SEASONS OF CALVING - - AGE, MANAGEMENT, AND GENETIC DIFFERENCES FOR MILK

Thesis for the Degree of Ph. D.
MICHIGAN STATE UNIVERSITY
WILLIAM WAYNE WUNDER
1967

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This is to certify that the

thesis entitled

SEASONS OF CALVING--AGE, MANAGEMENT,
AND GENETIC DIFFERENCES FOR MILK

presented by

WILLIAM WAYNE WUNDER

has been accepted towards fulfillment
of the requirements for

Ph.D. degree in Dairy

Date 16 Jur

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ABSTRACT

SEASONS OF CALVING--AGE, MANAGEMENT, AND GENETIC DIFFERENCES FOR MILK

by William Wayne Wunder

Maximum likelihood was used to study the effects of three ages (≤ 2, 3, ≥ 4 years), six seasons of calving (January-February, March-April, etc.), and their interactions on the 305 day-2x-ME milk of completed lactations of Holstein cows in Michigan DHIA. Maximum likelihood utilizes the probable producing ability of the cow and, therefore, should remove genetic differences between seasons from seasonal effects on lactational milk yield. Two values of repeatability, 0.4 and 0.55, made little difference in the constants for age, season, and age x season interaction effects.

Data were 37,247 records in 198 herds on test continuously at least from 1958 to 1964, 4195 records in 51 drylot herds, and 3651 records in 51 pasture herds. The drylot herds used no pasture during 1963-64 or 1962-64 and were paired with 51 pasture herds which used at least 85 days of pasture during the same years and were from the same counties. The drylot and pasture herds were matched as closely as possible for years on test, herd size, and

registered or grade cows.

Yields were largest in the January-February season. After this they declined steadily, were least in July-August, and sharply improved again. Below average production existed from May until October. The best and worst seasons differed by 776 lb milk. The magnitude of seasonal influence did not change from 1958-60 to 1962-64. Comparisons were made between the pasture and drylot herds and between quartiles of the 198 herds ranked on the DHIA herd average of milk for 1960 to 1964. The drylot herds showed more variation with season than did the pasture herds. For 1958-60 the greatest seasonal variation occurred in the first quartile herds, whereas the least occurred in the fourth. During 1962-64 seasonal variation was largest in the first quartile herds, intermediate in the second, and least in the third and fourth. Seasonal effects differed some among the quartiles and between pasture and drylot herds.

Interactions of age with season were present in that the total change associated with season was about 250 lb less for two-year-olds than for three-year-olds, while three-year-olds in turn varied 60 lb less than cows four years or older. July-August was much more detrimental to yield of the two older groups than to two-year-olds, whereas March-April calvings were distinctly more favorable to the two older groups. Cows of all ages yielded least

following July-August calvings, while maximum yields were associated with January-February calvings for the three-year-olds and November-December calvings for the others. Although the seasonal pattern was similar, age x season interactions varied among the quartiles and between the pasture and drylot herds, indicating herd x age x season interactions may be an important source of variation. Age x season interactions seemed to be largest in the lower producing herds.

Age constants varied widely among the sets of herds. For the 198 herds during 1958-64 the three-year-old constant was largest and the four years or older constant smallest.

An analysis of variance within herd and year, within sire-season groups, between sire groups within season, between seasons within sire, and between different sires in different seasons was unable to partition seasonal differences into genetic and environmental components because of excessive variation among paternal sisters within season.

Interactions of herds with age, season, and age x season appeared large enough to be a source of errors in the ranking of bulls tested in a limited number of herds.

SEASONS OF CALVING--AGE, MANAGEMENT, AND GENETIC DIFFERENCES FOR MILK

by

William Wayne Wunder

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Dairy

1967

ACKNOWLEDGMENTS

I wish to express my sincere appreciation to Dr. Lon D. McGilliard for his consistently sound advice during the formulation of the problem and the analysis of the data and for his encouragement and helpful suggestions during the writing of the thesis.

Dr. John L. Gill is gratefully acknowledged for his superb teaching of statistics and for statistical help during this study.

The encouragement and counsel of Dr. Clinton E. Meadows during the period of graduate study was appreciated.

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INTRODUCTION

The low reproductive rate, high percentage of involuntary losses, and long generation interval in dairy cattle make genetic progress from female selection very slow. Thus, almost all the genetic gain must come from the selection of sires. The rapid growth and acceptance of artificial insemination (AI) allows a greater selection differential among dairy sires than was possible with natural service and provides large enough breeding populations that progeny testing and using proven sires should provide the most rapid genetic improvement.

Because much of the variation among lactational records and progeny groups of sires is environmental, deviations of daughter records from herdmate averages have been widely used to remove the environmental effects of herds, years, and calving seasons from the differences between progeny groups. When sires have large numbers of daughters scattered over many herds, the environmental differences between sires usually are cancelled. However, in sampling young sires in AI there is usually a practical limit to how many matings should be made to young sires. This means either that sires may not have enough daughters to average out environmental differences between progeny groups, or that too few bulls will be sampled, limiting the selection differential. Thus, it is important to make the progeny test as accurate as possible with a minimal number of daughters, so that more sires can be sampled.

Recent research has shown the effects of season of calving may not be the same for two-year-olds as for older cows. Selection pressure varied between seasons in another study. Further research is needed to verify and determine the magnitude of these differences. If they are large enough, comparing cows with herdmates of the same age may increase the accuracy of progeny tests.

The objectives of this study were to use an analysis taking into account the probable producing abilities of the cows calving in each season to determine in what manner and how much seasonal variation differs between two-year-olds and older cows and what effect level of herd production and certain management practices have on seasonal variation. The final objective was to partition seasonal differences into genetic and environmental components.

REVIEW OF LITERATURE

The milk record of a cow is the result of her genotype and environment acting together. For this reason it is difficult to evaluate the genetic ability of a cow to produce milk. The same problem is present in progeny testing bulls since the average production of the daughters represents the genetic contribution of the sire, a genetic contribution from the dam, and an environmental influence of unknown magnitude or sign. Most sire proving work is concerned with eliminating or reducing the environmental contribution to daughter averages so that dairy sires may be ranked on some measure that is correlated as closely as possible with their genetic merit.

In one of the early studies of sources of variation among lactational fat records, Plum (1935) determined that differences between herds contributed 33% of the total variation. Van Vleck et al. (1961) reported herd differences accounted for 30% of the variation in lactational milk and fat records and that interactions involving herds contributed an additional 8 to 17% of the total variation. A smaller component of variance for herds was calculated by Sundaresan and Freeman (1961). They found herds contributed 5 to 6% of the total variation whereas interactions involving herds accounted for approximately 12% of the total variation among lactational milk and fat records from 12 state-owned herds in Iowa. Because herds and interactions involving herds are major contributors to variation among lactational milk and fat records, the influence of the herd should be considered in comparing the production records of animals in different herds.

In current evaluation of sires and dams, removal of herd and other environmental influences is attempted by subtracting from the production of a cow the average production of all other non-paternally related cows of the same breed in the same herd that calved in the same month as the cow being evaluated or in the previous or succeeding two months (herdmates). In actual practice the herdmate average is adjusted for finite numbers, and only 0.9 of the difference between the average of the herdmates and breed average is subtracted from the record of the cow being evaluated. However, the principal of using the average of the herdmates to measure the environmental opportunity afforded the cow in question is still present.

Identification and evaluation of sources of variation among lactational records within a herd give some indication of what adjustments should be made on records and what combinations of available records might yield the best estimate of environmental opportunity.

Some of the identifiable sources of variation among lactation records within a herd are the age of the cow, frequency of milking, length of the lactation, year the record was made, and the season in which initiated (season).

Conversion factors for standardizing records to a mature age (ME) and a twice-a-day (2x) frequency of milking are widely used and accepted in the United States. To standardize the length of lactation records, incomplete lactations are either excluded or extended to a 305 day equivalent while the production of only the first 305 days is used for longer lactations. Lactations shorter than 305 days and terminated by a normal drying-off are not extended. Year to year fluctuations are circumvented by comparing cows that calved within the same year or some other appropriately short time interval or are minimized by using deviations from yearly herd averages or from herdmate averages.

Variation Due to Season

Many workers have observed variation in lactational milk and fat yields due to the month or season of the year in which the cow calved. Generally, in the United States, Canada, and countries of Northern Europe, lactations initiated in the fall and winter months have a higher average yield than lactations begun at other times in the year. Lactational milk and fat yields differ little in the effect of season.

In one of the early investigations of the influence of season on milk production, McDowell (1922) observed that the cows freshening in the fall produced 6689 lb of milk, while those freshening in the winter, summer, and spring produced 6439, 5941, and 5842 lb, respectively.

Cows calving in November had the highest average yield (about 6% above the mean for both milk and fat) in a study by Cannon (1933) of 68,000 yearly records from Iowa cow testing associations for the years 1925-1930. Lactations begun in the month of June had the lowest yearly milk production while May, June, and July were equally low months for yearly fat production. Cows freshening each month from November to June were lower in yearly milk production than the group freshening in the preceding month. From June until November the cows freshening in each month averaged more milk than those in the preceding month.

Cows calving in November through January produced 13.6% more fat than cows calving in May through July in 5860 yearly records made by Guernsey, Jersey, or Holstein cows in Iowa between 1922 and 1932 (Plum, 1935).

Annis et al. (1959) reported cows calving in March and April produced 5% more milk than cows calving in July and August. The data were 35,000 lactations by Guernsey, Holstein, and Jersey cows in Washington. Lactations were adjusted to 305 day-2x-ME. Breeds differed little.

Among 38,000 Holstein records from Iowa DHIA files, cows calving in the late fall and winter months yielded about 5% more milk than cows calving in the late spring and summer months (Bereskin and Freeman, 1965). November and December were equal for the calving month with highest lactation production while cows calving in August had the lowest lactational milk yield. Records were corrected to 305 day-2x-ME.

In southeastern United States, Fosgate and Welch (1960) studied records from 15 Georgia DHIA herds of mixed breeds. Regression analysis indicated that cows calving in the spring (highest season) produced 990 lb more milk than cows calving in the summer (lowest season). In another study of Georgia DHIA cows of mixed breeds (Lee et al., 1961), the rank of the seasons in descending order was winter, spring, fall, and summer. Branton et al. (1958) reported that season had a highly significant effect on 722 lactations made by 283 Holstein cows in Louisiana. Season had a significant effect on the lactational milk yield made by Jersey cows at the Florida Agricultural Experiment Station (Wilcox et al., 1965).

Variations with season in lactational production have been noted in northeast United States. Among 22,000 lactational records made by cows of mixed breeds in Connecticut DHIA herds, cows calving in January through March produced approximately 10% more than cows calving in June, July, or August (Frick et al., 1947). In 4000 New York state DHIA lactation milk records, September, October, November, and December were the most favorable calving months for high production while April, June, and July were the most unfavorable (Hickman and Henderson, 1955). Cows calving in December produced 17% more than cows calving in July, based on 305 day-2x-ME milk lactation records of 4% made by 4000 cows of mixed breeds (Morrow et al., 1945).

In 49,000 Holstein HIR lactations from 35 states, cows freshening in the favorable part of the year (October through April) produced 5% more milk than cows freshening in the unfavorable part of the year (Tucker and Legates, 1965). Cows calving in the most favorable month, January, produced 8.7% more milk than those calving in July, the least favorable month.

Woodward (1945) analyzed records of 15,000 cows in 12 states and concluded that October and November were the most favorable months for calving while July was the least favorable.

Work in extending part records has shown that the extension factors vary with seasons (Lamb and McGilliard, 1960, and Aulerich, 1965). In addition, Aulerich (1965) found cows calving between August and March exhibited a more consistent lactation curve.

Among Holstein ROP lactations in western Canada, cows calving in November produced 9% more milk than cows calving in July (Jarvis, 1960). Differences between the average milk production of cows calving in each of the 12 months of the year or in each of three seasons were significant ($p < .01$).

Records of dairy cows in Great Britain are also influenced by season. Hammond and Sanders (1923) reported that among 1410 lactational milk yields by cows of mixed breeds in four milk recording societies in England, cows calving in October and November produced 978 lb more milk per lactation than did cows calving in June and July. Later with a much larger sample of cows Sanders (1927) determined that cows calving in November through February produced 10% more milk per lactation than cows calving in May through August. In Scotland cows of the Ayrshire breed calving in winter produced about 10% more milk than those calving in summer (Mahadevan, 1951).

