 prices. It was assumed that two inseminations were required per live calf. An average insemination cost of $15 was used. Feed to support gestation was determined at a low, medium and high price. Feed requirements for production and gestation are from 1978 NRC recommendations for a 590 kg cow. The $345 is a constant reflecting salvage value of the cow minus initial heifer calf value.

Relative net income per day (RNIPD) was also calculated for each cow. This was simply the RNI for each cow divided by the cow's days of productive life (DPL). DPL is defined as the number of days from first freshening until the end of the animal's tenth lactation or disposal. Date of disposal was date of last freshening plus length of last lactation.

Calculation of Contemporary Deviations and Deviated RNI

Contemporaries to a cow were defined as those cows calving for the first time in the same herd and year (HY) sired by another bull than the cow in question. Season of first calving was ignored. Herd-year of first freshening and herd-year-sire of first freshening (HYS) means were calculated for RNI and RNIPD for each HY and HYS.

Contemporary averages were calculated by:

$$\frac{[(N_i \times X_i) - (N_{ij} \times X_{ij})]}{(N_i - N_{ij})}$$

where:

- N_i = number of cows in the i^{th} HY.
- X_i = mean for i^{th} HY.
- N_{ij} = number of cows by the j^{th}sire in the i^{th} HY.
- X_{ij} = mean of progeny of the j^{th}sire in the i^{th} HY.

for each RNI and RNIPD. Each animal was required to have at least five contemporaries to be included in the final analysis.

Deviated RNI (DRNI) was calculated for each cow in the final data set. DRNI was RNI of the cow minus contemporary average RNI, and was calculated to be relatively free of variation in profit due to herd and year of first calving. Deviated RNIPD (DRNIPD) was also calculated. DRNIPD was RNIPD of the cow minus contemporary average RNIPD.

Prediction of RNI and RNIPD

Models were examined to determine the accuracy with which sire evaluations based on first, all, or later lactations could predict profit. Profit was defined as either DRNI or DRNIPD for each combination of product and feed price assumptions. Sire evaluations from the three lactation groups included in the models were Predicted Difference Milk (PDM), Predicted Difference Fat (PDF), and Predicted Difference Dollars (PDD). Predicted Difference Dollars was an index based on the January 1986 values of milk and fat. Values used for milk and fat were \$.1314/kg milk and \$3.62/kg fat.

Models examined were:

$$Profit_{ij} = \mu + \beta_1(\text{first lactation evaluation}) + e_{ij}$$

$$Profit_{ij} = \mu + \beta_1(\text{later lactation evaluation}) + e_{ij}$$

$$Profit_{ijk} = \mu + \beta_1(\text{first lactation evaluation}) + \beta_2(\text{later lactation evaluation}) + e_{ijk}$$

$$Profit_{ij} = \mu + \beta_1(\text{all lactation evaluation}) + e_{ij}$$

Models were examined for predicting individual daughter DRNI and DRNIPD. Models were also examined for predicting progeny group average DRNI and DRNIPD. Only sire evaluations with at least 25 daughters per progeny group were used. Models requiring 10 and 50 daughters per progeny group average were compared to determine the effect of requiring more daughters per progeny group average on the relationship of DRNI and DRNIPD and the regression variables. Regression coefficients and coefficients of determination (R^2) used to meet objectives are outlined in the introduction.

Sires were ranked by actual deviated relative net income E (DRNIE) and predicted DRNIE. The models above were used to predict DRNIE from PDM, PDF, and PDD. Ranks were examined for both DRNIE and deviated relative net income E per day (DRNIEPD). Error in sire rank was actual rank for sire group average DRNIE minus the rank for predicted sire group average DRNIE. Errors in rank were examined to determine which models ranked sires closest to their actual rank and to compare these models to the models with the largest coefficients of determination.

Results and Discussion

Results of this study will be presented by two methods. Regression coefficients and coefficients of determination for the prediction of RNI and RNIPD will be presented in tabular form in the appendixes. Representative sections of the prediction of RNI and RNIPD will be presented in Results and Discussion to show trends. This presentation will be divided into three parts: physical characterization of the cow and sire data sets, description of the eleven different RNI's calculated, and evaluation of the several models used to predict profit on a lifetime and per day basis.

Physical Characterization of the Data

Of the 2.9 million cows in the initial data set 176,902 passed all the edits placed on the cow data. Means and standard deviations for actual milk and fat yield can be found in Table 9. The percent of the 176,902 cows surviving to produce in each lactation is also presented. Only ten lactations were included as a very small percentage of cows survived to produce through ten or greater lactations. Percent of animals surviving be-

Table 9. Means and standard deviations of average actual milk and fat production (kg) by lactation for 176,902 cows in the final data set.

		Milk		Fat	
Lactation	Percent	Mean	Standard Deviation	Mean	Standard Deviation
1	100	5945	1705	216	62
2	79	6969	1904	252	70
3	58	7425	2060	268	77
4	40	7336	2312	266	85
5	22	6788	2626	247	96
6	9	6536	2683	238	98
7	3	6260	2683	228	98
8	1	5835	2649	213	97
9	.3	5445	2544	199	92
10	.05	4428	2502	159	89
Lifetime	100	21,082	14,328	765	522

yond the fifth lactation may have been influenced by restrictions placed on the data set. Mean lifetime milk and fat production were slightly larger than the range found in the literature (12,14,35,42). Milk and fat production increased steadily through the third lactation then gradually declined through the remaining lactations. Variability associated with milk and fat production in each lactation continued to increase through the sixth lactation. Variability decreased beyond the seventh lactation, perhaps due to terminal lactations. Trends associated with milk and fat production are in Figures 1 and 2 respectively.

Cows in the final data set averaged 3.13 lactations, similar to results reported in the literature (35,42). Means and ranges for herd life variables for cows in the final data set are in Table 10. Average days of productive life in which to generate income and expenses was 1060 with a range from 7 to 4221 days. Average days to first freshening was 856. This represents a period of time when only expenses are incurred on the animal. An average of 31 cows calved in the same year of first freshening for each cow represented in the data. Each animal had an average of 3.2 half-sibs from the same sire born in the same herd and calving in the same year of first freshening.

Means and variation of days in milk (DIM) and year of calving for the cows in the data set by lactation are in Table 11. Also shown is the number of animals surviving to produce in each lactation, a variable expressed in percentage in Table 9. Mean DIM decreased as number of lactations increased, while variation in DIM increased. This could reflect an increasing percentage of terminal records. Minimum calving year for each lactation increased nearly linearly. Maximum year of calving for each lactation plateaued at 1985 in the third lactation. This was due to only accepting data reported by the Summer 1985 MCC (approximately April 1, 1985). This constraint on the data may have negatively biased the number of animals surviving to produce in later lactations beyond fourth. It probably biased the estimate of the average number of

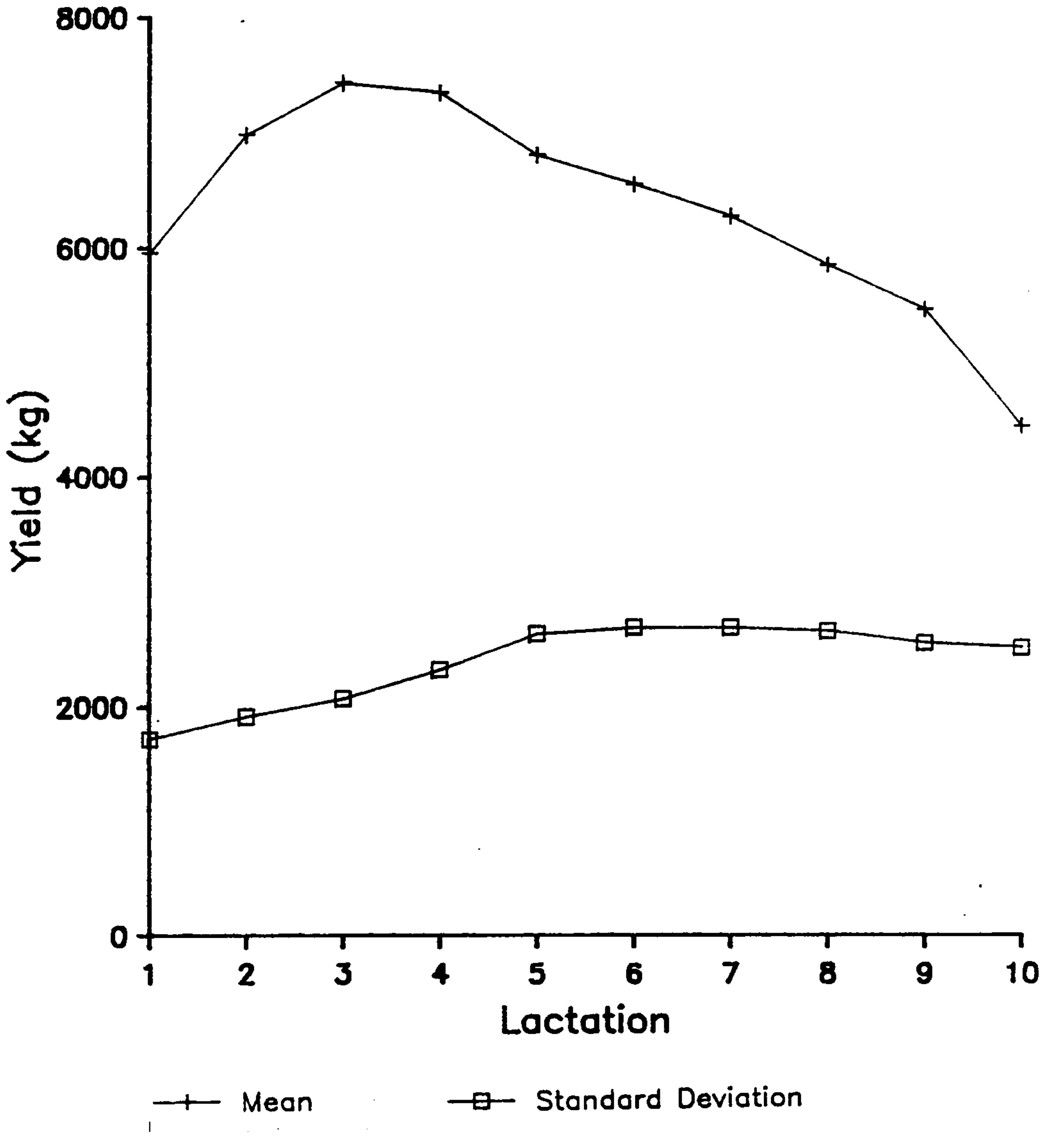

Figure 1. Average actual milk production by lactation for 176,902 cows in the final data set.

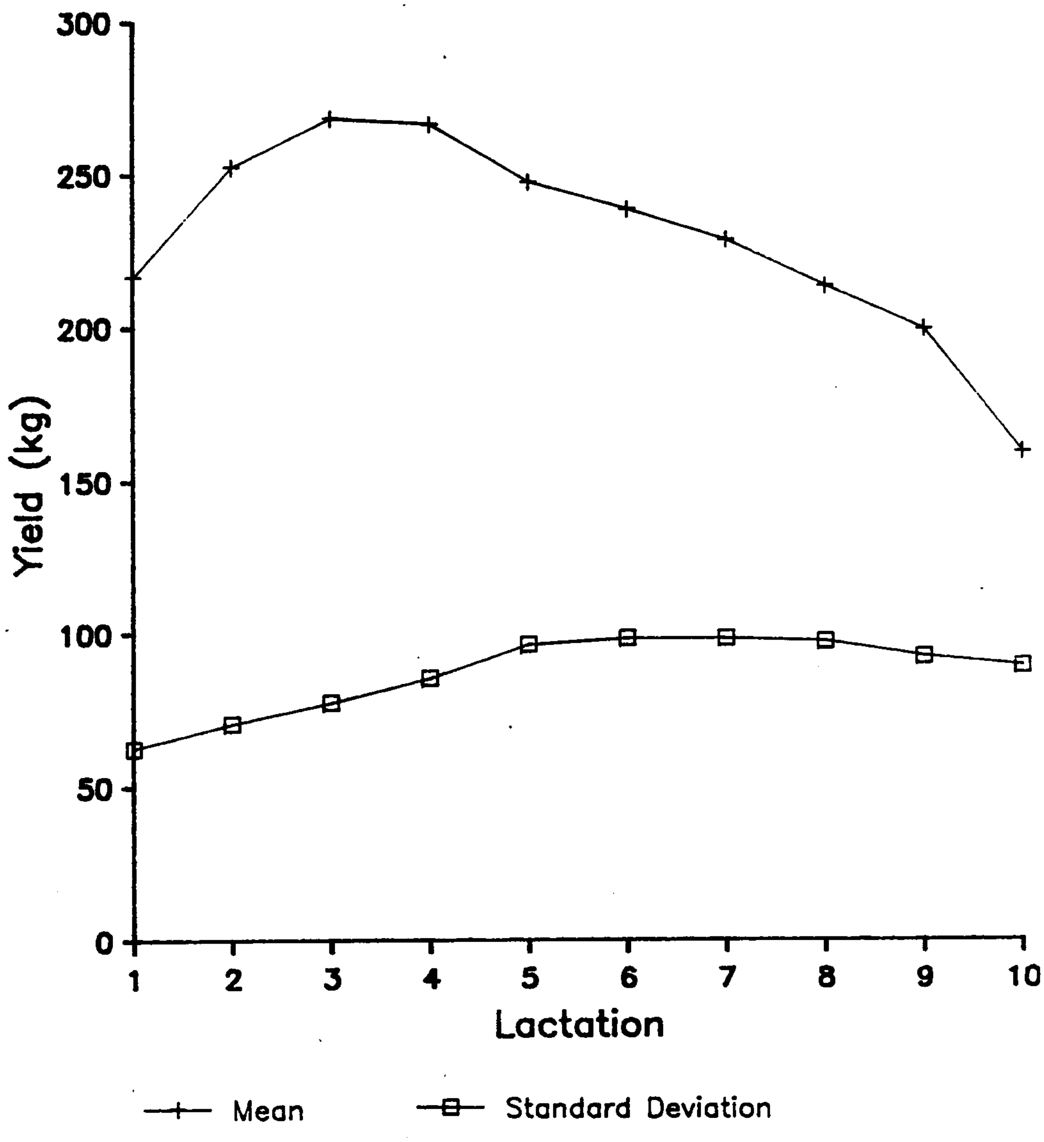

Figure 2. Average actual fat production by lactation for 176,902 cows in the final data set.