Season of calving had pronounced influence on the lactational yield of dairy cattle in Denmark and Sweden with summer being the unfavorable season (Hofmeyr, 1955). Among Norwegian Red-and-White cows season accounted for 4% of the within herd variation in milk yield (Syrstad, 1965). Season affected milk yield equally in high and low level herds while its influence varied somewhat among three districts. Autumn and early winter months were the most favorable in all three districts.

Dairying is seasonal in New Zealand with most cows calving in the spring months of July and August. Very few cows calve later than October and all cows are dried off in May. Season effects are due to weather, feed supplies, and length of lactation. Among cows calving in August 93% milked until the eighth month (March), while only 72% of the cows calving in October milked until the eighth month (May) according to Searle (1961).

No Seasonal Differences

Insignificant differences between the lactational production of cows freshening in different months of the year were reported by Oloufa and Jones (1948). The data were first lactation, two-year-old records from 10 Willamette Valley counties in Oregon, a region with a monthly mean temperature range from 38°F to 68°F.

Differences in average lactational milk yield of Jersey cows calving in the four seasons at the Florida Agricultural Experiment Station were not significant (Arnold and Becker, 1935).

In both of these studies, the authors felt that the mild weather of the area was the reason for no significant variation due to season.

Breed Differences in the Effects of Season

Differences between breeds in response to season were noted among New Hampshire Ayrshire, Guernsey, Holstein, Jersey, and Milking Shorthorn cows (Morrow et al., 1945). Jersey cows freshening in June, July, August, and September made above average lactational milk records while summer freshenings resulted in below average production for cows of the other four breeds. Also, the range between the highest and lowest month for lactational milk yield was least for the Jerseys.

Wylie (1925) observed an atypical response to season by Jersey cows. Among 2900 ROM records, those lactations initiated in July had the highest average while lactations begun in April through June and August and September were the lowest.

The general patterns of the association of month with lactational milk yield were similar for four breeds (Frick et al., 1947). The data were actual lactational records by 9000 Guernseys, 8000 Holsteins, 2000 Ayrshires, and 2000 Jerseys in Connecticut.

Differences in Seasons Associated with Age

Sundaresan and Freeman (1961) observed a difference in the percent of total variation caused by season for first records as compared with all records. The data were 12,623 completed records made by 4487 Holstein cows in 12 state-owned Iowa herds. The records were adjusted to 305 day-2x-ME and were made during 1940 to 1956. The variance components for season are listed below as percentages of the total variance.

Source	All Records	First Records
3 month season	1.5	0.2
6 month season	1.8	0.4

Variations in lactational milk yield due to month were smaller for two and three-year-old cows than for cows aged four to six or over six years among Guernsey, Holstein, and Jersey cows in Washington state (Annis et al., 1959). Of all four age groups three-year-olds showed the least variation due to month. The most unfavorable month among two-year-olds was June while for the three older groups of cows it was August. When two-year-olds were compared with all other cows, the younger cows showed less variation in lactational milk production due to season. To study interactions between the influence of season and the herd management level, the herds were assigned to a high, medium, or low group according to the average fat production of the herd. All cows over two years of age were grouped together. With but two exceptions the influence of season on milk yield was consistent at the three herd levels within ages. First, there was a slight reduction in seasonal variation for cows over two years of age in the high herds. Second, among two-year-olds spring was the least favorable season in high herds, whereas summer was the least favorable for medium and low herds. For fat production of two-year-olds a distinct reduction occurred in the influence of season in high herds while the medium herds exhibited greater seasonal variation than low herds. The effect of season on lactational fat production of cows over two years of age was not influenced by the level of herd production. No reasons were given to explain why, among two-year-old cows, high producing herds would show slightly greater variation in lactational milk production due to season than medium and low producing herds, while at the same time they show a sharply reduced variation in lactational fat production in comparison with the medium and low producing herds.

Using the actual lactational yield of milk, Frick et al. (1947) noted that differences between the most favorable and least favorable month became relatively greater as age increased. However, converting the records to a ME basis might remove these seasonal differences between the age groups.

The investigation by Jarvis (1960) indicated the least favorable calving for two-year-old Holsteins in western Canada was in May, June, and July while for older cows it occurred most frequently in July and August.

Seasonal differences in ME age correction factors were reported by McDaniel and Corley (1966) in 1,795,895 lactational milk and fat records of cows of all breeds and all areas of the United States. Separate factors developed for milk records by two-month seasons (January-February, etc.) and breed showed the age correction factors for milk yield of two-year-old cows of all breeds were smallest for July-August and September-October. These results would indicate that calvings during July to October have a more favorable effect or a smaller unfavorable effect on the lactational milk yield of two-year-olds than of mature cows. Analysis of variance of the age correction factors for Holsteins and Guernseys indicated a significant effect of seasons on age correction factors. The results of this study represent the average condition over 14 years and may not accurately describe present conditions.

Converse to the results of McDaniel and Corley (1966), Gravir and Hickman (1966) found no seasonal differences in the percentage increase in average level of production from first lactation to maturity in an analysis of 108,000 Holstein ROP lactational milk and fat records in Canada. Seasonal divisions were September through February and March through August and covered September, 1958, through August, 1960. The increase from second or third lactation to maturity was essentially the same for both seasons. However, they did find a significant difference in the slope of first-lactation yield-age regression curves for the two seasons.

Environmental Influences on Two-Year-Old Lactations

That cows calving at less than 36 months of age exhibit a more consistent lactation curve than do mature cows is well known. If, as suggested by Dr. Lon D. McGilliard, a more consistent lactation curve has greater resistance to environmental influences, then the lactational milk yield of two-year-old cows might be affected differently or to a lesser degree by season than the milk yield of older cows. The results of a study by Allaire and Gaunt (1965) support this hypothesis. They found the linear regression of first lactation records on first lactation or all lactation contemporaries to be smaller than when a record representing any parity was regressed on contemporaries that included all lactations. The authors suggested that these results might be interpreted to mean that first lactation records are not as susceptible to prevailing environmental conditions as are later lactation records. This interpretation is strengthened by higher heritabilities for first lactations (Barker and Robertson, 1966, Freeman, 1960, and Rendel et al., 1957) and smaller variation among first lactations (Deaton and McGilliard, 1964).

Genetic Differences Between Seasons

In Michigan, as in many other states, certain months of the year have been designated as a base building period for milk marketing purposes. During this time it is economically important to ship a maximum amount of milk to the processing plant. Consequently, it might be that cows due to calve during the base building period are subjected to less culling than cows due to calve during the other months of the year. If a differential culling rate occurs throughout the year, inequalities may exist in the average genetic value of cows calving during the various seasons of the year. As most heifers calve in the fall in Michigan, culling occurs with each lactation, and the average calving interval is 13 months; cows calving in the winter months may be a more selected group than those calving in the fall. In addition, any special effort by the dairyman to keep his better cows from calving in the months least favorable for high lactational production might also result in genetic differences between groups of cows calving in different months or seasons of the year.

In Holstein cows in New York, Allaire and Henderson (1966) found small differences in the percent of cows surviving to start another lactation when the calvings were divided into three seasons. For cows in the first through the fourth lactations, 77% of those calving in August through November, 73% of those calving in December through March, and 72% of those calving in April through July were saved. While these differences in culling are small, they do not preclude the possibility of seasonal differences in average genetic ability caused by an accumulation of differential culling over time and selection of the calving season for cows of different producing abilities.

The methods used to eliminate environmental differences between groups of offspring in progeny testing vary among countries. A review of these methods is given in Johansson (1961). The yield of daughters is compared with that of their contemporaries in the same herd in Great Britain and Finland; in Sweden and New Zealand the daughters' average yield is compared with the yield at corresponding ages of daughters of other bulls in herds on the same production level; and New York and the USDA use herdmates calving in the same year and season or in the same 5-month-moving season as a basis of comparison. In Denmark, Sweden, Norway, and Great Britain the progeny test is based on the first lactation of the daughters and age correction factors are avoided or are made to a standard age at first calving, whereas in the United States and New Zealand the individual records are corrected to a mature age. Season is ignored in Holland, Great Britain, Sweden, and Finland and is circumvented by seasonal calving in New Zealand, Norway, and the Danish progeny testing stations. Fixed year-seasons are used by New York and rolling 5-month-seasons are used by the USDA to remove seasonal influences. Such diversity in progeny testing methods implies that no one system is entirely correct and that continued study of ways to remove age, season, and other environmental influences is needed.

Summary

There is evidence in the literature that the lactational yield of two-year-old and possibly three-year-old cows is affected differently by season than is the lactational yield of older cows. However, no reports were found of the effects of season on the lactational production of cows of different ages taking into account possible differences in the producing ability of cows calving at different times in the year.

Many writers have expressed the opinion that the quantity and quality of feed available throughout the year may be contributing to the influence of season of calving. Estimates of seasonal effects for cows of different ages from records made in recent years at different levels of management should indicate the influence of management on seasonal effects. Such results could be useful in determining what records to use as herdmates in evaluating records.

To estimate genetic differences between the cows calving in different seasons would be of interest. If such differences exist, they need to be accounted for in evaluating dairy animals.

SOURCE OF DATA

Two sets of data were from Michigan DHIA Holstein herds, while a third set was simulated data. For the first set the Michigan DHIA annual herd summary sheets were used to identify 51 herds that used no pasture during 1963 and 1964, and 1962 where possible. The 51 herds were located in 20 counties and will be referred to as "drylot" herds. For comparison with the drylot herds, 51 herds using at least 85 days of pasture during each of the same two or three years will be referred to as "pasture" herds. To make the drylot and pasture herds as much alike as possible, the pasture herd chosen to pair with each drylot herd was from the same county, covered the same years, and was matched as closely as possible with respect to herd size, number of years on DHIA testing, and whether the herd had registered or grade cows.

The second set consisted of 198 Holstein herds from 14 counties in Michigan. The 14 counties represented each of four geographic areas of Michigan in the same ratio as if the entire Michigan DHIA population had been used. Records from herds in these counties that had been on test from at least 1958 to 1964 were obtained. Nine of the drylot herds and 10 of the pasture herds were also among the 198 herds.

In both sets of data only records of 305 days or those terminated by a dry date prior to the 305th day were used. All records were adjusted to 2x-ME using factors by Kendrick (1955). Each record was made by a Holstein cow whose sire and dam were Holsteins.

The 4195 drylot records by 2719 cows averaged 14,921 lb milk, while 3566 pasture records by 2318 cows averaged 14,175 lb milk. The 37,247 records in the 198 herds were from 15,507 cows and averaged 13,868 lb milk.

The third set of data, the simulated data, was used to evaluate the analysis of genetic differences between cows calving in different seasons. The data had been developed in a problem of improving milk production through breeding in an undergraduate course in dairy cattle breeding at Michigan State University. The simulated data (dummy herds) were generated with procedures and parameters developed from populations of real cows. The parameters used in the dummy herds are listed in Table 1.

At each class meeting the student received the records of his dummy herd for the current year and determined his own matings and culls. The genetic value of the offspring was computed as the average genetic value of the sire and dam plus a chance factor of about one-half the genic variance. The chance factor served to restore genetic variation and to simulate the random part of inheritance contributed by segregation and recombination in Mendelian inheritance.

Table 1. Variance used in generating records of dummy herds

Source	Variance*	Standard Deviation
Total	684	
Between herds (environmental)	225	15
Within herds	459	21
Genic	121	11
Permanent environment	64	8
Between years	49	7
Residual	225	15

*Variances are in $(100 \text{ lb milk})^2$, standard deviations in (100 lb milk)

A total of 8874 records representing 15 herds and 19 years was available.

METHODS

If an estimate of the probable producing ability of the cows (Lush, 1949) is not used in estimating effects of season (influence of season of calving on lactational yield) and the averages of the abilities of cows calving in the different seasons differ, then confounding between effects of season and differences in average ability will result.

Analysis by least squares does not utilize estimates of the ability of the cows. As Henderson (1949a) has pointed out, the least squares method may yield seriously biased estimates of some of the parameters because of the effects of culling. In populations where selection on the magnitude of performance has taken place, most of the cows surviving to make an additional record had favorable environmental conditions for the earlier record. Since the temporary environmental effects are random from lactation to lactation, the average of the temporary environmental influences for a group of later records is apt to be less favorable than for the earlier records and thus bias the estimates of years and other environmental effects downward.

Henderson (1949a) and Henderson et al. (1959) have shown that maximum likelihood techniques are appropriate for estimation in situations where repeated observations are used and selection based on the magnitude of previous performance was practiced. The model employed in the present analysis was

$$Y_{ijklm} = u + t_i + a_j + s_k + (as)_{jk} + h_l + c_{lm} + e_{ijklm}$$

where Y_{ijklm} is the 305 day-2x-ME record of the m^{th} cow in the l^{th} herd who calved at the j^{th} age in year i during the k^{th} season,

u is the population mean of ME milk records,

t_i is the amount the conditions peculiar to the i^{th} year raise or lower its average production from the average of all years,

a_j is the amount records made by cows of the j^{th} age group differ from the average of all ages,

s_k is the amount effects peculiar to the k^{th} season raise or lower its average production from the average of all seasons,

$(as)_{jk}$ is an interaction which causes the production of cows of age j calving in season k to differ from the sum of the effects of the j^{th} age group and the k^{th} season,

h_l is the amount conditions associated with the l^{th} herd cause the average of the l^{th} herd to differ from the average of all herds,

c_{lm} is an amount the production of the l^{th} cow in the m^{th} herd is above or below the average of all cows in the m^{th} herd, and

e_{ijklm} is a random deviation associated with the record of the m^{th} cow in the l^{th} herd, who calved in the i^{th} year at the j^{th} age in the k^{th} season.

The c_{lm} are random variables normally and independently distributed about a particular h_l with zero means and variance C. The e_{ijklm} are normally and independently distributed random variables with zero means and variance E. The c_{lm} and e_{ijklm} are uncorrelated.

Maximum likelihood estimation (ML) involves finding estimates which maximize the probability of obtaining the samples at hand. The likelihood is defined as the joint distribution of the sample and is written as

$$L = \prod_{ijklm} \frac{1}{\sqrt{2\pi E}} \exp. -\frac{1}{2E}\left(Y_{ijklm}-u-t_i-a_j-as_{jk}-h_l-c_{lm}\right)^2$$

$$\cdot \prod_{lm} \frac{1}{\sqrt{2\pi C}} \exp - \frac{c_{lm}^2}{2C}$$

Estimates of the parameters in the ML model are obtained in a manner similar to least squares. The logarithm of the likelihood function is differentiated with respect to each of the parameters and the resulting equations are set equal to zero. The ML equations obtained are of this form:

$$n_{.....}\hat{u} + \sum_i n_{i....}\hat{t}_i + \sum_j n_{.j...}\hat{a}_j + \sum_k n_{..k..}\hat{s}_k + \sum\sum_{jk} n_{.jk..}\widehat{(as)}_{jk} + \sum_l n_{...l.}\hat{h}_l + \sum\sum_{lm} n_{...lm}\hat{c}_{lm} = Y_{.....} \tag{1}$$

$$n_{i....}\hat{u} + n_{i....}\hat{t}_i + \sum_j n_{ij...}\hat{a}_j + \sum_k n_{i.k..}\hat{s}_k + \sum\sum_{jk} n_{ijk..}\widehat{(as)}_{jk} + \sum_l n_{i..l}\hat{h}_l + \sum\sum_{lm} n_{i..lm}\hat{c}_{lm} = Y_{i....} \tag{2}$$

and analogous equations for the other years (i);

$$n_{.j...}\hat{u} + \sum_{i} n_{ij...}\hat{t}_i + n_{.j...}\hat{a}_j + \sum_{k} n_{.jk..}\hat{s}_k + \sum\sum_{jk} n_{.jk..}(\widehat{as})_{jk} + \sum_{l} n_{.j.l.}\hat{h}_l + \sum\sum_{lm} n_{.j.lm}\hat{c}_{lm} = Y_{.j...} \tag{3}$$

and analogous equations for the other ages (j);

$$n_{..k..}\hat{u} + \sum_{i} n_{i.k..}\hat{t}_i + \sum_{j} n_{.jk..}\hat{a}_j + n_{..k..}\hat{s}_k + \sum_{j} n_{.jk..}(\widehat{as})_{jk} + \sum_{l} n_{..kl.}\hat{h}_l + \sum\sum_{lm} n_{..klm}\hat{c}_{lm} = Y_{..k..} \tag{4}$$

and analogous equations for the other seasons (k);

$$n_{.jk..}\hat{u} + \sum_{i} n_{ijk..}\hat{t}_i + n_{.jk..}\hat{a}_j + n_{.jk..}\hat{s}_k + n_{.jk..}(\widehat{as})_{jk} + \sum_{l} n_{.jkl.}\hat{h}_l + \sum\sum_{lm} n_{.jklm}\hat{c}_{lm} = Y_{.jk..} \tag{5}$$

and analogous equations for the other age-seasons (j,k);

$$n_{...l.}\hat{u} + \sum_{i} n_{i..l.}\hat{t}_i + \sum_{j} n_{.j.l.}\hat{a}_j + \sum_{k} n_{..kl.}\hat{s}_k + \sum\sum_{jk} n_{.jkl.}(\widehat{as})_{jk} + n_{...l.}\hat{h}_l + \sum_{m} n_{...lm}\hat{c}_{lm} = Y_{...l.} \tag{6}$$

and analogous equations for the other herds (l);

$$n_{...lm}\hat{u} + \sum_{i} n_{i..lm}\hat{t}_i + \sum_{j} n_{.j.lm}\hat{a}_j + \sum_{k} n_{..klm}\hat{s}_k + \sum\sum_{jk} n_{.jklm}(\widehat{as})_{jk} + n_{...lm}\hat{h}_l + (n_{...lm} + \frac{E}{C})\hat{c}_{lm} = Y_{...lm} \tag{7}$$

and analogous equations for the other cows (l,m).

$n_{i..lm} = 1$ if the mth cow in the lth herd made a record in the ith year and = o if she did not make a record in the ith year. A dot in the subscript denotes summation over that particular subscript.

Two additional equations are obtained to be solved simultaneously with the others;

$$\hat{C} = \frac{\sum\sum_{lm}\hat{c}^2_{lm}}{\sum\sum_{lm} n_{lm}} \qquad \text{and}$$

$$\hat{E} = \frac{\sum\sum\sum\sum\sum_{ijklm}(Y_{ijklm} - \hat{u} - \hat{t}_i - \hat{a}_j - \hat{s}_k - \hat{as}_{jk} - \hat{h}_l - \hat{c}_{lm})^2}{n_{.....}}$$

The equations for the variance components C and E cannot be solved simultaneously with the other ML equations; however, estimates of C and E are available in the literature and their use should allow valid estimates of the other parameters.

The above set has an equation for each year, age, season, age x season combination, herd, and cow. Among the cow equations the coefficient for cows differs from that used in least squares analysis by the quantity E/C. This quantity is related to repeatability as defined by Lush (1949). In terms of repeatability $r = C/(C+E)$ the coefficient for cows in the cow equation becomes $n_{...lm} + (1-r)/r$.

Solving equations (7) for the c_{lm} yields

$$\hat{c}_{lm} = \frac{n_{...lm}r}{1 + (n_{...lm} - 1)r} (\bar{Y}_{...lm} - \hat{u} - \overset{\Delta}{t} - \overset{\Delta}{a} - \overset{\Delta}{s} - \overset{\Delta}{as} - \hat{h}_l) \quad (8)$$

where $\overset{\Delta}{t}$ is the mean of the $\hat{t}_i$ associated with that particular cow, $\overset{\Delta}{a}$ is the mean of the $\hat{a}_j$, etc. The value of $\hat{c}_{lm}$ is closely related to the probable producing ability of the cow as defined by Lush (1949) illustrating that an approximation of the probable producing ability of the cow is used in finding estimates for the other elements in the model.

The original application of ML to dairy cattle problems was to estimate genetic and environmental changes.

Cows were nested in groups composed of animals born during a specified time period or perhaps sired by the same bull. These groups of cows served as fixed genetic points from which to estimate genetic and environmental changes. In the model used here cows belong to a herd which includes all animals that made a record in a three- or seven-year period. Consequently, there is no means of measuring genetic change over time.

Herd effects must also be considered as fixed, which is contrary to normal usage. The outcome on the accuracy of the other estimates from using fixed herd effects is not known. Miller et al. (1966), using a maximum likelihood model in which cows were nested in herds rather than birth year or sire groups, obtained estimates of age effects that were consistent with theoretical expectations. Inclusion of birth year groups in a model with age and year of record causes complications. As pointed out by Rendel and Robertson (1950), Henderson et al. (1959), and Miller et al. (1966), if ages, year of birth, and year of record are in the model, the last birth year will be confounded with the youngest age and the last year of record and a unique solution to the ML equations will not be possible.

Henderson et al. (1959) defined the repeatability used in the ML equations as intra-group rather than intra-herd since their model had cows nested within birth-year groups. In the present model, cows are nested within herds;

therefore, intra-herd repeatability was indicated. The appropriate value for intra-herd repeatability may range from 0.4 to 0.55 depending on whether or not the effects of year and season have been removed. The effect of errors in the repeatability used is not clear. Henderson (1958) reported on variation in environmental trends resulting from using different values for repeatability in a model estimating both yearly environmental and genetic trends. He observed that estimates of yearly environment were biased downward by 0.08 lb fat per cow per year for each 0.01 the value used for repeatability was above the true value. The effects of errors in repeatability in models where several parameters are being estimated is not apparent. To get indications of the effects on the estimates from different values for repeatability which might reasonably bracket closely the correct value, 0.4 and 0.55 were used in the model.

The interactions not fitted in the model such as herd x year, herd x season, year x age, year x season, and the three-way and four-way interactions may cause biases in the estimates of the parameters in the model.

Cows were not permitted to have two records in the same year. When this occurred, the second of the two records was removed if both records were classified as normal. If unusual conditions such as abortion, etc., affected one of the records, it was removed. When unusual conditions were listed for both records, the record appearing most nearly normal was retained.

Multiple records by a cow at two or three years of age were prevented by assigning the record to the next highest age classification if the cow had a previous record at that age. Cows were permitted to have multiple records in the four years and older age class. Cows less than 24 months of age at calving were classified as two-year-olds.

The parameters of interest in this model were the t_i, a_j, s_k, and the as_{jk}, whereas the h_l and c_{lm} were nuisance parameters. To reduce the matrix to a manageable size, it was necessary to absorb the equations for cows and restrict the number of herds to approximately 50. Henderson (1949a, 1949b) explained and illustrated absorption of cow equations into the rest of the ML equations. As shown above, equation (8), c_{lm} can be expressed in terms of the other elements in the model, thus making it possible to subtract this new expression for c_{lm} from the u, t_i, a_j, s_k, as_{jk}, and h_l equations and eliminate the cow rows and columns from the matrix (absorption). In his illustration Henderson constructed the full matrix, including all cow equations, before starting absorption. Even with a large computer, constructing the full matrix places an impractical limit on the number of cows that can be used in the analysis or makes the absorption of the cow equations a formidable task. The absorption procedure used in the present study required a matrix only one row and column larger than the absorbed matrix. To reduce the required matrix size, the data were ordered so that all records of a cow appeared consecutively in the data. Then the sequence of steps used by Henderson for absorption was changed in that as soon as all the information on a cow was in the matrix, the cow equation was absorbed and set back to zero before data on the next cow were added to the matrix. This sequence of steps permits one row and column of the matrix to be used repeatedly for all the cows in the analysis. Since the cow equations are independent of each other the resulting absorbed matrix is the same whether all cow equations are in the matrix before absorption begins or cow equations are incorporated and absorbed one at a time. This same procedure can be used to absorb herds and reduce the number of herd rows and columns in the matrix to one of each.

The months of the year were grouped into six consecutive two-month seasons to put more cows into each season and still retain several points at which to measure seasonal change. Three ages (≤ 2, 3, ≥ 4 years) were used since age correction factors show most of the increase to mature age production is reached by 48 months (Kendrick, 1955).

Standard errors of the ML constants were not calculated. The error mean square obtained using the ML constants is inflated compared to the least squares mean square. Therefore, standard errors for the ML constants should be calculated using the elements of the ML inverse matrix and the error mean square from least squares analysis of the same data (Miller, 1967). Least squares analysis of these data with cows nested within herds was not attempted because the herd equations disappear when the cow equations are absorbed.

A second objective concerned estimating genetic differences between the cows calving in different seasons of the year. If selection pressure on cows differs with the season in which they calved or are due to calve, then variation may exist between seasons in the average genetic value of the cows. Interpretation of the variance components resulting from a statistical analysis of paternal and non-paternal sisters calving in the same and different seasons provided estimates of genetic and environmental differences between seasons.

Analysis was within years within herds to avoid analyzing variation from these sources. Maternal sisters with records in the same year were withheld from the analysis along with any cow whose sire was unknown. In addition, all cows over 64 months of age were excluded to increase the average number of daughters per sire. Three seasonal divisions were used. The first was based on the base milk period and compared January through June calvings with July through December. The second division was suggested by Michigan DHIA averages and compared October through April calvings with those of May through September. The final comparison was based on the maximum likelihood estimates and contrasted November to April calvings with May to October calvings.