Table 10. Means and range for herdlife variables for 176,902 cows in the final data set.

Variable	Mean	Range	
		Minimum	Maximum
Birth year	1976	1965	1979
Herd-year-contemporaries (#)	31	5	678
Herd-year-sire contemporaries (#)	3.2	1	62
Herd life opportunity[1] (mos)	103	72	235
Days of productive life[2]	1060	7	4221
Rearing time[3] (days)	856	541	1096
Number of lactations	3.13	1	10
Total milk production (kg)	21,082	54	105,900
Total fat production (kg)	765	2.2	3797

1) Period of time between when the cow was born and the herd went off official DHI test.
2) Days from first freshening until disposal or end of tenth lactation.
3) Days from birth until first freshening.

Table 11. Means and variation of days in milk and year of calving by lactation for 176,902 cows in the final data set.

Lactation	N	Days in Milk Mean	Days in Milk Standard Deviation	Calving Year Mean	Calving Year Range Minimum	Calving Year Range Maximum
1	176902	282	56	78	67	82
2	139036	280	52	79	68	83
3	102864	278	56	81	69	85
4	70962	265	69	82	70	85
5	38995	242	86	82	71	85
6	16405	234	90	82	73	85
7	6042	228	93	83	74	85
8	1996	217	94	83	75	85
9	501	208	94	83	76	85
10	86	170	94	83	79	85

lactations downward slightly. However, herdlife opportunity of 72 months was provided for all cows.

Physical characteristics of the sire data will be presented as two subsets, referred to as subset 1 and subset 2. Subset 1 consisted of the 388 sires with daughters in the final cow data set. Subset 2 consisted of the 226 sires with at least 25 daughters in the same data set. This subset of sires was used to calculate and predict the sire group averages for deviated RNI and RNIPD.

The number of sires in subset 2 was determined by examining the coefficients of determination for DRNIE while requiring different numbers of daughters in the final cow data set for a sire to be in the data set. Table 12 shows the number of bulls, average number of total daughters, and R^2 for each level examined. As the number of daughters required increased from 10 to 25, variation explained by the model increased (from .179 to .360). When number of daughters required rose from 25 to 50, R^2 increased slightly. As number of daughters required increased beyond 50 variation explained in the models gradually decreased. Requiring 25 daughters per sire resulted in 226 sires to use in the prediction of sire group average DRNI, and explained nearly as much variation as the best model.

Means and ranges for year of birth, number of daughters, and number of herds for first, all, and later lactations are in Table 13 for subset 1. Mean birth year was 1971, with a range from 1964 to 1976. Sires had fewer daughters with later lactations on the average, and these were in fewer herds. Maximum number of daughters by one sire was 56,874 when all lactations were present. Means and ranges for the same variables for subset 2 are in Table 14. There are two primary differences between the two sire subsets. Sires represented in subset 2 have a mean birth year of 1969 versus 1971 for subset 1 sires. Sires in subset 2 on average have more daughters and are represented in more herds than are subset 1 sires in first, all, and later lactations. The maximum for number

Table 12. Effect of requiring a certain number of daughters in the final data set on: number of bulls, average number of daughters and R^2 for DRNIE[1]

Minimum Number of Daughters	Number of Bulls	Average Number of Daughters	R^2 for DRNIE, First and Later Lactation
10	311	6479	.179
25	226	7968	.360
50	199	8552	.396
100	178	9184	.393
500	112	11327	.367

1) Deviated Relative Net Income E.

Table 13. Means and ranges on selected variables from evaluations based on first, all, or later lactations for the 388 sires with daughters in the final data set.

Variable	Mean	Range	
		Minimum	Maximum
Birth year of sire	1971	1964	1976
First lactation evaluations:			
Number daughters	4978	166	48550
Number herds	1693	68	10876
All lactation evaluations:			
Number daughters	5647	204	56874
Number herds	1859	78	12569
Later lactation evaluations:			
Number daughters	3882	152	49138
Number herds	1434	51	11641

Table 14. Means and ranges on selected variables from evaluations based on first, all, or later lactations for the 226 sires with ≥ 25 daughters in the final data set.

		Range	
Variable	Mean	Minimum	Maximum
Birth year of sire	1969	1964	1976
First lactation evaluations:			
Number daughters	6912	201	48550
Number herds	2208	89	10876
All lactation evaluations:			
Number daughters	7968	242	56874
Number herds	2462	97	12569
Later lactation evaluations:			
Number daughters	5955	180	49138
Number herds	2087	83	11641

of daughters and number of herds is identical for the two subsets. However subset 2 sires have a larger minimum number of daughters than do subset 1 sires. Therefore on the average subset 2 sires are older and are represented by more daughters and in more herds than are subset one sires.

Means and standard deviations for PDM, PDF, and PDD for first, all and later lactation evaluations are in Tables 15 and 16 for subsets 1 and 2 respectively. Differences, PD later minus PD first for milk fat and dollars are also presented. Average differences, milk, fat, and dollars, were positive for subset 1. The standard deviation for PDM difference of 145 kg was remarkably similar to the 149 kg reported by Cassell et al. (8). This indicated that considerable variation existed among bulls in difference between later and first lactation evaluations. Means for all variables, including differences, were negative for subset 2 sires. They were also slightly more variable than subset 1 sires for all variables examined. This may be a consequence of the average earlier year of birth for the subset 2 sires.

Economic Values

Means and standard deviations for different estimates of lifetime relative net income (RNIA through RNIK) and contemporary average RNIA through RNIK are given in Table 17. Respective prices for the calculation of each RNI were presented earlier. Relative net incomes are grouped by feed price (low, medium, and high) except RNIJ and RNIK. Within each feed price the product value was increased from low to medium to high. Largest average RNI's were found at the low feed price (RNIA, RNIB,

Table 15. Means and standard deviations for variables from sire evaluations based on first, all, and later lactations for the 388 sires with daughters in the final data set.

	Mean	Standard Deviation
PDM[1] First (kg)	26.3	269
PDF[2] First (kg)	.47	9
PDD[3] First ($)	6.08	61
PDM All (kg)	30.8	268
PDF All (kg)	.05	9
PDD All ($)	4.22	61
PDM Later (kg)	34.9	278
PDF Later (kg)	.77	9
PDD Later ($)	7.42	64
PDM Diff[4] (kg)	8.6	145
PDF Diff (kg)	.05	5
PDD Diff ($)	1.35	36

1) Predicted Difference Milk.
2) Predicted Difference Fat.
3) Predicted Difference Dollars.
4) Later lactation evaluation minus first lactation evaluation.

Table 16. Means and standard deviations for variables from sire evaluations based on first, all, and later lactations for the 226 sires with ≥ 25 daughters in the final data set.

	Mean	Standard Deviation
PDM[1] First (kg)	-23.6	286
PDF[2] First (kg)	-.95	10
PDD[3] First ($)	-6.58	65
PDM All (kg)	-23.6	286
PDF All (kg)	-2.18	9
PDD All ($)	-12.64	63
PDM Later (kg)	-44.5	288
PDF Later (kg)	-1.7	10
PDD Later ($)	-12.14	65
PDM Diff[4] (kg)	-20.9	152
PDF Diff (kg)	-.77	5
PDD Diff ($)	-5.56	38

1) Predicted Difference Milk.
2) Predicted Difference Fat.
3) Predicted Difference Dollars.
4) Later lactation evaluation minus first lactation evaluation.

Table 17. Means and standard deviations of 176,902 individual cows and contemporary averages for relative net income[1]

Relative Net Income Used	Individual Cow Mean	Individual Cow Standard Deviation	Contemporary Average Relative Net Income Mean	Contemporary Average Relative Net Income Standard Deviation
A	$1063	1401	$ 969	627
B	2210	2154	2068	922
C	3551	3051	3356	1279
D	215	1054	145	508
E	1341	1769	1223	780
F	2749	2701	2572	1146
G	-825	676	-866	393
H	367	1334	277	627
I	1677	2177	1531	949
J	2230	2218	2085	935
K	-121	1134	-193	596

1) All cows were required to have at least five contemporaries.

and RNIC). As feed price increased average RNI decreased. This relationship held for individual RNI and contemporary average RNI. As product value within a feed price increased, (e.g., A vs. B vs. C) the standard deviation increased. However as feed price increased within a product value (e.g., A vs. D vs. G) the standard deviation decreased. Net percentage, product value remaining after feed to support production and discarded milk were considered, also increased as product value increased within a feed price and decreased as feed value increased within a product value.

As product value increased, a decreased percentage of that product was required to cover feed cost to support production. Therefore at low feed price and high product value, a premium was placed on production in calculating RNI. As product value remained constant and feed price increased, a higher percentage of product value was required to cover feed costs to support production. A combination of low product value and high feed cost (RNIG) placed less emphasis on production and more on days from birth to first freshening, number of lactations, and days of productive life. Average RNIJ, with low rearing and low fixed and operating costs per day was higher than RNIK which had a high rearing and high fixed and operating cost per day. Standard deviations associated with contemporary average RNI were less than the standard deviations associated with individual RNI yet followed the same trends.

Economic assumptions used in this study make comparison of mean RNIE, medium product and feed price, to average RNI estimates reported in the literature (26,35) difficult. Norman et al. (26) reported an average lifetime RNI of $699 for Jerseys. The mean RNI of $1234 found by Tigges (35) is similar to the average of $1341 found in this study, both using Holstein data.

Means and standard deviations for individual relative net income per day of productive life (RNIAPD through RNIKPD) and contemporary average RNIAPD through RNIKPD are in Table 18.

Table 18. Means and standard deviations of 176,902 individual cows and contemporary averages for relative net income per day[1]

Relative Net Income Per Day Used	Individual Cow		Contemporary Average Relative Net Income Per Day	
	Mean	Standard Deviation	Mean	Standard Deviation
A	$0.05	3.27	$-0.08	1.19
B	1.12	3.33	0.98	1.24
C	2.37	3.42	2.22	1.31
D	-1.07	4.37	-1.23	1.55
E	-0.02	4.41	-0.19	1.59
F	1.29	4.49	1.11	1.64
G	-2.36	5.44	-2.55	1.91
H	-1.25	5.48	-1.45	1.94
I	-0.03	5.53	-0.24	1.98
J	0.94	3.98	0.79	1.44
K	-1.59	5.05	-1.77	1.80

1) All cows were required to have at least five contemporaries.

Trends for the means across feed and product prices were similar to trends on lifetime variables for both individual and contemporary average RNIPD. Standard deviations increased relatively little with an increase in product value over a constant feed price (A vs B vs C). In contrast to lifetime RNI, the standard deviation increased considerably as feed price increased over a constant product value on a per day basis (RNIAPD vs. RNIDPD vs. RNIGPD).

Of the average lifetime RNI estimates, two were negative, while on a per day basis, six RNI's were negative. A cow must have a positive lifetime RNI to have a positive RNIPD. The inconsistency may be explained by the difference in length of productive life of the cows in the study. Days of productive life weights RNI in RNIPD. Animals culled in the first lactation would be expected to have a negative lifetime and per day RNI, and short length of productive life. Conversely, animals producing through later lactations would be more likely to have positive lifetime RNI, but more days of productive life. Therefore, on a lifetime basis the greater RNI of the cows producing later into life would be regressed by a larger denominator in determining RNIPD. On a per day basis the loss incurred in RNI on the younger culled animals would be accentuated by short productive lives. This assumption may also explain the considerable increase in the standard deviation for feed price over a constant product value.

The differences between individual RNI and contemporary average RNI on a lifetime and per day basis were examined. Means and standard deviations for each are in Table 19. Average deviations were all positive. Individual lifetime and per day RNI's were calculated on the daughters of the 388 sires represented in the final data set. Contemporary average lifetime and per day RNI was calculated on all animals passing the initial edits. Therefore the individuals with deviated RNI's calculated would have

Table 19. Means and standard deviations of deviated relative net income ((RNI) - contemporary average RNI) of 176,902 individual cows[1]

Relative Net Income Used	Lifetime		Per Day	
	Mean	Standard Deviation	Mean	Standard Deviation
A	93	1347	0.13	3.37
B	141	2097	0.14	3.39
C	198	2986	0.15	3.46
D	71	991	0.16	4.47
E	118	1709	0.17	4.51
F	177	2635	0.18	4.57
G	40	589	0.18	5.57
H	90	1265	0.19	5.61
I	145	2109	0.21	5.66
J	145	2167	0.15	4.07
K	73	1033	0.19	5.17

1) All cows were required to have at least five contemporaries.

been daughters of heavily used sires in the dairy cattle population. Standard deviations associated with the differences are similar to standard deviations of individual RNI's for both lifetime and per day measures.

Sire Group Averages

Table 20 includes means and ranges for sire group average deviated RNIA through RNIK for subset 1 sires. Sire group average deviated RNI (DRNI) was the average of the deviation of the sire's daughters' RNI from their contemporary average RNI. Means for sire group average DRNI followed trends similar to individual daughter RNI. Means increased as product value increased within a feed price and decreased as feed price increased within a product value. The range for each RNI showed considerable variation between sires, as was the case with the cows. Variation in sire group average DRNI, consistent with individual daughters' RNI measures, increased as product value increased, and decreased as feed price increased.