In the first mathematical model the 305 day-2x-ME milk record of the k^{th} daughter of the i^{th} sire calving in the j^{th} season is:

$$Y_{ijk} = u + s_i + m_j + e_{ijk}$$

where u is the yearly herd mean; s_i is the deviation of the daughter average of the i^{th} sire from u; m_j is the average differences between u and cows calving in the j^{th} season; and e_{ijk} is the deviation of the record of the k^{th} daughter of sire i from the average of the daughters of the i^{th} sire calving in the j^{th} season. u is a fixed quantity, the s_i, m_j, and e_{ijk} are uncorrelated variables drawn from populations with zero means and with variances, S, M, and E, respectively.

This model was used to analyze differences among daughters of the same sire in the same season, differences between groups of daughters by different sires in the same season, and differences between groups of daughters by different sires calving in different seasons. The expected values of the mean squares obtained in these analyses are:

Within Sires Within Season	E	(I)
Among Sires Within Season	$E + k_1 S$	(II)
Among Sires in Different Seasons	$E + k_2 S + k_3 M$	(III)

The k's are the appropriate coefficients for the components of variance.

One further analysis was made of differences among groups of daughters by the same sire but calving in different seasons. This analysis was according to a second model in which the 305 day-2x-ME milk record of the k^{th} daughter of the i^{th} sire which calved in the j^{th} season is:

$$Y_{ijk} = u + s_i + m'_{ij} + e_{ijk}$$

where u is the yearly herd mean; s_i is the deviation of the daughter average of the i^{th} sire in the herd from u; m'_{ij} is the average difference between daughters in the ij^{th} sire-season group and the average of all the daughters of the i^{th} sire in that herd and year; and e_{ijk} is the deviation of the record of the k^{th} daughter in the ij^{th} sire-season group from the average of the ij^{th} group. In this model seasons are nested within sires. Again, u is a fixed quantity and the s_i, m'_{ij}, and e_{ijk} are uncorrelated variables drawn from populations with zero means and with the variances, S, M', and E, respectively.

The expected value of the mean square from this analysis is:

Between Seasons Within Sire	$E + k_4 M'$	(IV)

Again k_4 is the appropriate coefficient for the component of variance.

M is a measure of the genetic variation between seasons (GS) plus the environmental variation between seasons (ES) while M′ is a measure of $\frac{1}{4}$GS + ES. This can be shown by letting $m_{ij} = gs_{ij} + es_{ij}$ where gs_{ij} is the average genetic merit of the daughters of the i^{th} sire in the j^{th} season and es_{ij} is the environmental level of the ij^{th} sire-season group. Then

$$m_{ij} - m_{i'j'} = (gs_{ij} - gs_{i'j'}) + (es_{ij} - es_{i'j'}) \text{ and}$$
$$E(M) = \frac{1}{2}E(m_{ij} - m_{i'j'})^2 = GS + ES + 2Cov(GS)(ES)$$

where $sire_i \neq sire_{i'}$ and $season_j \neq season_{j'}$.
The correlation between GS and ES is assumed to be zero so E(M) = GS + ES. Since seasons are always compared within sires in the second model, all comparisons are between groups of cows who received half their genes from the same sire. In this case $m'_{ij} = \frac{1}{2}gs_{ij} - es_{ij}$. Then

$$m'_{ij} - m'_{ij'} = \frac{1}{2}(gs_{ij} - gs_{ij'}) + (es_{ij} - es_{ij'}) \text{ and}$$
$$E(M') = \frac{1}{2}E(m'_{ij} - m'_{ij'})^2 = \frac{1}{4}GS + ES + Cov(GS)(ES)$$

Once more the correlation between GS and ES is assumed to be zero so that $E(M') = \frac{1}{4}GS + ES$.

Equating the expectations of the four mean squares to their actual results will yield estimates of E, S, ES, and GS. ES and GS were of primary interest while E and S were necessary to get solutions to the set of simultaneous equations.

RESULTS AND DISCUSSION

Effects of season, age at calving, and their interactions on ME lactational milk yield were estimated by maximum likelihood for six seasons of two months each (January-February, March-April, etc.) and three ages (≤ 2, 3, ≥ 4 years). Because the exact repeatability of milk for these data was not known, 0.4 and 0.55 were chosen to bracket the range within which repeatability might fall. Examples of the best and worst agreement between the estimates of the effects of season plus age x season interaction from using the two values are in Table 2. Even in the most divergent case the results for season plus age x season interaction differed little.

Some of the changes in the constants for year and age from varying repeatability also can be seen in Table 2. Changing repeatability affected randomly the estimates for ages but affected the estimates for years in a consistent manner. When years were improving, 0.55 estimated a smaller amount of improvement, whereas the decline for deteriorating yearly effects was larger than for 0.4. This is compatible with earlier work (Henderson, 1958) in which values of repeatability larger than the true value produced a downward bias in yearly environment. In the present investigation yearly effects were not partitioned into genetic and

Table 2. Examples of best and poorest agreement between ML estimates of years, ages, and season plus age x season interactions obtained using r = 0.4 and r = 0.55

	Best (3rd Quartile 1962-4)		Worst (Pasture 1962-4)	
	r=0.4	r=0.55	r=0.4	r=0.55
1962	-306	-281	-338	-303
1963	125	121	98	93
1964	182	160	240	210
$\leq$ 2 yrs.	-167	-161	23	12
3 yrs.	73	70	31	60
$\geq$ 4 yrs.	94	91	-54	-72
2 x S_1	-120	-129	520	512
2 x S_2	-681	-656	-85	-152
2 x S_3	-159	-171	-71	-89
2 x S_4	-273	-274	-220	-222
2 x S_5	-20	14	-72	-101
2 x S_6	251	250	66	124
3 x S_1	198	187	-87	-6
3 x S_2	492	491	188	259
3 x S_3	-66	-63	379	477
3 x S_4	-398	-397	-422	-415
3 x S_5	6	0	285	254
3 x S_6	206	202	-157	-209
4 x S_1	276	293	296	268
4 x S_2	534	503	320	334
4 x S_3	3	-18	-191	-184
4 x S_4	-610	-595	-714	-731
4 x S_5	-46	-29	-69	-99
4 x S_6	407	391	34	-20

environmental components because of confounding between year of birth and age. Since effects of herd, year, and season were removed for estimating the producing ability of the cows (see equation 8 in Methods) and the results of using the two values differed little, only the results from 0.55 will be shown and discussed.

Constants for Seasons

The ML estimates of seasonal effects on lactational milk yield for cows in the 198 herds appear in Figure 1. Highest yield occurred for calvings in January-February. After this yield declined steadily through March-April, drastically deteriorated during May-June and again in July-August, and then sharply improved through December. Below average production existed from May until October. These results agree well with those of Tucker and Legates (1965). Since the magnitude of seasonal influences did not change from 1958-60 to 1962-64, changes in management of dairy herds during this time had little effect on seasonal variation.

Total farm labor requirements are usually least during the winter, and there is opportunity for dairymen to provide better management for their dairy herds. This period coincides with the most productive part of the lactation for cows calving during late fall and winter. In addition these same cows often get a boost in production from pasture in spring during the latter part of their

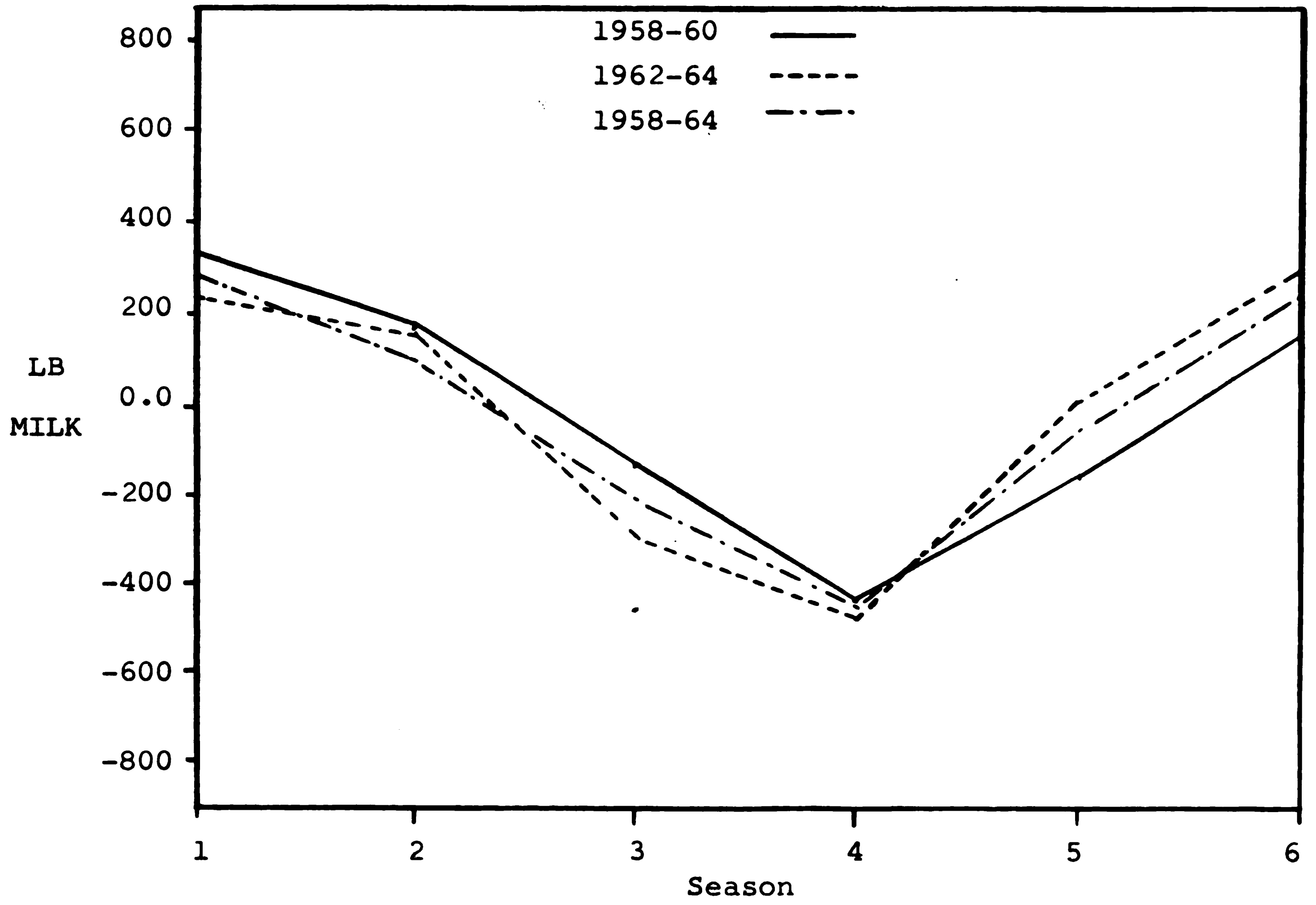


Fig. 1. Season constants from 198 herds 1958-60, 1962-64, and 1958-64.
1=Jan-Feb, 2=Mar-Apr, 3=May-Jun, 4=Jul-Aug, 5=Sep-Oct, 6=Nov-Dec

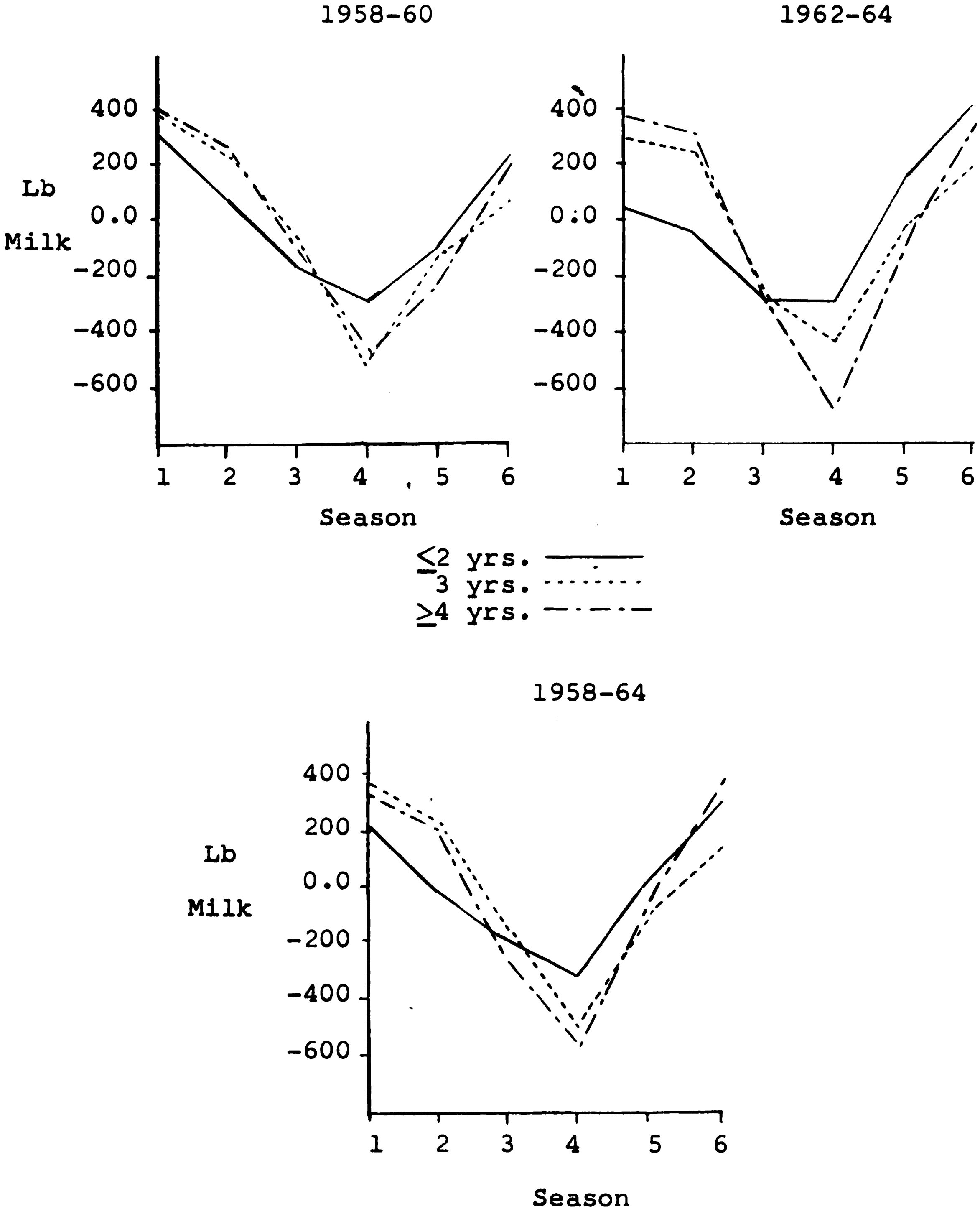
lactation when they normally would be declining rapidly in production. Pasture in late summer frequently does not provide as much feed as spring pasture; this condition occurs when the feed requirement of cows freshening in fall and winter is at or near its least. Temperatures above 80-85° and high humidity accompanied by high temperatures both depress the cow's feed intake and milk yield. Since these conditions normally occur during the summer, cows freshening in spring and summer would be affected most. Other factors probably play important roles in causing seasonal variation.

Age by Season Interactions

The sums of the ML constants for season and age x season interactions in the 198 herds are in Figure 2. The total change associated with season for 1958-64 was about 250 lb less for two-year-olds than for three-year-olds, while the three-year-olds in turn exhibited 60 lb less change with season than did four-year-olds. The seasonal pattern was the same for all three ages, but there were interactions. The yield of the two older groups was much lower for calvings in July-August than the yield of two-year-olds. Cows three or older produced more milk than two-year-olds when calvings were in March-April, while three-year-olds produced the least among cows that calved in November-December.

There were differences between 1958-60 and 1962-64

Figure 2. Constants for season plus age x season interaction from 198 herds 1958-60, 1962-64, and 1958-64



in that conditions for January to April were less favorable to two-year-olds in 1962-64 and July-August was more unfavorable to cows four years or older during 1962-64. For 1958-64 cows of all ages yielded least following July-August calvings while maximum yields were associated with January-February calvings for three-year-olds and November-December for the other two ages.

The age-season relationships are similar to those presented by McDaniel and Corley (1966) with remarkable agreement for July-August calvings. Their figures, however, indicate yields of two-year-olds were most and equally below the yields of the older cows for January-February and March-April and nearly as much below the yields of the older cows in November-December. Differences between the results of the present inquiry and those of McDaniel and Corley may be due to age-season interactions and/or age-yield relationships which are unique to Michigan but are not typical of the entire United States.

The present results differ from those of Annis et al. (1959) in which three-year-olds varied less with season than did the other ages and reached maximum yields when they calved in November-December. The differences again may be due to geographic location.

The causes of age x season interactions could not be determined by the ML analyses, but some possible causes might be conjectured. Two-year-olds, because of the flatter lactation curve, probably have more resistance to the causes of seasonal variation. Cows of all ages freshening in all seasons differ little in the amount of milk produced on the ninth and tenth test days (Aulerich, 1965). As two-year-olds start their lactations approximately 15 lb milk per day lower than older cows (Aulerich, 1965), their potential for variation in lactational yield is smaller. The relatively larger records made by two-year-olds for lactations initiated by July and August calvings may be due to both a flatter lactation curve and inadequate feed during late summer and early fall. If the average two-year-old Holstein weighs 1100 lb and milks 42 lb on the first two test days and the average mature Holstein weighs 1350 lb and milks 57 lb on the first two test days, the TDN requirement for the older cow is 4 lb per day larger (Morrison, 1956). If pasture conditions and supplemental feeding practices from late July through September provide insufficient TDN, the cows with the largest requirements may decline most in production. Likewise, if larger or older cows are affected more quickly by increasing heat and humidity, the two-year-olds should again perform relatively better for July and August calvings than older cows. In many herds heifers may be managed differently from cows prior to freshening, and this could contribute to age x season interactions.

Effects of Management on Seasonal Variation

Comparisons were made between herds using pasture and no pasture and between groups of herds at different levels of production to evaluate the influence of different management on seasonal variation. Fifty-one pairs of drylot and pasture herds were compared. In addition, the DHIA herd averages of milk for 1960 to 1964 were used to order 198 herds from high to low. To avoid rewriting the ML computer program for different numbers of herds used, the 198 were assigned to four quartiles of 51 herds each. To accomplish this, the herds ranked 49, 50, and 51 were assigned to both the first and second quartiles, and the herds ranked 148, 149, and 150 were assigned to both the third and fourth quartiles.

Results for season alone and for season plus age x season interaction are shown in Figures 3 through 8, and the numbers of observations for each age-season combination are listed in Table 3. The drylot herds showed more variation with season than did the pasture herds, even though one might expect the drylot herds to receive a more adequate and uniform supply of feed. The May-June was much more unfavorable in the drylot herds than in the pasture herds. Age x season interactions were present but dissimilar between groups of herds, and seasonal variation was much less for two-year-olds than for older cows in the drylot herds.

From 1958 to 1960 (Figure 5) the greatest seasonal

Figure 3. Season constants for pasture and drylot herds

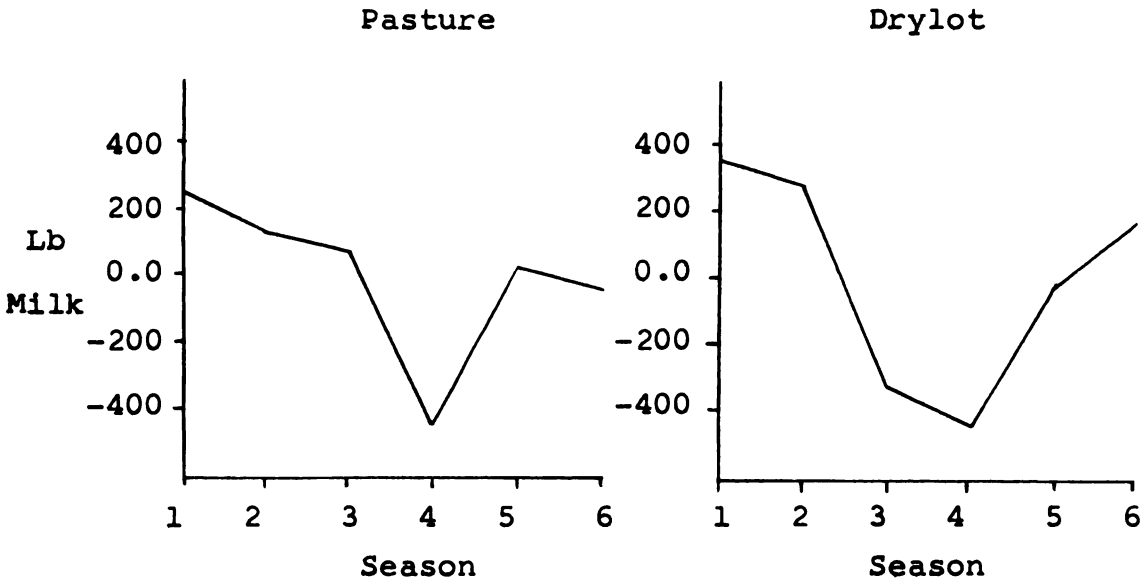


Figure 4. Season plus age x season constants for pasture and drylot herds

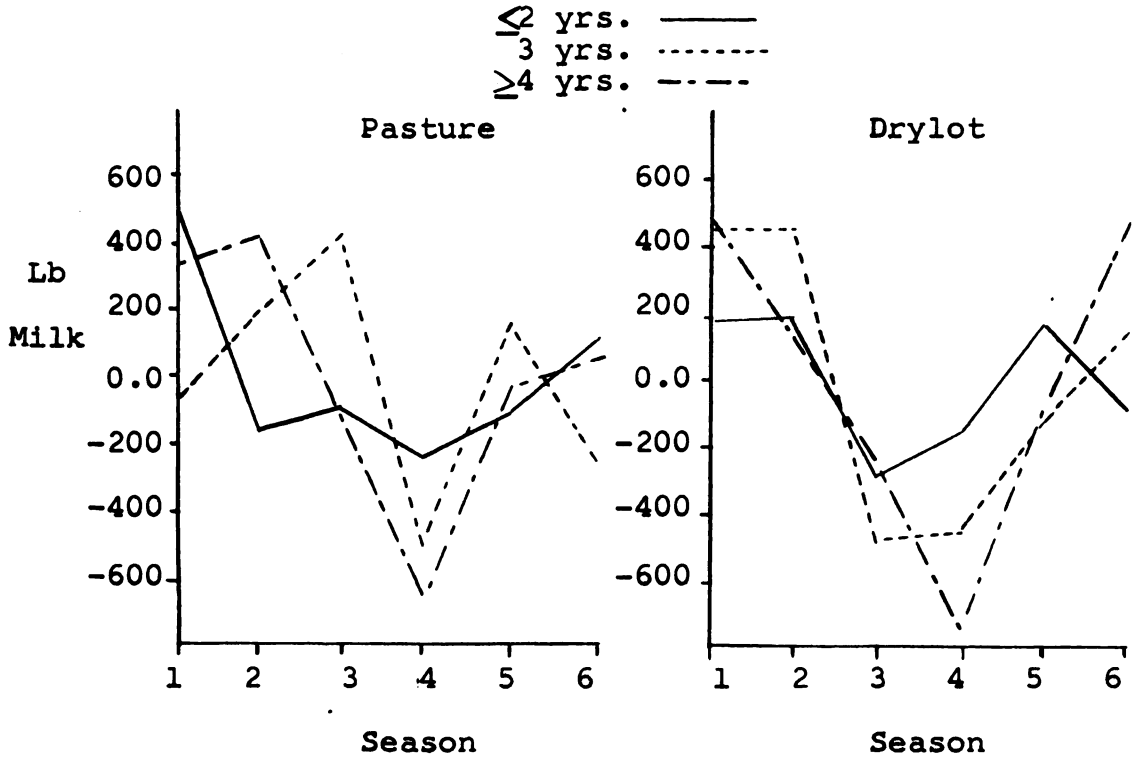
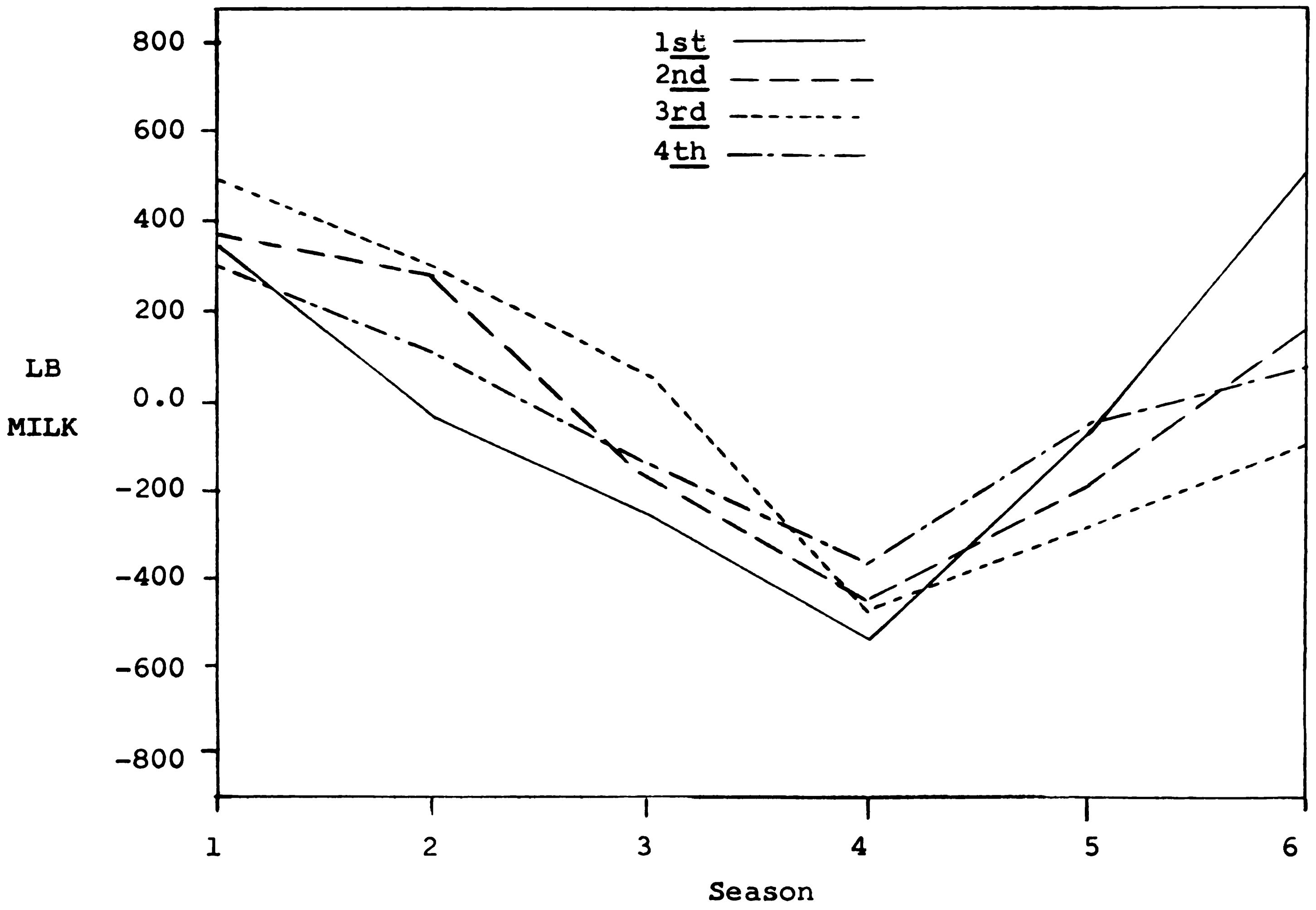