Means and ranges for subset 2 sires are in Table 21. The mean of each DRNI calculated was less than for subset 1 sires. Trends in the averages and variation of each DRNI for subset 2 sires were similar to those for subset 1 sires and individual daughter RNI. Variation in subset 2 sires for the eleven RNI's was considerably less than for the subset 1 sires, but still showed considerable variation between sires. Again trends of product value variation within feed price were similar to those in subset 1 sires and individual daughter RNI.

Subset 1 sire group average deviated RNIPD (DRNIPD) means and ranges are in Table 22. Means for each DRNIPD were similar with trends characteristic of daughter RNIPD. Considerable variation in DRNIPD was found between sires on a

Table 20. Means and ranges for sire group average deviated relative net income ($) for the 388 sires with daughters in the final data set.

Economic parameters used in Relative Net Income (RNI)[1]	Mean	Standard Deviation	Range	
			Minimum	Maximum
RNIA[2]	151	495	-1802	3551
RNIB	223	758	-2779	5461
RNIC	307	1068	-3906	7745
RNID	119	371	-1305	2636
RNIE	190	625	-2265	4510
RNIF	278	949	-3450	6899
RNIG	76	218	-708	1421
RNIH	150	472	-1659	3389
RNII	232	769	-2763	5610
RNIJ	225	775	-2841	5555
RNIK	130	392	-1305	2768
Number of daughters	456		1	7147

1) See Table 8 for economic values used.
2) Relative Net Income A.

Table 21. Means and ranges for sire group average deviated relative net income ($) for the 226 sires with ≥ 25 daughters in the final data set.

Economic parameters used in Relative Net Income (RNI)[1]	Mean	Standard Deviation	Range	
			Minimum	Maximum
RNIA[2]	78	227	-632	1153
RNIB	111	342	-1030	1725
RNIC	149	478	-1499	2354
RNID	65	173	-429	850
RNIE	97	284	-820	1415
RNIF	137	427	-1311	2081
RNIG	46	107	-194	455
RNIH	80	218	-569	1050
RNII	118	349	-1027	1672
RNIJ	112	348	-1091	1748
RNIK	71	186	-367	860
Number of daughters	775		26	7147

1) See Table 8 for economic values used.
2) Relative Net Income A.

Table 22. Means and ranges for sire group average deviated relative net income per day ($) for the 388 sires with daughters in the final data set.

Economic parameters used in Relative Net Income Per Day[1]	Mean	Standard Deviation	Range	
			Minimum	Maximum
RNIAPD[2]	0.20	.71	-3.42	3.38
RNIBPD	0.22	.75	-3.54	3.48
RNICPD	0.24	.78	-3.94	3.62
RNIDPD	0.25	.93	-4.51	4.45
RNIEPD	0.26	.96	-4.56	4.55
RNIFPD	0.28	.99	-4.63	4.69
RNIGPD	0.29	1.13	-5.54	5.47
RNIHPD	0.30	1.16	-5.61	5.58
RNIIPD	0.32	1.19	-5.67	5.71
RNIJPD	0.24	.87	-4.13	4.13
RNIKPD	0.29	1.08	-5.19	5.17

1) See Table 8 for economic values used.
2) Relative Net Income A Per Day.

per day basis. Variation increased as product value increased over a constant feed price and as feed price increased over a constant product value. An increase in feed price was associated with a larger increase in variation than was an increase in product value. This may have been in part caused by feed cost being increased at a higher proportion from low medium to high than was product value. This rate of increase appeared to have a larger impact on per day profitability measures for both sire group average DRNI's and individual daughter RNI than on lifetime measures of RNI for both daughters and sire groups.

Sire group average DRNIPD means and ranges for subset 2 sires are in Table 23. Means and ranges for subset 2 sires were lower than for subset 1 sires. Trends displayed for subset 1 sires also held for subset 2 sires. However, differences between sire group average DRNIPD were reduced, as displayed by the smaller standard deviations. Subset 1 and 2 sires had smaller differences than individual daughters in means from price to price on a per day of productive life basis.

Prediction of Lifetime Relative Net Income

Objectives of this study were threefold. The first was to determine relationships between sire evaluations calculated using first, all, and later lactation records and profit of individual daughters. The second was to determine what function of sire evaluations from first and later records provide the best predictor of lifetime profit for individual daughters. The final objective was to evaluate the importance of later records in sire evaluations for the prediction of lifetime and per day profitability. Eleven RNI's were

Table 23. Means and ranges for sire group average deviated relative net income per day ($) for the 226 sires with ≥ 25 daughters in the final data set.

Economic parameters used in Relative Net Income Per Day[1]	Mean	Standard Deviation	Range	
			Minimum	Maximum
RNIAPD[1]	0.08	.39	-1.61	1.11
RNIBPD	0.09	.41	-1.66	1.13
RNICPD	0.10	.43	-1.73	1.16
RNIDPD	0.09	.51	-2.07	1.47
RNIEPD	0.10	.52	-2.12	1.48
RNIFPD	0.11	.54	-2.19	1.50
RNIGPD	0.10	.62	-2.51	1.81
RNIHPD	0.11	.63	-2.56	1.82
RNIIPD	0.12	.65	-2.63	1.85
RNIJPD	0.09	.47	-1.94	1.34
RNIKPD	0.11	.59	-2.39	1.69

1) See Table 8 for economic values used.
2) Relative Net Income A Per Day.

examined to determine what effect, if any, different price combinations would have on the ability to predict RNI and RNIPD. All individual and sire group average RNI's predicted were deviated from contemporaries.

Four models were used to predict profit on a lifetime and per day basis. These included: first, all, later, and first and later lactation evaluations jointly, for PDM, PDF, and PDD. Quadratic and interaction terms were also included in the models and examined. No quadratics or interactions were significant at the .01 level. At the .05 level a limited number of quadratic terms were significant. These results suggest that the relationship between sire evaluation variables and measures of profit are primarily linear and only linear results are reported.

Correlations between the eleven lifetime DRNI measures were examined and are in Table 24. Values above the diagonal represent correlations between DRNI's on an individual cow basis, values below the diagonal represent sire group average DRNI correlations. Generally, correlations were ≥.94 for individual cow DRNI's, except for correlations with DRNIG and DRNIK. For these two DRNI's, correlations were lower, ranging from .715 to .980 Results presented in the main text will be for DRNIE, DRNIG, and DRNIK. These particular price combinations were chosen as DRNIE represents the medium feed and product price, and DRNIG and DRNIK are the most variable of the remaining measures. Models not presented in this section can be found in Appendix A.

Regression coefficients and coefficients of determination for prediction of individual cow DRNIE are in Table 25. Regression coefficients are presented for all models examined as are coefficients of determination for PDM, PDF, and PDD from first, all, and later records. Graphical representation of the coefficients of determination is in Figure 3. Ability to predict individual DRNIE was less than 1% for all models examined. Expectation of the prediction of first lactation individual milk yield from PDM

Table 24. Correlations between the various relative net income measures[1]

RNI[2]	RNIA	RNIB	RNIC	RNID	RNIE	RNIF	RNIG	RNIH	RNII	RNIJ	RNIK
RNIA		.994	.985	.987	.999	.991	.822	.994	.998	.988	.936
RNIB	.997		.998	.964	.997	+.999	.755	.977	.999	.999	.893
RNIC	.993	.999		.946	.991	+.999	.715	.963	.994	+.999	.865
RNID	.995	.985	.977		.981	.957	.902	.998	.975	.951	.980
RNIE	+.999	.999	.996	.992		.995	.801	.990	+.999	.993	.923
RNIF	.996	+.999	+.999	.981	.998		.740	.972	.997	+.999	.883
RNIG	.916	.885	.865	.952	.906	.877		.877	.786	.726	.967
RNIH	.998	.990	.984	.999	.996	.988	.940		.986	.967	.967
RNII	.999	.999	.997	.989	+.999	.999	.898	.994		.995	.913
RNIJ	.995	.999	+.999	.979	.997	+.999	.871	.986	.998		.871
RNIK	.973	.954	.942	.991	.967	.949	.982	.986	.963	.945	

1) Values above the diagonal are on an individual cow basis, values below the diagonal are sire group average correlations. Values with a (+) indicate a correlation ≥ .9995.
2) Relative Net Income, definition of RNIA through RNIK are in Table 7.

Table 25. Regression coefficients and coefficients of determination from 176,902 individual cows for DRNIE on Predicted Difference milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.21			.005
		.25		.007
			.25	.007
	.02		.23	.007
PDF[3]				
	5.65			.005
		6.69		.006
			6.62	.007
	-0.25		6.84	.007
PDD[4]				
	2.14			.006
		2.65		.009
			2.61	.009
	0.22		2.42	.009

1) Deviated Relative Net Income E, see text for variable explanation, all regression coefficients significant ($P < .01$), all cows required to have at least five contemporaries.
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

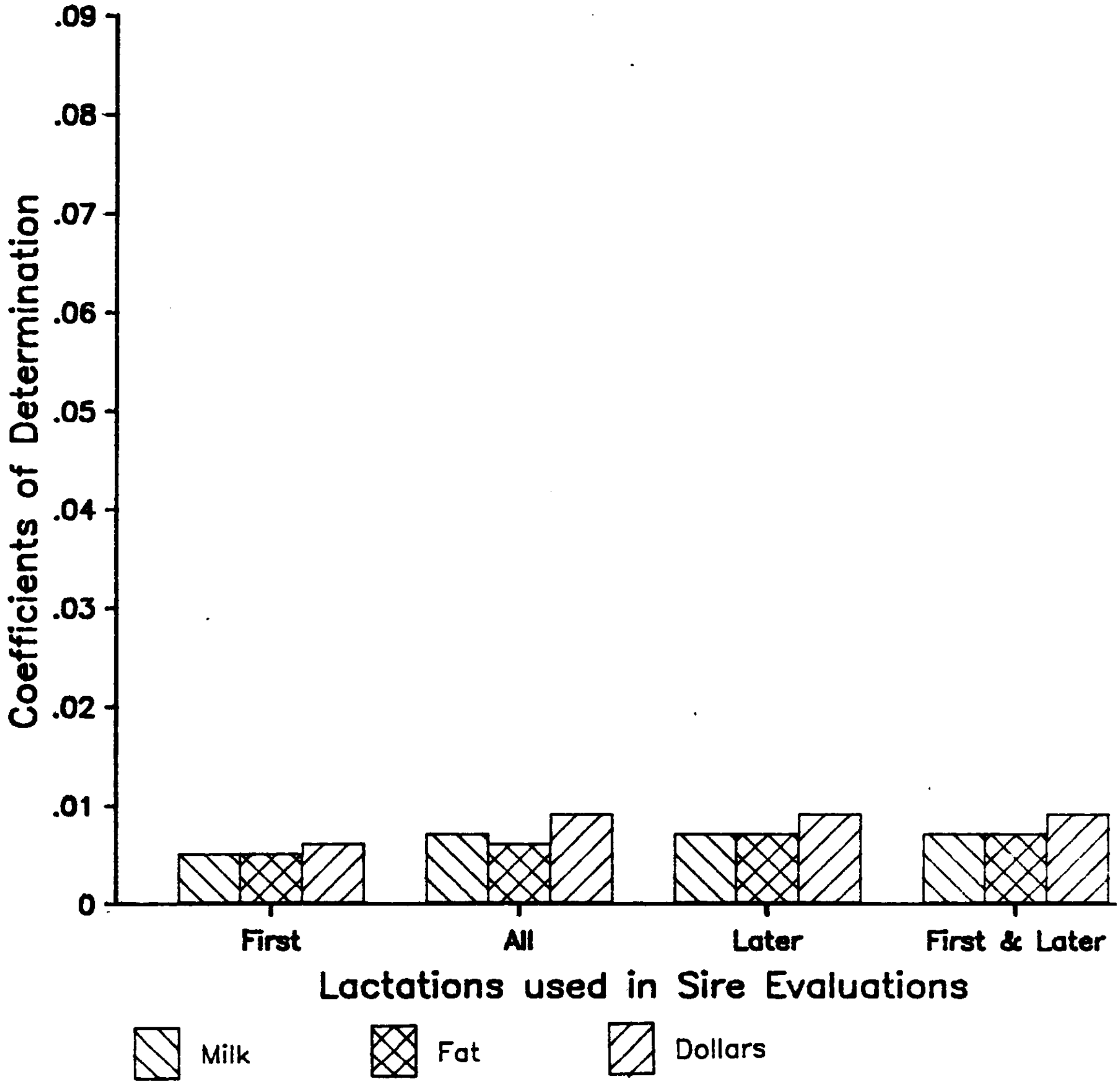

Figure 3. Coefficients of determination from 176,902 individual cows for DRNIE on Predicted Difference milk, fat, and dollars, for first, all, and later lactation evaluations.

was 5%, assuming a heritability of 20% for milk yield and that all daughters were half-sibs. In the prediction of DRNI, variables associated with herdlife are included as well as production from later records. In essence the models attempt to predict herdlife as well as production from sire evaluation variables. DeLorenzo and Everett (10) found heritabilities of .28 and .26 for 41 and 54 month stayability respectively. Genetic correlations between milk production and stayability range from .27 to .65 (9,12,20). Attempts to predict both production and herdlife from a production trait logically resulted in less variation being accounted for than in the prediction of a production trait.

Later record evaluations were more useful in predicting DRNIE than were first record evaluations. Later lactation evaluations were as useful in predicting DRNIE as were all and a combination of first and later lactation evaluations. Predicted Difference dollars was more useful (as measured by R^2) in predicting DRNIE than either PDM or PDF. In models with both first and later lactation evaluations included, the regression coefficients were substantially larger for later lactation evaluations. In one model, PDF, first lactation had a negative regression coefficient when included in the model with later lactation evaluations. All other regression coefficients were positive, indicating that selection of genetically superior sires for production traits would produce daughters with increased total lifetime profit.