Fig. 5. Season constants from herds in quartiles by yield of milk 1958-60, each quartile fitted separately

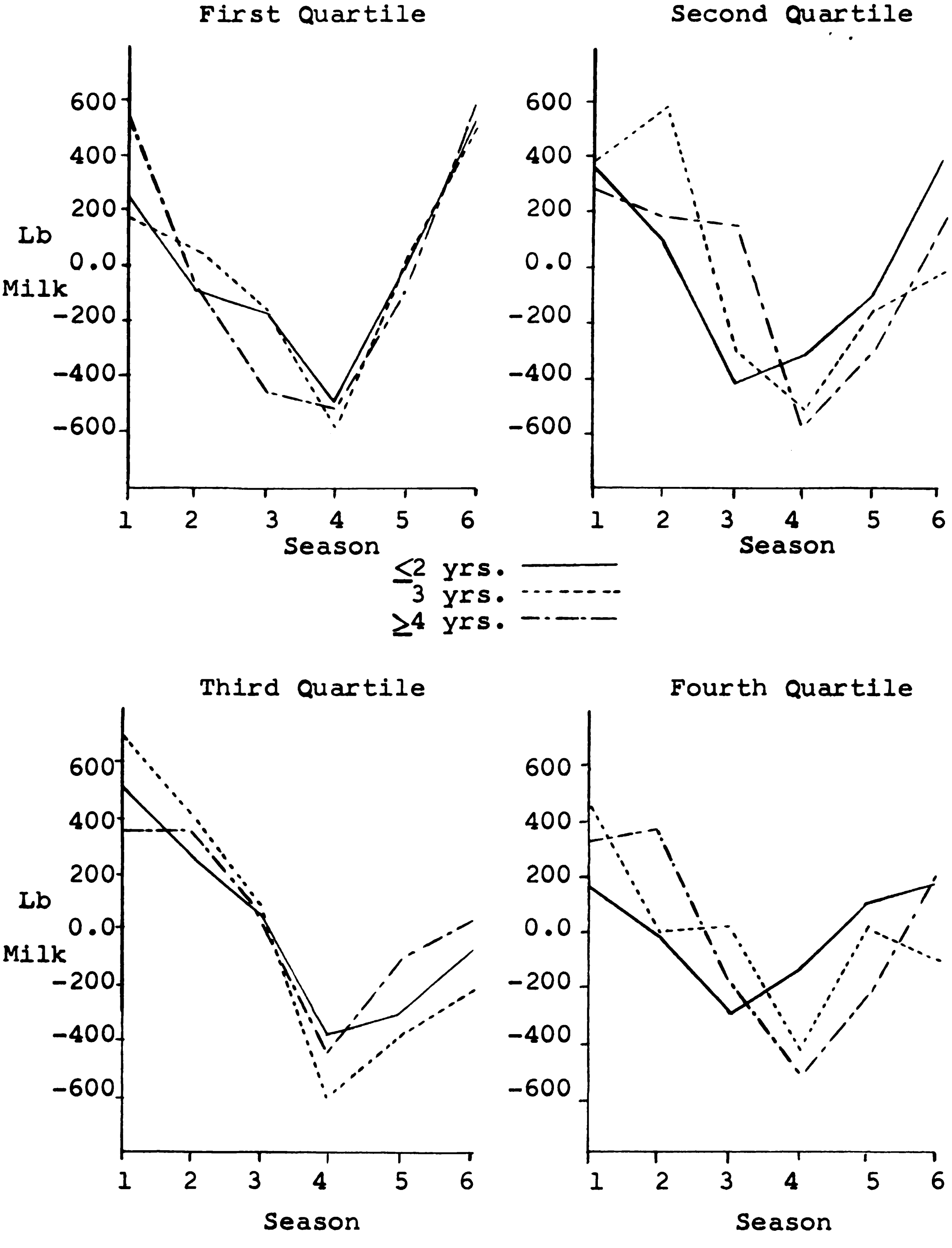


variation occurred in the first quartile herds, whereas the least variation occurred in the fourth. November-December effects were unusual in that the second and fourth quartiles had only slightly favorable effects, and the third quartile had unfavorable effects. Age x season interaction was most predominant in the second and fourth quartiles (Figure 6).

During 1962 to 1964 seasonal variation (Figure 7) was greatest in the first quartile herds, intermediate in the second, and least in the third and fourth. The quartiles differed in seasonal effects in that January-February and March-April were less favorable in the third and fourth quartiles. The most unfavorable season was May-June in the fourth quartile, whereas in the others it was July-August. Age x season interactions were largest in the two lowest quartiles (Figure 8). Cows four years or older varied more with season than did younger cows in all four quartiles and in the drylot and pasture herds (Figure 4).

Higher producing herds exhibited the most seasonal variation during 1962 to 1964 (Figure 7). This relationship between production and seasonal variation was not as distinct from 1958 to 1960 but might be partially explained by the fact that herd rankings were based on 1960 to 1964 production. Age x season interactions may be more pronounced in lower producing herds as evidenced by Figures 4 and 8, but this hypothesis is not supported by the 1958-60 results shown in Figure 6.

Figure 6. Season plus age x season constants for herds in quartiles by yield of milk 1958-60



First Quartile

Second Quartile

Third Quartile

Fourth Quartile

Fig. 7. Season constants from herds in quartiles by yield of milk 1962-64

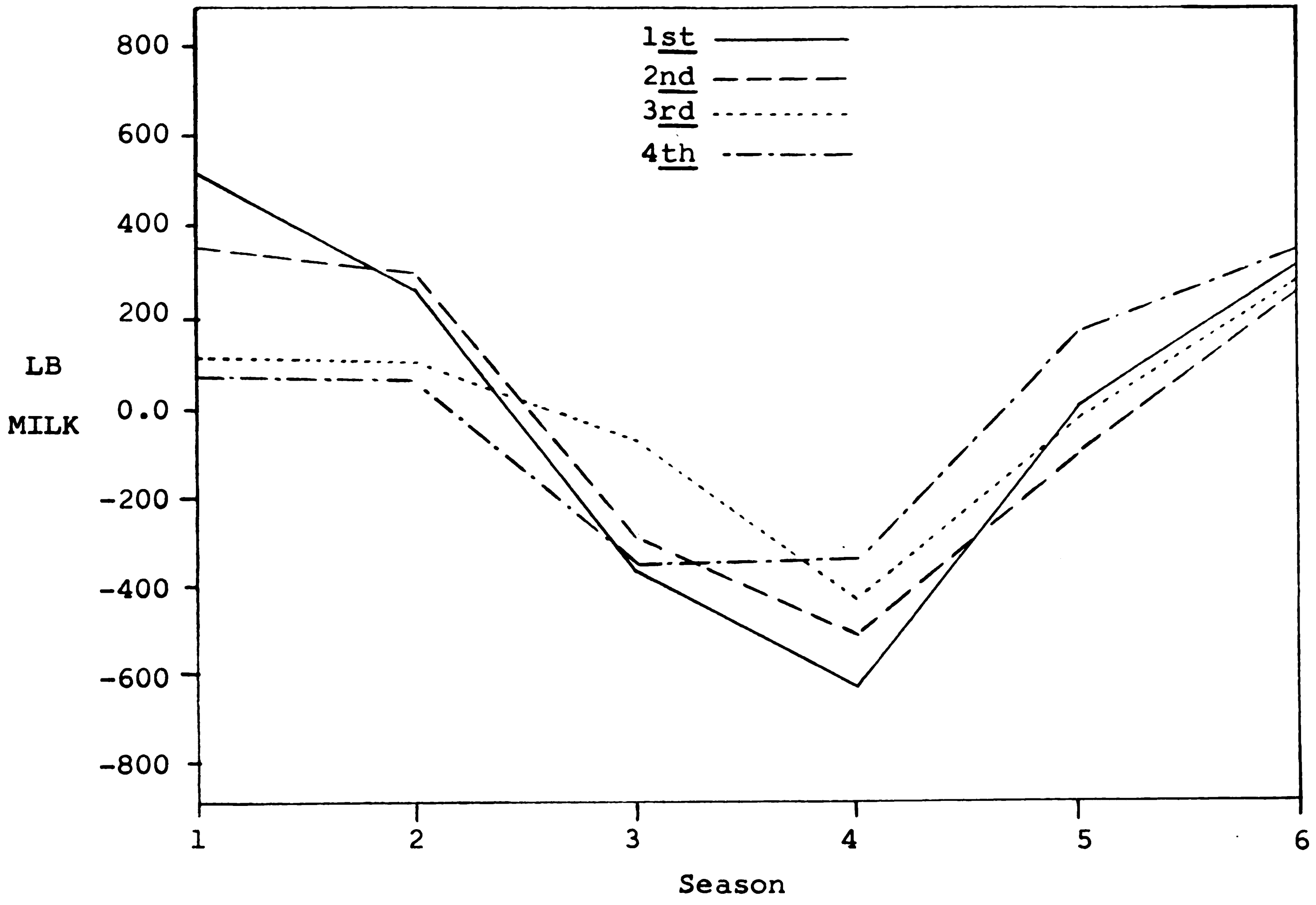
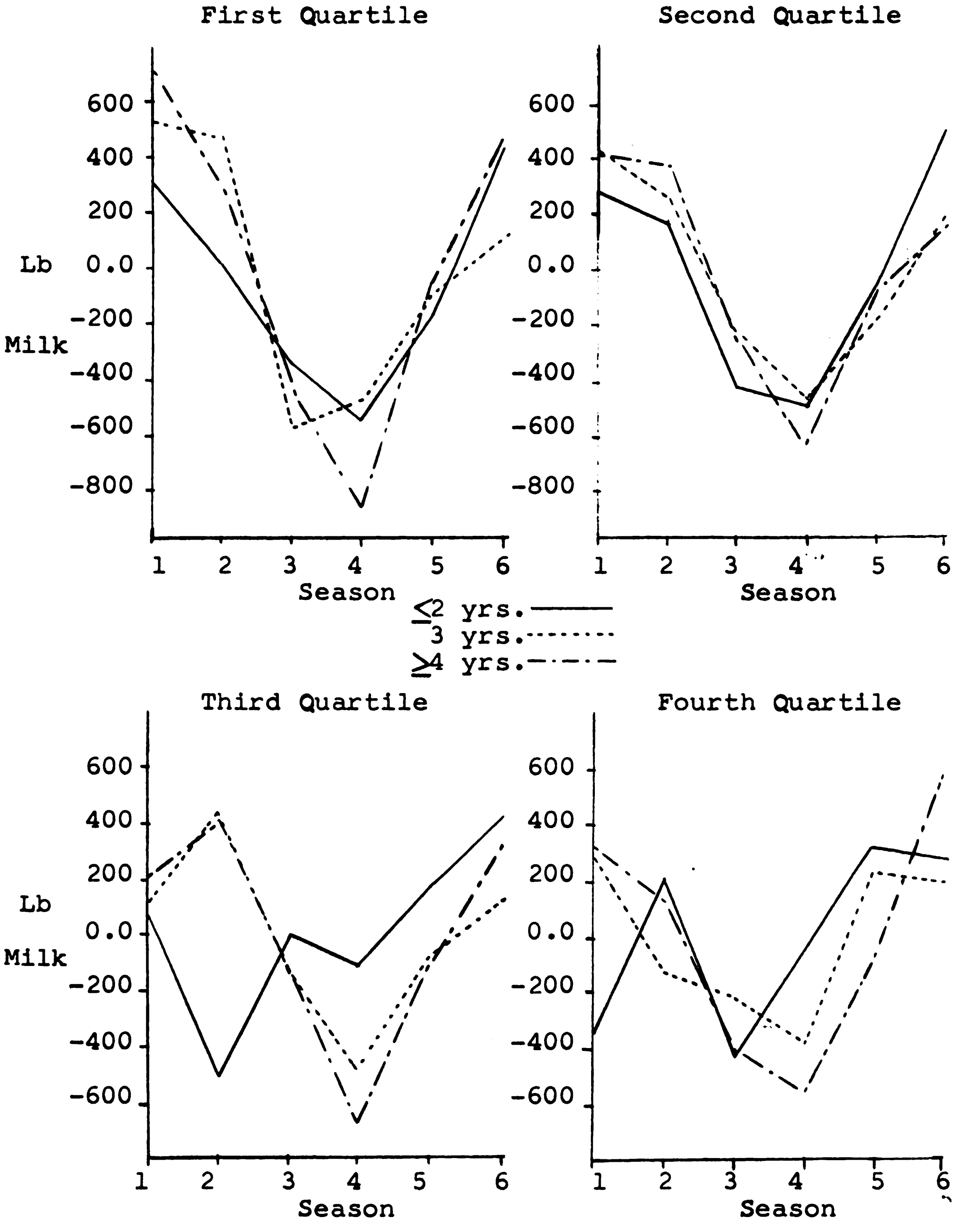


Figure 8. Season plus age x season constants for herds in quartiles by yield of milk 1962-64



Patterns of Seasonal Calving

Table 3 lists the number and percentage of cows calving in each season for the three ages. Most two-year-olds, about 55%, calve in July through October; but as they get older, the calving distribution becomes more uniform throughout the year. Differences in the seasonal calving distribution between the quartiles and pasture vs. drylot are small and inconsistent, indicating that establishing a favorable market for milk is the most important factor in deciding when the cows should calve. The age composition of the herds varied slightly with about 2.5% more two-year-olds in the top two quartiles and about 5% more in the drylot herds.

If older cows are better producers because of having survived more culling, then March-April with 13% more cows at least four years old includes animals of higher average ability than does July-August. Thus using herdmates of all ages would be another source of bias in addition to that caused by age x season interaction in comparing cows that freshened in March-April with those calving in July-August.

Effects of Age

Constants for ages in Table 4 show that in the 198 herds from 1958 to 1964 three-year-olds had the highest production with two-year-olds intermediate. The estimate for two-year-olds is 56 lb larger than the weighted average

Table 3. Number of cows of three ages calving in each season. Number in parentheses is per cent of season total. Number with % is per cent of total over all seasons.

a. 198 herds, 1958-64

Age	1	2	3	4	5	6	Total
≤2	1057	828	875	2724	2668	1588	9740
	(.25)	(.21)	(.26)	(.31)	(.27)	(.23)	26%
3	840	839	606	2105	2395	1479	8264
	(.20)	(.21)	(.18)	(.24)	(.24)	(.21)	22%
≥4	2374	2367	1915	3919	4805	3863	19243
	(.55)	(.58)	(.56)	(.45)	(.49)	(.56)	52%
Total	4271	4034	3396	8748	9868	6930	37247
	11%	11%	9%	24%	26%	19%	

b. 198 herds, 1958-60

Age	1	2	3	4	5	6	Total
≤2	410	242	251	1065	1038	709	3715
	(.26)	(.17)	(.22)	(.32)	(.27)	(.23)	26%
3	304	291	197	770	970	675	3207
	(.20)	(.20)	(.17)	(.23)	(.26)	(.22)	22%
≥4	844	906	693	1508	1807	1650	7408
	(.54)	(.63)	(.61)	(.45)	(.47)	(.55)	52%
Total	1558	1439	1141	3343	3815	3034	14330
	11%	10%	8%	23%	27%	21%	

c. 198 herds, 1962-64

Age	1	2	3	4	5	6	Total
≤2	512	461	507	1273	1259	636	4648
	(.25)	(.23)	(.28)	(.31)	(.28)	(.23)	27%
3	407	440	330	993	1080	579	3829
	(.19)	(.22)	(.19)	(.25)	(.24)	(.21)	22%
≥4	1178	1109	950	1787	2193	1561	8778
	(.56)	(.55)	(.53)	(.44)	(.48)	(.56)	51%
Total	2097	2010	1787	4053	4532	2776	17255
	12%	12%	10%	24%	26%	16%	

Table 3, continued

d. First Quartile 1958-1960

Age	1	2	3	4	5	6	Total
≤2	88	44	65	338	297	184	1016
	(.23)	(.13)	(.22)	(.35)	(.30)	(.25)	27%
3	84	67	52	217	267	169	856
	(.22)	(.19)	(.17)	(.22)	(.27)	(.23)	23%
≥4	205	237	182	416	434	387	1861
	(.55)	(.68)	(.61)	(.43)	(.43)	(.52)	50%
Total	377	348	299	971	998	740	3733
	10%	9%	8%	26%	27%	20%	

e. First Quartile 1962-1964

Age	1	2	3	4	5	6	Total
≤2	124	113	146	366	331	185	1265
	(.26)	(.25)	(.29)	(.36)	(.30)	(.26)	30%
3	96	103	97	247	272	163	978
	(.20)	(.23)	(.19)	(.25)	(.24)	(.23)	23%
≥4	259	239	258	390	513	364	2023
	(.54)	(.52)	(.52)	(.39)	(.46)	(.51)	47%
Total	479	455	501	1003	1116	712	4266
	11%	11%	12%	23%	26%	17%	

f. Second Quartile 1958-1960

Age	1	2	3	4	5	6	Total
≤2	117	70	49	230	311	224	1001
	(.26)	(.18)	(.20)	(.29)	(.29)	(.27)	26%
3	77	67	31	181	286	173	815
	(.17)	(.17)	(.13)	(.22)	(.26)	(.21)	21%
≥4	252	259	161	397	491	433	1993
	(.57)	(.65)	(.67)	(.49)	(.45)	(.52)	53%
Total	446	396	241	808	1088	830	3809
	12%	10%	6%	21%	29%	22%	

Table 3, continued

g. Second Quartile 1962-1964

Age	1	2	3	4	5	6	Total
≤2	151	133	133	364	348	168	1297
	(.26)	(.25)	(.29)	(.34)	(.28)	(.22)	28%
3	105	105	84	264	297	157	1012
	(.18)	(.19)	(.19)	(.24)	(.23)	(.20)	22%
≥4	325	298	233	452	619	444	2371
	(.56)	(.56)	(.52)	(.42)	(.49)	(.58)	50%
Total	581	536	450	1080	1264	769	4680
	12%	12%	10%	23%	27%	16%	

h. Third Quartile 1958-1960

Age	1	2	3	4	5	6	Total
≤2	87	70	67	318	279	173	994
	(.24)	(.19)	(.21)	(.34)	(.26)	(.20)	25%
3	64	83	61	226	274	191	899
	(.18)	(.22)	(.19)	(.24)	(.25)	(.23)	23%
≥4	208	221	189	394	530	480	2022
	(.58)	(.59)	(.60)	(.42)	(.49)	(.57)	52%
Total	359	374	317	938	1983	844	3915
	9%	9%	8%	24%	28%	22%	

i. Third Quartile 1962-1964

Age	1	2	3	4	5	6	Total
≤2	127	105	142	355	345	137	1211
	(.21)	(.20)	(.29)	(.29)	(.26)	(.18)	25%
3	115	114	83	289	324	143	1211
	(.20)	(.22)	(.17)	(.24)	(.25)	(.19)	22%
≥4	350	300	261	571	636	467	2585
	(.59)	(.58)	(.54)	(.47)	(.49)	(.63)	53%
Total	592	519	486	1215	1305	747	4864
	12%	11%	10%	25%	27%	15%	

Table 3, continued

j. Fourth Quartile 1958-1960

Age	1	2	3	4	5	6	Total
≤2	127	65	81	246	200	169	888
	(.29)	(.17)	(.24)	(.30)	(.25)	(.23)	25%
3	89	80	59	191	188	158	765
	(.21)	(.21)	(.17)	(.24)	(.23)	(.21)	22%
≥4	215	239	199	376	417	411	1857
	(.50)	(.62)	(.59)	(.46)	(.52)	(.56)	53%
Total	431	384	339	813	805	738	3510
	12%	11%	10%	23%	23%	21%	

k. Fourth Quartile 1962-1964

Age	1	2	3	4	5	6	Total
≤2	129	141	128	271	276	166	1111
	(.24)	(.23)	(.27)	(.27)	(.26)	(.25)	26%
3	109	137	87	253	240	143	969
	(.21)	(.23)	(.18)	(.26)	(.22)	(.21)	22%
≥4	294	326	258	464	549	361	2252
	(.55)	(.54)	(.55)	(.47)	(.52)	(.54)	52%
Total	532	604	473	988	1065	670	4332
	12%	14%	11%	23%	25%	15%	

l. Pasture Herds

Age	1	2	3	4	5	6	Total
≤2	109	91	96	332	272	101	1001
	(.22)	(.19)	(.25)	(.37)	(.28)	(.23)	28%
3	94	101	71	217	230	101	814
	(.19)	(.21)	(.19)	(.24)	(.24)	(.23)	22%
≥4	294	285	210	343	466	238	1836
	(.59)	(.60)	(.56)	(.39)	(.48)	(.54)	50%
Total	497	477	377	892	968	440	3651
	14%	13%	10%	24%	27%	12%	

Table 3, continued

m. Drylot Herds

Age	1	2	3	4	5	6	Total
≤2	153	141	152	409	382	135	1372
	(.26)	(.29)	(.38)	(.38)	(.34)	(.24)	33%
3	131	107	82	277	273	119	989
	(.23)	(.22)	(.20)	(.26)	(.25)	(.22)	23%
≥4	296	244	170	380	449	295	1834
	(.51)	(.49)	(.42)	(.36)	(.41)	(.54)	44%
Total	580	492	404	1066	1104	549	4195
	14%	12%	10%	25%	26%	13%	

of the three- and four-year-olds. Most studies, Allaire and Gaunt (1965), Robertson and Barker (1966), Tucker et al. (1960), and Tucker and Legates (1962) have shown the average production of older cows exceeds the average of two-year-olds. The discrepancy between the results of this study and other research may be due to variations in the age-yield relationship among herds (Castle, 1953; Hickman and Henderson, 1955; and Searle and Henderson, 1959) and geographic areas (Miller, 1964; Tucker and Legates, 1962; Fairchild et al., 1966) or to differences between ML age estimates and observed means of age groups. The age constants for the 198 herds from 1962-64 agree better with the literature. Extensive variation exists among the age constants listed in Table 4 indicating variation in the age-yield relationship among herds or groups of herds in this study and a lack of correspondence between level of herd production and age-yield relationships.