Regression coefficients and coefficients of determination for deviated RNIG are in Table 26. Deviated RNIG was the high feed and low product price combination which also had the lowest net percentage (65%). Trends for DRNIG were similar to those found for DRNIE (Figure 4). The relationship between DRNIG and the sire evaluation variables is greater than for any other DRNI studied. Differences between the relationships of all, later, and first and later evaluations with DRNIG were minimal. Regression coefficients followed similar trends as those in the DRNIE models but were smaller due to less variation in DRNIG. In the model that combined first and later

Table 26. Regression coefficients and coefficients of determination from 176,902 individual cows for DRNIG on Predicted Difference milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.09			.009
		.11		.011
			.11	.011
	.02		.09	.011
PDF[3]				
	2.87			.010
		3.29		.013
			3.22	.013
	0.36		2.90	.013
PDD[4]				
	1.02			.012
		1.23		.015
			1.20	.016
	0.19		1.04	.016

1) Deviated Relative Net Income G, see text for variable explanation, all regression coefficients significant (P < .01), all cows required to have at least five contemporaries.
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

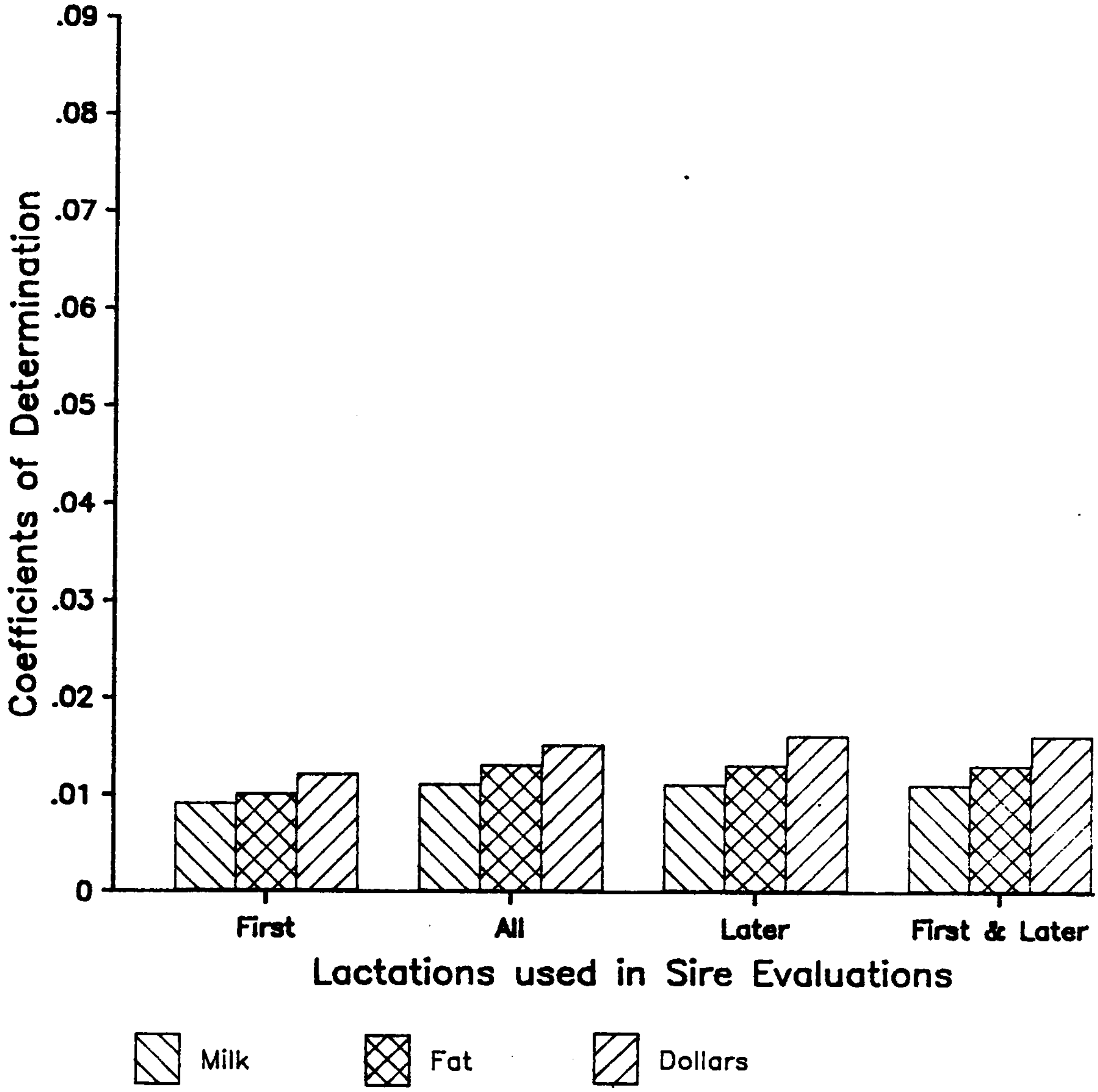

Figure 4. Coefficients of determination from 176,902 individual cows for DRNIG on Predicted Difference milk, fat, and dollars, for first, all, and later lactation evaluations.

evaluations, later evaluations had larger regression coefficients than first evaluations. Predicted Difference fat was more useful in predicting DRNIG than was PDM (Figure 4) but less useful than PDD.

Table 27 contains models for DRNIK which used medium feed and product prices with high rearing and high fixed and operating costs per day of productive life. Coefficients of determination and regression coefficients were intermediate between those of DRNIE and DRNIG respectively. Consistent to the prediction of DRNIE and DRNIG, models with all, later, or first and later evaluation variables were similar in the ability to predict DRNIK. First lactation evaluation variables were least useful in the ability to predict DRNIK. Predicted difference milk and fat were nearly identical in the amount of variation explained when included in the models, yet accounted for less variation than models based on PDD (Figure 5). Examination of regression coefficients when first and later lactation evaluations were in the model showed the considerably larger influence of later lactation evaluations.

The relationships between sire group average DRNI and sire evaluation variables were examined for the 226 sires that had at least 25 daughters in the final data set. Sire group averages reduce the variation associated with measures of lifetime profit on individual daughters. Therefore the ability of sire evaluations for yield to predict DRNI was expected to increase when sire group averages were used. This expectation was supported by the increased coefficients of determination over prediction of individual daughters DRNI. The correlations between the sire group average DRNI for the eleven DRNI's calculated were greater than .94, except for correlations with DRNIG (Table 24). The three RNI's previously examined (DRNIE, DRNIG, and DRNIK) are also presented here. Results for the eight remaining RNI's calculated are in Appendix B. The scale used on the Y-axis for Figures 6, 7, and 8 differs from the scale used in Figures 3, 4, and 5 by a factor of ten.

Table 27. Regression coefficients and coefficients of determination from 176,902 individual cows for DRNIK on Predicted Difference milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.16			.008
		.19		.011
			.18	.011
	.03		.16	.011
PDF[3]				
	4.50			.008
		5.23		.011
			5.13	.011
	0.29		4.88	.011
PDD[4]				
	1.66			.010
		2.02		.014
			1.98	.014
	0.27		1.75	.014

1) Deviated Relative Net Income K, see text for variable explanation, all regression coefficients significant (P<.01), all cows required to have at least five contemporaries.
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

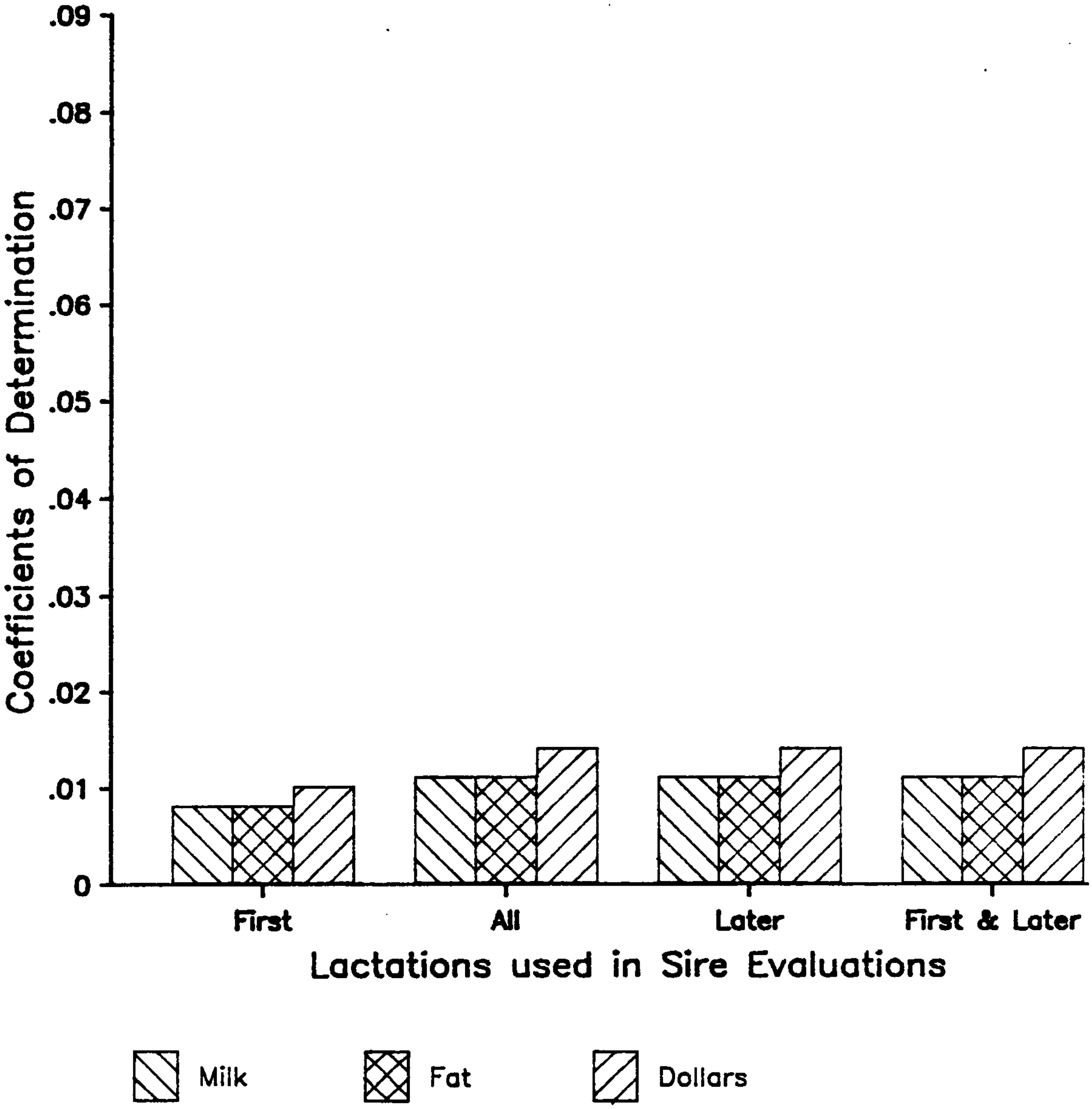

Figure 5. **Coefficients of determination from 176,902 individual cows for DRNIK on Predicted Difference milk, fat, and dollars, for first, all, and later lactation evaluations.**

Regression coefficients and coefficients of determination for sire group average DRNIE are in Table 28. The ability of sire evaluations to predict mean daughter DRNIE increased markedly over that for individual daughters (R^2 = .009 versus .36 for individual and sire group average DRNIE respectively) for PDD with first and later lactation evaluations in the model. Trends found for sire group average DRNIE were consistent with those found for individual DRNIE. Predictive ability increased when models included later lactation information (R^2 = .348, .359, and .360 for all, later, and first and later lactation evaluations respectively), as compared to first lactation evaluations alone (R^2 = .267) for PDD. Similar trends were apparent for PDM and PDF (Figure 6). In all models examined, later lactation evaluations accounted for more variation than did the all lactation proofs for DRNIE. The same was true for models that contained first and later lactation evaluations. This suggested that the weights placed on first and later lactation evaluations to derive the all lactation published progeny evaluation in the MCC were not optimal for predicting DRNIE on a lifetime basis. Examination of the coefficients of determination and regression coefficients showed more weight should be placed on later than on first lactation evaluations.

Regression coefficients for the various models resembled those found for individual DRNIE. For example, regression coefficients from models containing later lactation proofs were .25 vs. .25 for PDM, 6.62 vs. 6.89 for PDF, and 2.61 vs. 2.61 for PDD, for individual versus sire group average models respectively. Using the later lactation model, a sire $10.00 above the breed average PDD was expected to have daughters that on average yielded $26.10 more income than the breed average sire's daughters for DRNIE. In all models with first and later lactation evaluation variables, later lactation variables remained considerably more important in the prediction of DRNIE. Comparison of regression coefficients for models containing first and later

Table 28. Regression coefficients and coefficients of determination from 226 sires for sire group average DRNIE on PD milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.22			.236
		.25		.299
			.25	.305
	.02		.23	.305
PDF[3]				
	6.15			.199
		7.06		.257
			6.89	.270
	0.06		6.84	.270
PDD[4]				
	2.28			.267
		2.67		.348
			2.61	.359
	0.28		2.38	.360

1) Deviated Relative Net Income E, see text for variable explanation, all regression coefficients significant ($P < .01$),
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

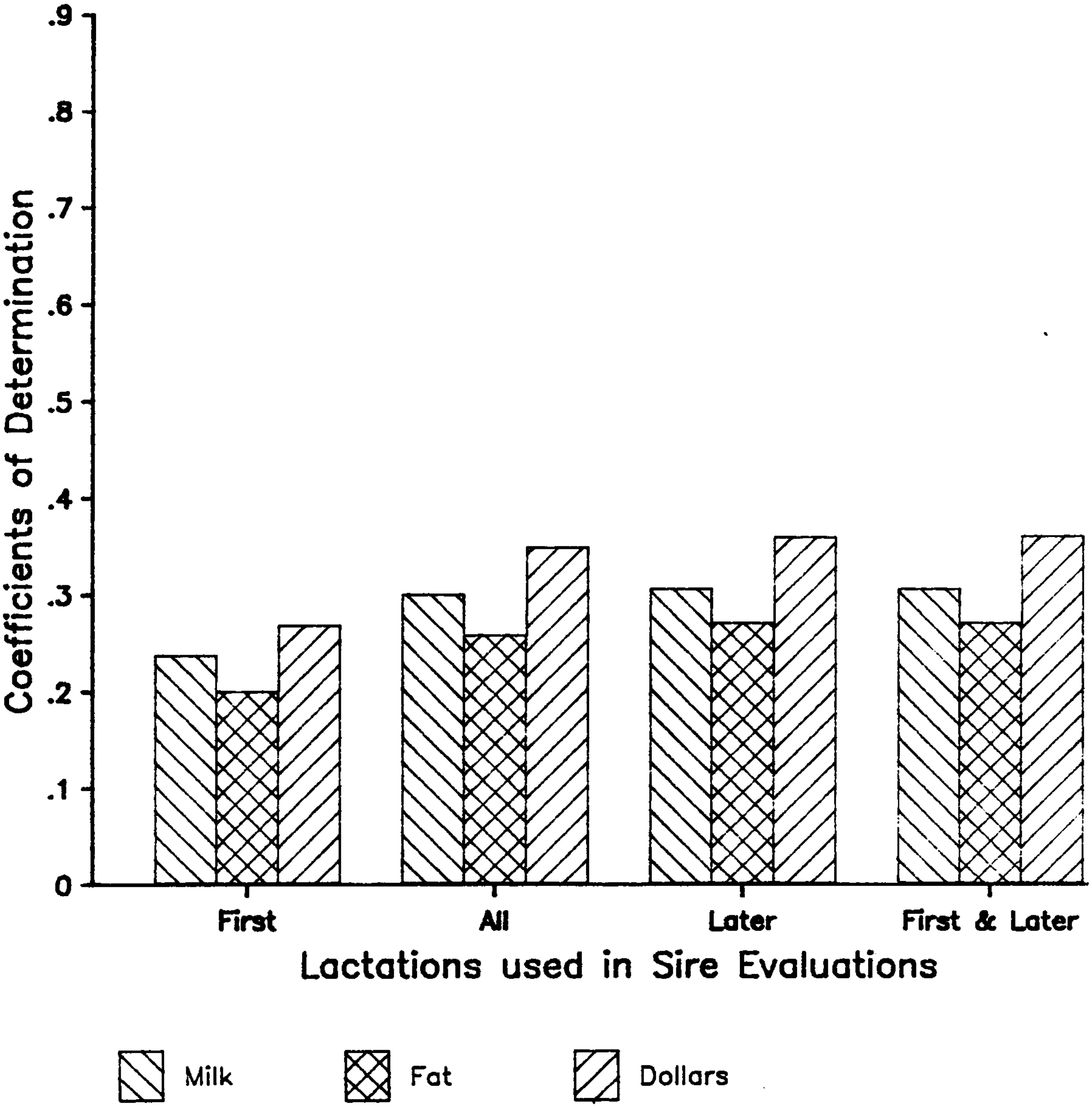

Figure 6. Coefficients of determination from 226 sires for sire group average DRNIE on Predicted Difference milk, fat, and dollars, for first, all, and later lactation evaluations.

lactation evaluations were .02 vs. .23 for PDM, .06 vs. 6.84 for PDF, and .28 vs. 2.38 for PDD, for first versus later evaluations respectively.

Sire group average DRNIG regression coefficients and coefficients of determination are in Table 29. Deviated RNIG and the model that used PDD from first and later lactations had the highest coefficient of determination of all models examined in this study (R^2 = .587). Variation accounted for by the models that contained later lactation information (all, later, and first and later) was greater than for models that contained only first lactation information. The all lactation evaluation models for PDD had slightly higher R^2 (.583) than did models with only later lactation information (R^2 = .576) but marginally lower R^2 than models based on first and later lactation evaluations as shown in Figure 7.

Regression coefficients for the PDD model from prediction of individual DRNIG from first, all, and later lactation evaluations (1.02, 1.23, and 1.20 respectively) were similar to those from the first, all, and later sire group average DRNIE models (1.14, 1.30, and 1.24). This was also true for the models based on PDM and PDF. Later lactation models for PDM, PDF, and PDD showed that regression coefficients of sire group average DRNIG were approximately half of those for sire group average DRNIE (i.e. .25 vs. .11, 6.89 vs. 3.36, and 2.61 vs. 1.24 for DRNIE vs. DRNIG). This could be due to greater sire differences in DRNIE shown in Table 21. The coefficients of determination for the three comparisons made above were .305 vs. .467, .270 vs. .456, and .359 vs. .576 for DRNIE versus DRNIG.

Regression coefficients and coefficients of determination for sire group average DRNIK are in Table 30. The ability to predict DRNIK was intermediate between that for DRNIE and DRNIG. Regression coefficients were similar to those presented for individual DRNIK and were intermediate to the regression coefficients of sire group

Table 29. Regression coefficients and coefficients of determination from 226 sires for sire group average DRNIG on PD milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.11			.390
		.12		.475
			.11	.467
	.03		.09	.473
PDF[3]				
	3.18			.377
		3.53		.457
			3.36	.456
	0.69		2.80	.461
PDD[4]				
	1.14			.473
		1.30		.583
			1.24	.576
	0.31		0.99	.587

1) Deviated Relative Net Income G, see text for variable explanation, all regression coefficients significant ($P < .01$),
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

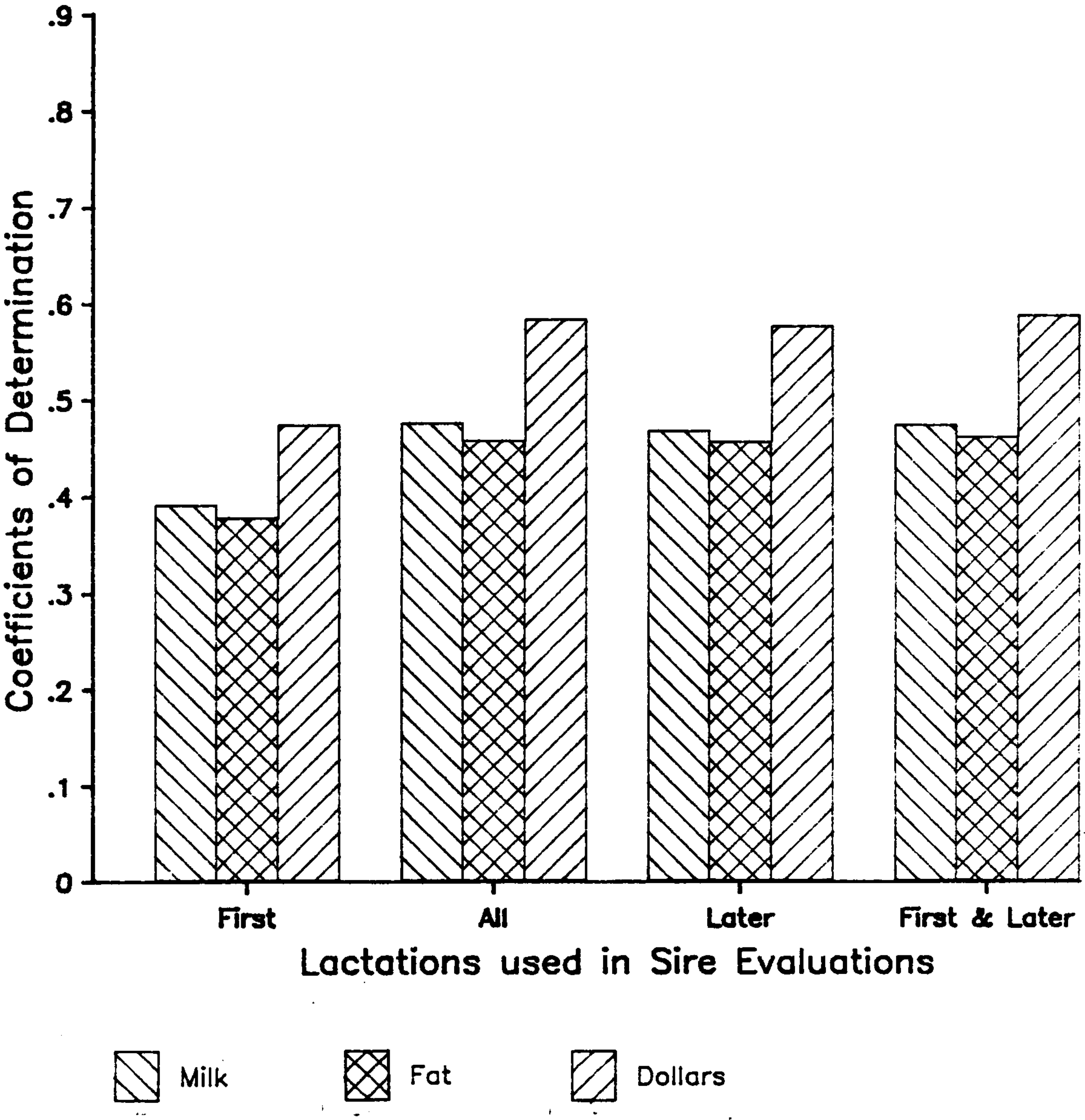

Figure 7. Coefficients of determination from 226 sires for sire group average DRNIG on Predicted Difference milk, fat, and dollars, for first, all, and later lactation evaluations.

Table 30. Regression coefficients and coefficients of determination from 226 sires for sire group average DRNIK on PD milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.17			.350
		.20		.425
			.19	.421
	.04		.16	.425
PDF[3]				
	4.95			.302
		5.56		.374
			5.34	.379
	0.77		4.70	.381
PDD[4]				
	1.82			.400
		2.09		.501
			2.01	.499
	0.43		1.66	.506

1) Deviated Relative Net Income K, see text for variable explanation, all regression coefficients significant ($P < .01$),
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

average DRNIE and DRNIG. Patterns familiar to the prediction of all DRNI measures remained consistent for the prediction of DRNIK (Figure 8).

Several trends emerged from the prediction of lifetime individual and sire group average DRNI. Coefficients of determination increased as sire evaluations from all or later lactations were used. Predicted Difference dollars, an index of PDM and PDF, predicted RNI better than did PDM or PDF alone. All regression coefficients were positive, except in a few cases where evaluations from both first and later lactations were included. This indicated that selection of sires based on production variables would increase lifetime relative net income. In all models later lactation evaluations were more useful than evaluations based on firsts, and generally as useful as all, or first and later evaluations together in the prediction of DRNI.

Prediction of Relative Net Income Per Day

Correlations between the eleven DRNIPD measures are in Table 31. All correlations between individual DRNIPD were ≥.974. Correlations between sire group average DRNIPD's were all ≥.968. Cow or progeny group rank was essentially unaffected by economic parameters used in calculating daily RNI. Due to the close relationship of the DRNIPD measures, only individual and sire group average DRNIEPD are presented in detail. The regression coefficients and coefficients of determination for the remaining individual and sire group average DRNIPD measures are in Appendix C and D respectively.

Regression coefficients and coefficients of determination for predicting individual DRNIEPD from the different sire evaluations are in Table 32. Ability to predict

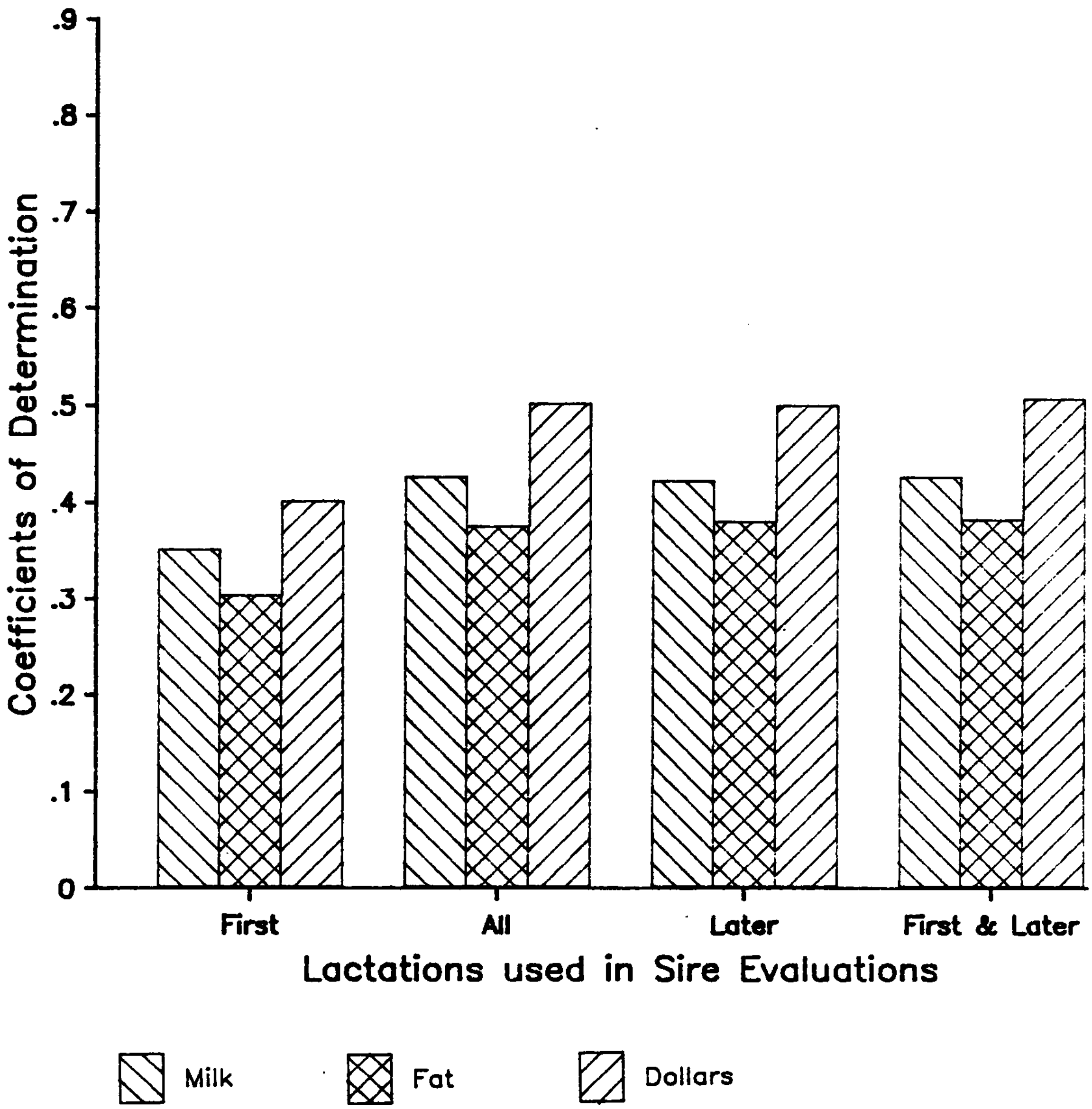

Figure 8. Coefficients of determination from 226 sires for sire group average DRNIK on Predicted Difference milk, fat, and dollars, for first, all, and later lactation evaluations.

Table 31. Correlations between the various relative net income per day measures[1]

RNI[2]	RNIA	RNIB	RNIC	RNID	RNIE	RNIF	RNIG	RNIH	RNII	RNIJ	RNIK
RNIA		.998	.993	.998	+.999	.999	.994	.997	.999	+.999	.999
RNIB	.998		.998	.993	.997	.999	.986	.991	.996	.998	.994
RNIC	.992	.998		.983	.990	.996	.974	.982	.988	.993	.986
RNID	.997	.991	.980		.999	.996	.999	+.999	.999	.998	+.999
RNIE	.999	.996	.988	.999		.999	.996	.999	+.999	+.999	+.999
RNIF	.999	.999	.995	.995	.998		.991	.995	.998	.999	.997
RNIG	.991	.982	.968	.999	.995	.988		.999	.997	.994	.998
RNIH	.996	.989	.978	+.999	.998	.994	.999		.999	.997	+.999
RNII	.999	.994	.986	.999	+.999	.998	.996	.999		.999	+.999
RNIJ	+.999	.998	.992	.997	+.999	.999	.992	.997	.999		.999
RNIK	.998	.993	.984	+.999	+.999	.997	.997	+.999	+.999	.999	

1) Values above the diagonal are on an individual cow basis, values below the diagonal are sire group average correlations. Values with a (+) indicate a correlation ≥ .9995.
2) Relative Net Income, definition of RNIA through RNIK are in Table 7.

Table 32. Regression coefficients and coefficients of determination from 176,902 individual cows for DRNIEPD on Predicted Difference milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.0003			.0014
		.0003		.0013
			.0003	.0011
	.0002		.00005	.0014
PDF[3]				
	.0069			.0010
		.0070		.0010
			.0063	.0009
	.0057		.0015	.0011
PDD[4]				
	.0028			.0015
		.0029		.0015
			.0026	.0013
	.0021		.0008	.0016

1) Deviated Relative Net Income E Per Day, see text for variable explanation, all regression coefficients significant ($P < .01$), all cows required to have at least five contemporaries.
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

DRNIEPD was minimal. Trends associated with the prediction of DRNIPD differed from those for DRNI. First lactation sire evaluations were more useful in the prediction of DRNI on a per day basis than for lifetime DRNI. For all models examined, first lactations were more useful than later lactation evaluations (i.e. R^2 = .0014 vs .0011 for PDM). First lactations were as useful as all lactations and only slightly less useful than the combination of first and later evaluations in the prediction of DRNIEPD. This relationship is shown in Figure 9. Regression coefficients in all models examined were positive. In all models that included first and later evaluations, the regression coefficient for first lactation was considerably larger than the regression coefficient for later lactation evaluations.

Sire group average DRNIEPD regression coefficients and coefficients of determination are in Table 33. Highest R^2 (.139) was from the model that used PDD from first and later evaluations. Several results for the coefficients of determination were similar to those for individual DRNIEPD. One exception was the R^2 for all lactation sire evaluations was always higher than the R^2 for first lactation evaluations. Another variant was the utility of PDF in predicting group average DRNIEPD (Figure 10). In the prediction of individual DRNIEPD, PDF was less useful than PDM or PDD. In the prediction of sire group average DRNIEPD PDF accounted for more of the variation in DRNIEPD than did PDM. Regression coefficients were close to those found for individual DRNIEPD. First lactation regression coefficients were slightly larger than later lactation coefficients when both first and later evaluations were included in the model.

Several characteristics emerged that were similar for all DRNIPD measures studied. First lactation evaluations were more important than later lactations in the prediction of DRNIPD. This was supported by both an increase in coefficients of determination and larger regression coefficients for first lactations when both evaluations were included in the model. The index consisting of PDM and PDF, (PDD) accounted

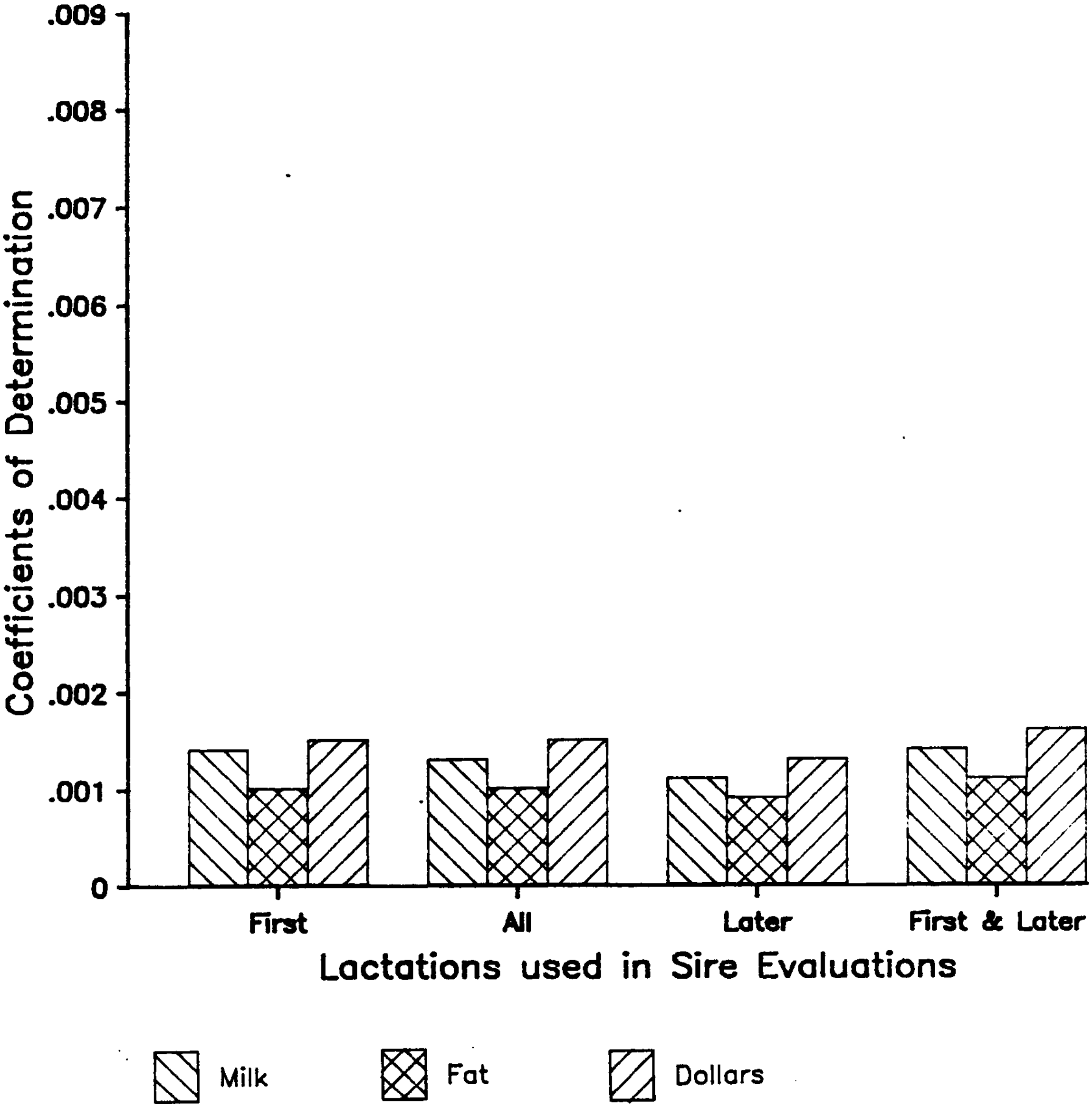

Figure 9. Coefficients of determination from 176,902 individual cows for DRNIEPD on Predicted Difference milk, fat, and dollars, for first, all, and later lactation evaluations.

Table 33. Regression coefficients and coefficients of determination from 226 sires for sire group average DRNIEPD on PD milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.0003			.101
		.0003		.103
			.0003	.097
	.0002		.0001	.107
PDF[3]				
	.0083			.110
		.0086		.113
			.0078	.104
	.0052		.0035	.115
PDD[4]				
	.0029			.129
		.0030		.135
			.0028	.125
	.0017		.0014	.139

1) Deviated Relative Net Income E Per Day, see text for variable explanation, all regression coefficients significant ($P < .01$).
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

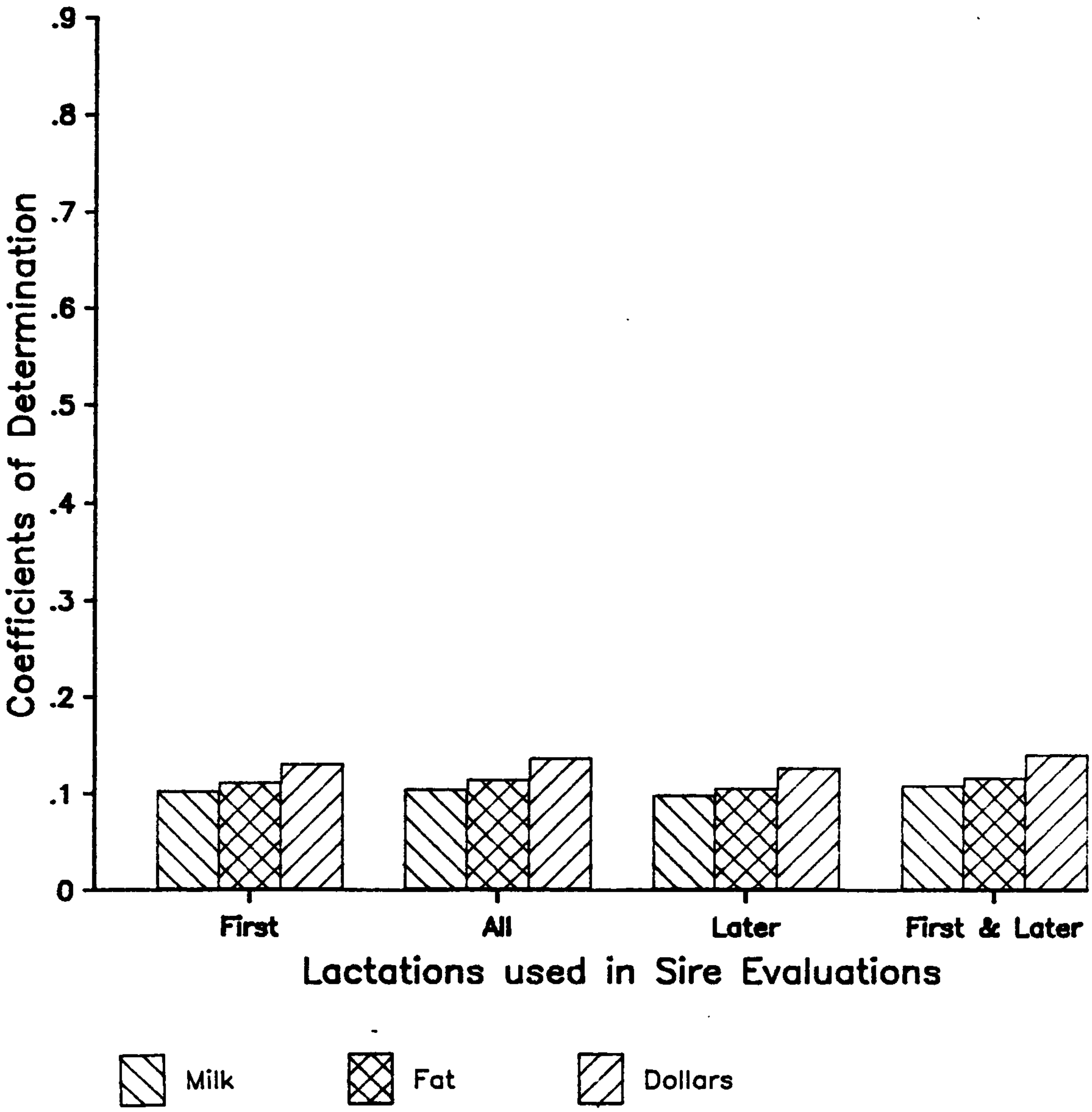

Figure 10. Coefficients of determination from 226 sires for sire group average DRNIEPD on Predicted Difference milk, fat, and dollars, for first, all, and later lactation evaluations.

for more variation than did PDM or PDF alone in the model. Similar to lifetime DRNI trends, regression coefficients increased as product value increased within feed price and decreased as feed price increased within product value.

Ranking Sires for Relative Net Income Measures

Sires were ranked on actual progeny group average DRNIE and predicted DRNIE for both lifetime and per day measures. Deviated RNIE was predicted from each of the twelve previously examined models. Difference in rank was actual rank (based on progeny group mean) minus predicted rank. No regressed estimates of breeding value for DRNIE measures were calculated. Means and variation for changes in rank are in Table 34 for lifetime DRNIE. The data set consisting of the 226 sires used to predict sire group averages was used to examine rank changes. Standard deviations associated with rank changes ranged from 56 to 69. The most extreme increase in rank for DRNIE was a sire that increased 206 positions for the model based on PDM from first lactation evaluations. Such a sire would be drastically underevaluated for daughter profit on the basis of first lactation evaluation for milk. The most extreme decrease in rank for DRNIE occurred in the first lactation evaluation PDF model where a sire decreased 172 positions. The extreme changes in rank exemplify the small amount of variation in DRNIE that was accounted for by the models examined. For models that included later or first and later lactation evaluations, rank changes were less extreme and standard deviations were smaller. Models based on PDD showed slightly smaller changes in rank, as observed by the standard deviations. As expected, models with

Table 34. Errors in sire rank when predicting DRNIE[1] from first, all, and later lactation sire evaluations from the 226 sires with ≥ 25 daughters[2]

Evaluation used to Predict DRNIE	Mean	Standard Deviation	Range	
			Minimum	Maximum
PDM[3]				
First	0	66	-161	206
All	0	62	-161	203
Later	0	60	-162	165
First and Later	0	60	-162	170
PDF[4]				
First	0	69	-172	196
All	0	65	-165	189
Later	0	63	-164	158
First and Later	0	63	-164	158
PDD[5]				
First	0	64	-152	203
All	0	58	-139	199
Later	0	56	-137	157
First and Later	0	56	-137	165

1) Deviated Relative Net Income E.
2) Error is actual rank for sire group average DRNIE minus the rank for predicted sire group average DRNIE.
3) Predicted Difference milk.
4) Predicted Difference fat.
5) Predicted Difference dollars.

smaller rank changes were the same models that accounted for larger R^2 in the prediction of DRNIE.

Rank changes associated with the prediction of DRNIEPD were more variable than for DRNIE (Table 35). Standard deviations and the range from minimum to maximum rank change was larger. The maximum a sire increased in rank was 214 places out of a possible 226. Maximum decrease in rank was 205. Amount of variation accounted for by the DRNIEPD models was less than for the DRNIE models, this was also illustrated by larger standard deviations in rank change. Standard deviations ranged from 72 to 76 suggesting that there was little difference between the per day models in their ability to rank sires. A sire extreme for rank change for a specific predicted DRNI was generally extreme for all models on both a lifetime and per day basis.

No estimates of breeding value have been calculated. The genetic control of DRNI is unknown and may be quite low. The results of this study, for the prediction of DRNI, may be all that can realistically be expected.

Table 35. Errors in sire rank when predicting DRNIEPD[1] from first, all, and later lactation sire evaluations from the 226 sires with ≥ 25 daughters[2]

Evaluation used to Predict DRNIEPD	Mean	Standard Deviation	Range	
			Minimum	Maximum
PDM[3]				
First	0	76	-199	201
All	0	75	-205	199
Later	0	76	-206	201
First and Later	0	75	-206	197
PDF[4]				
First	0	75	-172	211
All	0	75	-167	214
Later	0	76	-166	214
First and Later	0	74	-168	214
PDD[5]				
First	0	73	-183	213
All	0	72	-184	212
Later	0	74	-184	209
First and Later	0	73	-186	212

1) Deviated Relative Net Income E Per Day.
2) Error is actual rank for sire group average DRNIEPD minus the rank for predicted sire group average DRNIEPD.
3) Predicted Difference milk.
4) Predicted Difference fat.
5) Predicted Difference dollars.

Summary and Conclusions

Relationships between sire evaluations using first, all, and later lactations and profit measures on a lifetime and per day basis were examined. Eleven RNI's were calculated to determine the impact of various economic assumptions on the ability to predict profit from first, all, and later lactation sire evaluations.

Progeny group average estimates of DRNI could be predicted with reasonable accuracy. Coefficients of determination for progeny group average lifetime DRNI ranged from .152 (DRNIC) from the model using PDF from first lactation evaluations to .587 (DRNIG) from the model using PDD from first and later lactation evaluations. Accuracy of prediction of sire group average DRNIPD was less. Coefficients of determination ranged from .062 (DRNIGPD) from the model using PDM from later lactation evaluations to .224 (DRNICPD) from the model including PDD from first and later lactation evaluations. In all models examined, PDD with first and later lactation evaluations accounted for an equivalent or greater amount of variation when compared to other models on both a lifetime and per day basis.

In the prediction of individual DRNI, for lifetime and per day, the variation accounted for by the models examined was very small, though statistically significant.

Coefficients of determination for DRNI ranged from a low of .003 (DRNIC) from the model using PDF from first lactation evaluations to a high of .016 (DRNIG) from the model including first and later lactation evaluations from PDD. The range for DRNIPD was from .0005 (DRNIGPD) from the model using PDF from later lactation evaluations to .0028 (DRNICPD) from the model including first and later lactation evaluations from PDD. Management and uncontrollable environmental influences on individual daughter profit measures dwarf variation explained by estimated transmitting ability of a daughters'sire. However, positive regression of ETA's on profit indicate that selection for increased yield improves profit.

Lifetime and per day measures of profit are not the same trait. This was evidenced by the relative importance of first and later lactation evaluations in the prediction of each profit measure. Further evidence was supplied by the correlation of lifetime DRNI and per day DRNI. All correlations between lifetime and per day measures of profit were positive and ranged from .39 to .48. Correlations of sire group average DRNI and DRNIPD was higher, ranging from .51 to .62, but still indicated that lifetime and per day measures of profit were separate traits.

Later lactation sire evaluations were somewhat more important than evaluations based on first lactations in the prediction of lifetime profit. Later lactation evaluations were as important as evaluations from all lactations and as useful as a combination of evaluations from first and later records for lifetime profit measures. Evidence was an increase in the accuracy of prediction for models based on evaluations from later or first lactations, and the magnitude of regression coefficients when first and later evaluations were in the same model. Accuracy of prediction increased as feed price increased within constant product value and decreased as product value increased within a constant feed price. Deviated RNIG, high feed price and low product value, was predicted with the greatest accuracy for all models examined (Table 34). The ability to predict DRNI when rearing and fixed and operating costs per day were high was second only to DRNIG. Regression coefficients were generally positive, with an exception being first lactation evaluations when both first and laters for PDF were in the same model. The size of regression coefficients moved conversely to coefficients of determination. They increased as product value increased within a constant feed price and decreased as feed price increased within a constant product value.

Profit on a per day basis placed more emphasis on first lactation evaluations than evaluations based on later lactations. The predictive ability of first lactation evaluations was as good as all lactation evaluations and almost as good as first and later lactation evaluations combined in predicting profit. However, overall accuracy of prediction was reduced relative to lifetime profit and differences between evaluations from different lactations were not large. In contrast to the prediction of lifetime profit, accuracy of prediction increased as product value increased within a feed price and decreased as feed price increased within a constant product value. Regression coefficients were all positive. When first and later evaluations were included in the same model first lactation regression coefficients were 2 to 3 times larger than later lactation regression coefficients.

Lifetime and per day profitability measures appeared to emphasize different variables in the RNI function. Lifetime profit was most accurately predicted by later lactation evaluations when feed price was high and product value low. This combination of economic conditions placed more emphasis on number of lactations and length of herdlife and less on production relative to other lifetime profit measures. Profit per day was most accurately predicted by first lactation evaluations when feed price was low and product value high. This combination reduced emphasis on number of lactations and herd life and placed more importance on production relative to other economic conditions examined.

The question of which lactations to use in sire evaluations to predict profit depends on the profit measure to be predicted. If lifetime total profit measures are deemed more useful, then later lactation evaluations clearly are important, predicting lifetime profit more accurately than first lactation evaluations by about 35%. If, on the other hand, per day measures of profit are the desired measure, then later lactation evaluations are less useful, adding only about 7% to the accuracy with which per day profit is predicted by first lactation evaluations.

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Appendix A. Individual DRNI

Table 36. Regression coefficients and coefficients of determination from 176,902 individual cows for DRNIA on Predicted Difference milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.17			.005
		.20		.007
			.20	.007
	.02		.18	.007
PDF[3]				
	4.70			.005
		5.56		.007
			5.49	.007
	-0.13		5.60	.007
PDD[4]				
	1.74			.007
		2.15		.009
			2.12	.009
	0.19		1.96	.009

1) Deviated Relative Net Income A, see text for variable explanation, all regression coefficients significant ($P < .01$), all cows required to have at least five contemporaries.
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Table 37. Regression coefficients and coefficients of determination from 176,902 individual cows for DRNIB on Predicted Difference milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.24			.005
		.29		.006
			.29	.006
	.03		.27	.006
PDF[3]				
	6.44			.004
		7.68		.006
			7.62	.006
	-0.47		8.02	.006
PDD[4]				
	2.46			.006
		3.06		.008
			3.01	.008
	0.22		2.83	.008

1) Deviated Relative Net Income B, see text for variable explanation, all regression coefficients significant ($P < .01$), all cows required to have at least five contemporaries.
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Table 38. Regression coefficients and coefficients of determination from 176,902 individual cows for DRNIC on Predicted Difference milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.33			.004
		.40		.006
			.40	.006
	.03		.37	.006
PDF[3]				
	8.33			.003
		9.99		.005
			9.93	.005
	-0.91		10.71	.005
PDD[4]				
	3.30			.005
		4.10		.007
			4.05	.007
	0.26		3.83	.007

1) Deviated Relative Net Income C, see text for variable explanation, all regression coefficients significant ($P < .01$), all cows required to have at least five contemporaries.
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Table 39. Regression coefficients and coefficients of determination from 176,902 individual cows for DRNID on Predicted Difference milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.14			.007
		.16		.009
			.16	.009
	.02		.14	.009
PDF[3]				
	3.93			.007
		4.60		.009
			4.53	.009
	0.09		4.46	.009
PDD[4]				
	1.44			.008
		1.76		.011
			1.73	.011
	0.19		1.57	.012

1) Deviated Relative Net Income D, see text for variable explanation, all regression coefficients significant ($P < .01$), all cows required to have at least five contemporaries.
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Table 40. Regression coefficients and coefficients of determination from 176,902 individual cows for DRNIF on Predicted Difference milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.30			.005
		.37		.006
			.36	.006
	.03		.33	.006
PDF[3]				
	7.65			.004
		9.15		.005
			9.08	.005
	-0.71		9.69	.005
PDD[4]				
	3.02			.005
		3.75		.007
			3.70	.007
	0.26		3.48	.007

1) Deviated Relative Net Income F, see text for variable explanation, all regression coefficients significant ($P < .01$), all cows required to have at least five contemporaries.
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Table 41. Regression coefficients and coefficients of determination from 176,902 individual cows for DRNIH on Predicted Difference milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.17			.006
		.21		.008
			.20	.008
	.02		.18	.008
PDF[3]				
	4.71			.006
		5.53		.008
			5.45	.008
	0.01		5.44	.008
PDD[4]				
	1.77			.008
		2.17		.010
			2.13	.011
	0.22		1.94	.011

1) Deviated Relative Net Income H, see text for variable explanation, all regression coefficients significant (P < .01), all cows required to have at least five contemporaries.
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Table 42. Regression coefficients and coefficients of determination from 176,902 individual cows for DRNII on Predicted Difference milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.26			.005
		.31		.007
			.31	.007
	.03		.28	.007
PDF[3]				
	6.57			.004
		7.82		.006
			7.75	.006
	-0.41		8.10	.006
PDD[4]				
	2.58			.006
		3.19		.008
			3.14	.008
	0.26		2.92	.008

1) Deviated Relative Net Income I, see text for variable explanation, all regression coefficients significant ($P < .01$), all cows required to have at least five contemporaries.
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Table 43. Regression coefficients and coefficients of determination from 176,902 individual cows for DRNIJ on Predicted Difference milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.24			.004
		.29		.006
			.29	.006
	.02		.27	.006
PDF[3]				
	6.34			.004
		7.57		.005
			7.52	.005
	-0.58		8.01	.005
PDD[4]				
	2.44			.005
		3.03		.007
			2.99	.007
	0.19		2.83	.007

1) Deviated Relative Net Income J, see text for variable explanation, all regression coefficients significant ($P < .01$), all cows required to have at least five contemporaries.
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Appendix B. Sire Group Average DRNI

Table 44. Regression coefficients and coefficients of determination from 226 sires for sire group average DRNIA on PD milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.18			.238
		.20		.302
			.20	.307
	.02		.18	.308
PDF[3]				
	5.11			.217
		5.85		.278
			5.69	.291
	0.15		5.57	.291
PDD[4]				
	1.86			.280
		2.17		.363
			2.12	.373
	0.25		1.92	.375

1) Deviated Relative Net Income A, see text for variable explanation, all regression coefficients significant ($P < .01$),
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Table 45. Regression coefficients and coefficients of determination from 226 sires for sire group average DRNIB on PD milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.25			.211
		.29		.270
			.28	.278
	.01		.27	.278
PDF[3]				
	6.99			.178
		8.06		.232
			7.90	.246
	-0.17		8.05	.246
PDD[4]				
	2.59			.239
		3.06		.315
			2.99	.327
	0.25		2.78	.327

1) Deviated Relative Net Income B, see text for variable explanation, all regression coefficients significant ($P < .01$),
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Table 46. Regression coefficients and coefficients of determination from 226 sires for sire group average DRNIC on PD milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.34			.200
		.39		.258
			.39	.266
	.01		.38	.266
PDF[3]				
	9.03			.152
		10.49		.201
			10.33	.214
	-0.59		10.81	.215
PDD[4]				
	3.45			.217
		4.08		.287
			4.01	.300
	0.27		3.78	.300

1) Deviated Relative Net Income C, see text for variable explanation, all regression coefficients significant ($P < .01$),
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Table 47. Regression coefficients and coefficients of determination from 226 sires for sire group average DRNID on PD milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.15			.285
		.17		.356
			.16	.358
	.02		.15	.360
PDF[3]				
	4.30			.263
		4.87		.332
			4.71	.342
	0.39		4.40	.343
PDD[4]				
	1.55			.337
		1.80		.431
			1.75	.437
	0.27		1.52	.440

1) Deviated Relative Net Income D, see text for variable explanation, all regression coefficients significant ($P < .01$),
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Table 48. Regression coefficients and coefficients of determination from 226 sires for sire group average DRNIF on PD milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.31			.214
		.36		.274
			.36	.281
	.02		.34	.281
PDF[3]				
	8.32			.162
		9.64		.213
			9.46	.226
	-0.36		9.76	.226
PDD[4]				
	3.18			.231
		3.75		.305
			3.67	.316
	0.30		3.43	.317

1) Deviated Relative Net Income F, see text for variable explanation, all regression coefficients significant ($P < .01$),
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Table 49. Regression coefficients and coefficients of determination from 226 sires for sire group average DRNIH on PD milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.18			.280
		.21		.350
			.20	.353
	.02		.18	.354
PDF[3]				
	5.15			.238
		5.86		.303
			5.69	.313
	0.35		5.40	.314
PDD[4]				
	1.90			.318
		2.22		.409
			2.15	.416
	0.32		1.89	.419

1) Deviated Relative Net Income H, see text for variable explanation, all regression coefficients significant ($P < .01$),
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Table 50. Regression coefficients and coefficients of determination from 226 sires for sire group average DRNII on PD milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.27			.239
		.31		.303
			.31	.309
	.02		.28	.309
PDF[3]				
	7.18			.181
		8.27		.235
			8.08	.248
	-0.05		8.12	.248
PDD[4]				
	2.74			.258
		3.22		.337
			3.14	.347
	0.33		2.87	.348

1) Deviated Relative Net Income I, see text for variable explanation, all regression coefficients significant ($P < .01$),
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Table 51. Regression coefficients and coefficients of determination from 226 sires for sire group average DRNIJ on PD milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.25			.198
		.29		.255
			.28	.263
	.01		.28	.263
PDF[3]				
	6.86			.165
		7.95		.218
			7.82	.232
	-0.36		8.12	.232
PDD[4]				
	2.55			.223
		3.02		.296
			2.96	.309
	0.19		2.81	.309

1) Deviated Relative Net Income J, see text for variable explanation, all regression coefficients significant ($P < .01$),
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Appendix C. Individual DRNIPD

Table 52. Regression coefficients and coefficients of determination from 176,902 individual cows for DRNIAPD on Predicted Difference milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.0002			.0016
		.0002		.0014
			.0002	.0012
	.0002		.00004	.0016
PDF[3]				
	.0056			.0012
		.0056		.0012
			.0051	.0011
	.0044		.0014	.0013
PDD[4]				
	.0022			.0017
		.0023		.0017
			.0021	.0015
	.0016		.0007	.0018

1) Deviated Relative Net Income A Per Day, see text for variable explanation, all regression coefficients significant ($P < .01$), all cows required to have at least five contemporaries.
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Table 53. Regression coefficients and coefficients of determination from 176,902 individual cows for DRNIBPD on Predicted Difference milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.0003			.0020
		.0003		.0019
			.0002	.0016
	.0002		.00005	.0020
PDF[3]				
	.0063			.0016
		.0064		.0015
			.0059	.0013
	.0049		.0017	.0016
PDD[4]				
	.0025			.0022
		.0026		.0022
			.0024	.0019
	.0018		.0009	.0023

1) Deviated Relative Net Income B Per Day, see text for variable explanation, all regression coefficients significant ($P < .01$), all cows required to have at least five contemporaries.
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Table 54. **Regression coefficients and coefficients of determination from 176,902 individual cows for DRNICPD on Predicted Difference milk, fat, and dollars, for first, all, and later lactation evaluations[1]**

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.0003			.0026
		.0003		.0025
			.0003	.0021
	.0002		.0001	.0026
PDF[3]				
	.0071			.0019
		.0072		.0018
			.0066	.0016
	.0054		.0020	.0019
PDD[4]				
	.0029			.0027
		.0030		.0027
			.0028	.0024
	.0020		.0010	.0028

1) Deviated Relative Net Income C Per Day, see text for variable explanation, all regression coefficients significant ($P < .01$), all cows required to have at least five contemporaries.
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Table 55. Regression coefficients and coefficients of determination from 176,902 individual cows for DRNIDPD on Predicted Difference milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.0003			.0011
		.0003		.0011
			.0002	.0009
	.0002		.00003	.0011
PDF[3]				
	.0062			.0008
		.0062		.0008
			.0056	.0007
	.0052		.0012	.0009
PDD[4]				
	.0025			.0012
		.0026		.0012
			.0023	.0010
	.0019		.0007	.0013

1) Deviated Relative Net Income D Per Day, see text for variable explanation, all regression coefficients significant ($P < .01$), all cows required to have at least five contemporaries.
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Table 56. Regression coefficients and coefficients of determination from 176,902 individual cows for DRNIFPD on Predicted Difference milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.0003			.0018
		.0003		.0017
			.0003	.0015
	.0003		.00007	.0019
PDF[3]				
	.0077			.0013
		.0078		.0012
			.0071	.0011
	.0062		.0018	.0013
PDD[4]				
	.0032			.0019
		.0033		.0019
			.0030	.0016
	.0023		.0010	.0020

1) Deviated Relative Net Income F Per Day, see text for variable explanation, all regression coefficients significant ($P < .01$), all cows required to have at least five contemporaries.
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Table 57. Regression coefficients and coefficients of determination from 176,902 individual cows for DRNIGPD on Predicted Difference milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.0003			.0009
		.0003		.0008
			.0003	.0007
	.0003		.00003	.0009
PDF[3]				
	.0067			.0006
		.0066		.0006
			.0060	.0005
	.0059		.0009	.0006
PDD[4]				
	.0027			.0009
		.0028		.0009
			.0025	.0007
	.0022		.0006	.0010

1) Deviated Relative Net Income G Per Day, see text for variable explanation, all regression coefficients significant ($P < .01$), all cows required to have at least five contemporaries.
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Table 58. Regression coefficients and coefficients of determination from 176,902 individual cows for DRNIHPD on Predicted Difference milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.0003			.0011
		.0003		.0010
			.0003	.0009
	.0003		.00004	.0011
PDF[3]				
	.0075			.0008
		.0074		.0007
			.0067	.0006
	.0064		.0013	.0008
PDD[4]				
	.0030			.0012
		.0031		.0011
			.0028	.0009
	.0024		.0008	.0012

1) Deviated Relative Net Income H Per Day, see text for variable explanation, all regression coefficients significant ($P < .01$), all cows required to have at least five contemporaries.
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Table 59. Regression coefficients and coefficients of determination from 176,902 individual cows for DRNIIPD on Predicted Difference milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.0004			.0014
		.0004		.0013
			.0003	.0011
	.0003		.00006	.0014
PDF[3]				
	.0082			.0009
		.0082		.0009
			.0074	.0008
	.0069		.0016	.0009
PDD[4]				
	.0034			.0014
		.0035		.0014
			.0032	.0012
	.0026		.0010	.0015

1) Deviated Relative Net Income I Per Day, see text for variable explanation, all regression coefficients significant ($P < .01$), all cows required to have at least five contemporaries.
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Table 60. Regression coefficients and coefficients of determination from 176,902 individual cows for DRNIJPD on Predicted Difference milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.0003			.0016
		.0003		.0015
			.0002	.0012
	.0002		.00005	.0016
PDF[3]				
	.0066			.0012
		.0066		.0011
			.0060	.0010
	.0053		.0015	.0012
PDD[4]				
	.0026			.0017
		.0028		.0016
			.0025	.0014
	.0020		.0008	.0017

1) Deviated Relative Net Income J Per Day, see text for variable explanation, all regression coefficients significant ($P < .01$), all cows required to have at least five contemporaries.
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Table 61. Regression coefficients and coefficients of determination from 176,902 individual cows for DRNIKPD on Predicted Difference milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.0003			.0013
		.0003		.0012
			.0003	.0010
	.0003		.00005	.0013
PDF[3]				
	.0074			.0009
		.0074		.0009
			.0067	.0008
	.0062		.0015	.0009
PDD[4]				
	.0030			.0013
		.0031		.0013
			.0028	.0011
	.0023		.0008	.0014

1) Deviated Relative Net Income K Per Day, see text for variable explanation, all regression coefficients significant ($P < .01$), all cows required to have at least five contemporaries.
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Appendix D. Sire Group Average DRNIPD

Table 62. Regression coefficients and coefficients of determination from 226 sires for sire group average DRNIAPD on PD milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.0002			.111
		.0002		.114
			.0002	.107
	.0001		.00009	.117
PDF[3]				
	.0067			.126
		.0069		.131
			.0063	.120
	.0042		.0028	.133
PDD[4]				
	.0023			.145
		.0024		.152
			.0022	.141
	.0013		.0011	.156

1) Deviated Relative Net Income A Per Day, see text for variable explanation, all regression coefficients significant ($P < .01$).
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Table 63. Regression coefficients and coefficients of determination from 226 sires for sire group average DRNIBPD on PD milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.0002			.140
		.0002		.144
			.0002	.133
	.0001		.0001	.147
PDF[3]				
	.0075			.148
		.0078		.153
			.0071	.140
	.0047		.0032	.155
PDD[4]				
	.0026			.176
		.0028		.185
			.0026	.170
	.0016		.0013	.189

1) Deviated Relative Net Income B Per Day, see text for variable explanation, all regression coefficients significant ($P < .01$).
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Table 64. Regression coefficients and coefficients of determination from 226 sires for sire group average DRNICPD on PD milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.0003			.177
		.0003		.181
			.0002	.166
	.0002		.0001	.185
PDF[3]				
	.0084			.164
		.0086		.170
			.0078	.154
	.0053		.0034	.172
PDD[4]				
	.0030			.210
		.0032		.220
			.0029	.200
	.0018		.0014	.224

1) Deviated Relative Net Income C Per Day, see text for variable explanation, all regression coefficients significant ($P < .01$).
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Table 65. Regression coefficients and coefficients of determination from 226 sires for sire group average DRNIDPD on PD milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.0002			.081
		.0002		.082
			.0002	.079
	.0001		.0001	.086
PDF[3]				
	.0075			.094
		.0077		.097
			.0070	.089
	.0046		.0032	.099
PDD[4]				
	.0026			.107
		.0027		.112
			.0025	.104
	.0015		.0013	.115

1) Deviated Relative Net Income D Per Day, see text for variable explanation, all regression coefficients significant ($P < .01$).
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Table 66. Regression coefficients and coefficients of determination from 226 sires for sire group average DRNIFPD on PD milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.0003			.130
		.0003		.133
			.0003	.123
	.0002		.0001	.137
PDF[3]				
	.0093			.127
		.0095		.131
			.0086	.119
	.0059		.0037	.132
PDD[4]				
	.0033			.158
		.0035		.165
			.0032	.151
	.0020		.0016	.169

1) Deviated Relative Net Income F Per Day, see text for variable explanation, all regression coefficients significant ($P < .01$).
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Table 67. Regression coefficients and coefficients of determination from 226 sires for sire group average DRNIGPD on PD milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.0002			.063
		.0003		.064
			.0002	.062
	.0001		.0001	.067
PDF[3]				
	.0082			.074
		.0084		.076
			.0077	.071
	.0050		.0035	.078
PDD[4]				
	.0028			.084
		.0029		.087
			.0027	.082
	.0016		.0014	.091

1) Deviated Relative Net Income G Per Day, see text for variable explanation, all regression coefficients significant ($P < .01$).
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Table 68. Regression coefficients and coefficients of determination from 226 sires for sire group average DRNIHPD on PD milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.0003			.079
		.0003		.080
			.0003	.076
	.0002		.0001	.084
PDF[3]				
	.0091			.088
		.0093		.091
			.0085	.083
	.0057		.0038	.093
PDD[4]				
	.0031			.102
		.0033		.106
			.0030	.099
	.0018		.0016	.110

1) Deviated Relative Net Income H Per Day, see text for variable explanation, all regression coefficients significant ($P < .01$).
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Table 69. Regression coefficients and coefficients of determination from 226 sires for sire group average DRNIIPD on PD milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.0003			.100
		.0003		.101
			.0003	.095
	.0002		.0001	.105
PDF[3]				
	.0100			.101
		.0102		.104
			.0093	.095
	.0063		.0041	.106
PDD[4]				
	.0035			.123
		.0037		.128
			.0034	.118
	.0021		.0017	.132

1) Deviated Relative Net Income I Per Day, see text for variable explanation, all regression coefficients significant ($P < .01$).
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Table 70. Regression coefficients and coefficients of determination from 226 sires for sire group average DRNIJPD on PD milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.0002			.111
		.0003		.113
			.0002	.106
	.0002		.0001	.116
PDF[3]				
	.0079			.119
		.0081		.123
			.0074	.113
	.0050		.0033	.125
PDD[4]				
	.0027			.140
		.0029		.147
			.0027	.136
	.0016		.0013	.151

1) Deviated Relative Net Income J Per Day, see text for variable explanation, all regression coefficients significant (P < .01).
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

Table 71. Regression coefficients and coefficients of determination from 226 sires for sire group average DRNIKPD on PD milk, fat, and dollars, for first, all, and later lactation evaluations[1]

	Regression Coefficient			
	First	All	Later	R^2
PDM[2]				
	.0003			.090
		.0003		.092
			.0003	.087
	.0002		.0001	.096
PDF[3]				
	.0090			.099
		.0092		.102
			.0084	.094
	.0056		.0038	.104
PDD[4]				
	.0031			.116
		.0033		.121
			.0030	.113
	.0018		.0015	.125

1) Deviated Relative Net Income K Per Day, see text for variable explanation, all regression coefficients significant ($P < .01$).
2) Predicted Difference Milk.
3) Predicted Difference Fat.
4) Predicted Difference Dollars.

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