Since age constants and age x season interactions varied from one set of herds to another and seasonal variation was only mildly related to level of herd production, interactions of herds with age, season, and age x season are probably important sources of variation, or the number of cows within herds was too small to estimate the true herd effect for age and season. Differences from herd to herd in the way calves are raised and how heifers are fed before freshening and during lactation could cause differences in changes of production with age. Since only completed records were used in this investigation, extreme variations in culling rates between age groups from herd to herd could also contribute to herd x age interactions. Unusual season or age x season effects between herds could arise from fluctuations in management due to competition or lack of competition for the dairyman's time from other enterprises or from his response to changes in temperature or length of daylight hours. Other causes might be modifications of the way dry cows and/or springing heifers are handled or variations in the length of the dry or open periods of cows throughout the year.

Estimates of year effects in Table 5 infer that yearly environment and/or genetic values declined from 1958 to 1960 and then improved from 1960 to 1964. The decline in production during the early years apparently was not

Table 4. Maximum likelihood estimates of age effects (in lb ME milk)

Data	Years	2 yrs.	3 yrs.	4 yrs. or older
198 Herds	1958-64	+28	+92	-120
198 Herds	1958-60	-54	+93	-39
198 Herds	1962-64	-44	+24	+20
First Quartile	1958-60	-78	+79	-1
Second Quartile	"	-171	+104	+67
Third Quartile	"	+8	+158	-166
Fourth Quartile	"	-55	-33	+88
First Quartile	1962-64	-77	+90	-13
Second Quartile	"	+241	-94	-147
Third Quartile	"	-167	+73	+94
Fourth Quartile	"	-202	+56	+146
Drylot	"	+131	+17	-148
Pasture	"	+23	+31	-54

Table 5. Constants (in lb of ME Milk) for years 1958-64 from 198 herds

Year	Constant	No. Records
1958	-436	4304
1959	-515	4693
1960	-602	5332
1961	-179	5662
1962	+241	5687
1963	+673	5973
1964	+818	5595

due to expanding herd size since herds expanded in size during both the increasing and decreasing production phases. With the number of herds and cows involved, it would be unusual for year to year variations in genetic values to be as large as the changes shown in Table 5. In late 1960 dairy scientists at Michigan State University suggested feeding more grain to dairy cows could be a profitable practice, but the idea did not get much emphasis from extension personnel until late 1961. Therefore, feeding more grain to dairy cows could explain some or most of the increases in yearly effects since 1960, but without information about feeding of grain for the herds this is only speculation.

Genetic Variation Between Seasons

Evidence (Allaire and Henderson, 1966) and suspicions of unequal culling rates throughout the year suggest genetic differences could contribute to differences observed between seasons.

The results of the analyses for genetic differences are shown in Table 6. The three seasonal groupings chosen were defined in Methods. In addition, two-year-olds and older cows were analyzed separately in one seasonal grouping to determine the effects of selection on the statistical model. All differences between seasons were genetic in seasonal grouping A. But in groupings B and C a solution was impossible because mean square for variance between seasons within sire (equation IV, page 33) became negative when the expected component of residual variance was removed. Equation IV was negative again when two-year-olds and older cows were analyzed separately using seasonal grouping A.

Table 6. Variance components from genetic and environmental season analysis of DHIA data

Season Classification		Components of variance[(a)]				
		E	S	GS	ES	SEAS
Jan-June vs. Jul-Dec	A	4576	397	239	-30	
≤2-yr-olds	A2	4287	233			147
≥3-yr-olds	A3	4857	286			78
Oct-Apr vs. May-Sept	B	4487	455			317
Nov-Apr vs. May-Oct	C	4503	456			425

(a) E-residual, S-sires, GS-genetic season, ES-environmental season, SEAS-season variance component from mean square for different sires in different seasons with GS=0. Variances x 10^{-6}.

Because of the unexpected difficulties concerning equation IV, the dummy herd data were analyzed to evaluate the statistical model. Results of these analyses (Table 7) were variable and differed from expectation. GS and ES were expected to be zero when data (a), (b), and (c) were analyzed, whereas the expectations of GS and ES were zero and 1250, respectively, when data (d) and (e) were analyzed. Negative components in (c) developed when results for seasons within sires and different sires in different seasons were both negative after component of residual variance was removed. In none of the analyses did the results suggest that all of the seasonal differences were genetic.

Table 7. Variance components from genetic and environmental season analysis of dummy herd data

		Components of variance			
Data	No. Records	E	S	GS	ES
Season = 0					
(a) all	6126	356	25	-13	13
(b) 2-yr-olds	2392	355	34	17	11
(c) $\geq$ 3 years	3734	350	23	-17	-10
Season = 50					
(d) 2-yr-olds	2392	355	34	-148	1276
(e) $\geq$ 3 years	3734	350	23	-16	1270

The results in Table 7 do not explain the difficulties with equation IV so perhaps residual and sire variances estimated from variance within sire within season and variance among sires in the same season are too large. Ratios of the components of variance for sires, seasons, and residual were compared with the reports of other workers (Table 8) to determine whether the components for sires and residual variance might be the source of the difficulties in solving equation IV. Minor differences exist between the present study and the others in Table 8 in that the investigators studied fat yield, and their components of variance for seasons measure variation among seasons among years. The ratios from A and B and those of C except seasons/sires agree with the other studies. Therefore, since error could not be located in the expected mean square for equation IV, unusual relationships were suspected within the sire groups which made paternal sisters in seasons B and C more alike than paternal sisters within the same season.

Table 8. Ratios of variance components for sires, seasons, and residual

Source	S/E	SEAS/E	SEAS/S
Barr (1962)	.08	.04	.54
Bereskin (1963)	.11	.03	.26
Henderson (1956)	.13	.09	.71
Van Vleck et al. (1961)	.11	.04	.39
Table 6			
A	.11	.05	.53
A2	.05	.03	.63
A3	.06	.02	.27
B	.09	.07	.70
C	.10	.09	.93

Table 8 shows the ratios of the components for sires or seasons to residual are smaller in A2 and A3 than in the others. The values shown in Table 6 confirm that the components for sires and seasons from A2 and A3 are unusually small. It seems unlikely that the sire component from two-year-olds and from cows three years or older should be smaller than the sire component from all ages together. The sire component among two-year-olds might be expected to be largest since selection tends to leave only good cows in each progeny group, thus removing some of the differences between progeny groups. According to the results of the maximum likelihood analyses the component of variance for seasons among the two-year-olds should be smaller than the component obtained from the older cows. Evidently, unusual relationships exist among sires and seasons within the age groups in these data.

A negative correlation between the genetic value of the cows calving within a season and the environmental effect of a season would cause Cov(GS)(ES) to be negative. This negative covariance would make the result for equation IV smaller and more apt to be negative after the residual variance component was removed.

The results from analyzing both the actual and the dummy herd data for genetic differences between seasons were inconclusive. Although about 8,000 of the 18,500 records in the actual data were in single daughter sire-season groups, it is doubtful whether eliminating the single daughter progeny groups would make the analysis any more useful.

CONCLUSIONS AND APPLICATIONS OF RESULTS

Variation in milk yield with season of calving is smaller for two-year-olds than for older cows and slightly less for three-year-olds than for cows four years or older. In five of the six two-month seasons the effect for season plus age x season interaction was closer to zero for young cows than was the effect for the older cows. Therefore, comparing two-year-olds with contemporaries in any lactation is likely to underestimate the environmental opportunity during the most unfavorable season of the year (July and August) and overestimate the environmental opportunity during the favorable season (November to April). Biases could result from a comparison between sires whose two-year-old daughters do not have the same calving distribution through the year. A less likely source of bias among sires might occur where the age composition of the herdmates for the daughters differs markedly between sires. This bias is not likely because age composition of groups of herds in this study varied only slightly. Any differences between herds in age composition would probably be temporary because of the biological dynamics of age.

Large age x season interactions occurred frequently, but their statistical significance is unknown. First quartile herds had the smallest interactions and fourth quartile herds the largest, which suggests that better management may reduce age x season interactions or that genetic differences may exist between the best and poorest herds which cause different age x season interactions. When all 198 herds for 1958-1964 were analyzed, age x season interactions caused differences as much as 200 lb milk between age groups in certain seasons. If these age x season interactions are real and not due to sampling, cows should be compared with herdmates of their own age to measure accurately the environmental opportunity. On the other hand, if age x season interactions are sampling variation, then larger herdmate groups are preferred, i.e., herdmates in any lactation.

Age x season interactions varied widely from one set of herds to another indicating herd x age x season interactions. Correction factors for age for different seasons have been studied and are now being used (McDaniel and Corley, 1966). However, their usefulness is questionable if herd x age x season interaction is as prevalent as appears in this study. With an interaction of this sort the general correction factors would be in error frequently, and a sire would have to have his daughters distributed in an appropriate set of herds to avoid incorporating bias. The need to have daughters in a set of herds whose average age x season interaction effects were the same as the population from which the factors were derived would be true whether ages were corrected by the old factors of Kendrick

(1955) or the new factors of McDaniel and Corley.

For evaluating females within a single herd, applying the new age-season factors when herd x age x season interaction exists will seldom be appropriate and may increase occasionally the bias due to season, since only a small percentage of the herds fits the average situation. In general, with herd x age x season interaction the reduction in age-season bias from using age-season factors will be small compared to the total bias from this source. The most satisfactory way of dealing with herd x age x season interactions is to compare cows within herd-season-age groups.

Variation from one group of herds to another in effects of age suggests a herd x age interaction. The overall effect was for three-year-olds to have the highest production. No relationship was evident between the age effects and the level of herd production. The two-year-old age constant should be largest in the low production level herds and smallest in the high herds according to Searle and Henderson (1959). Biases arising from herd x age interactions could be minimized by comparing cows with herdmates of the same age or by correcting first lactations to a standard age at first calving (Johansson, 1961).

McDaniel and Corley (1966) reported a region x age interaction, and Michigan was in a region in which the old age-correction factors for two-year-olds (Kendrick,

1955) were too large. The age constants from the 198 herds for 1958-64 agree with their work, but the results from all the analyses suggest a larger error occurs because the factors for three-year-olds are too large.

The analysis for genetic differences between seasons did not function adequately, leaving the question unanswered. However, if genetic differences between seasons did exist, they could be minimized most easily by using only two-year-old cows compared with two-year-old herdmates, because they are relatively unselected and selection would be the primary source of genetic differences between seasons.

This study indicates a need for further research in several areas. Firstly, a measure of the three-way interaction between herds, ages, and seasons is needed to determine the appropriateness of age-season correction factors. If the variation due to age x season interaction is significantly larger than that due to herd x age x season interaction, then the reduction in bias by using age-season factors will be worthwhile. Also, if some method could be found of classifying herds into groups with like age x season interactions, the use of age-season correction factors would be fitting. Developing a suitable method of correcting for age-season effects would allow the use of cows in any lactation as herdmates, thereby permitting larger herdmate groups and reducing chance variation. Secondly, since the production of two-year-olds seems to deviate less from the yearly herd average in most of the seasons than does the production of older cows, an evaluation of averages of herdmates in any lactation that are regressed toward the yearly herd average should be examined for use in evaluating two-year-old records. In the USDA system the adjusted herdmate average is calculated as: breed season average + [n/(n+1)] (herdmate average-breed season average). This method does not always move the adjusted herdmate average toward the yearly herd average. Lastly, further study should be made concerning genetic differences between seasons. This is a challenging problem because of the confounding between genetic and environmental influences of seasons.

SUMMARY

Maximum likelihood was used to study the effects of three ages (≤ 2, 3, ≥ 4 years), six seasons of calving (January-February, March-April, etc.), and their interactions on the 305 day-2x-ME milk of completed lactations of Holstein cows in Michigan DHIA. Maximum likelihood utilizes the probable producing ability of the cow and, therefore, should remove genetic differences between seasons from seasonal effects on lactational milk yield. Two values of repeatability, 0.4 and 0.55, made little difference in the constants for age, season, and age x season interaction effects.

Data were 37,247 records in 198 herds on test continuously at least from 1958 to 1964, 4195 records in 51 drylot herds, and 3651 records in 51 pasture herds. The drylot herds used no pasture during 1963-64 or 1962-64 and were paired with 51 pasture herds which used at least 85 days of pasture during the same years and were from the same counties. The drylot and pasture herds were matched as closely as possible for years on test, herd size, and registered or grade cows.

Yields were largest in the January-February season. After this they declined steadily, were least in July-August, and sharply improved again. Below average production existed from May until October. The best and worst seasons differed by 776 lb milk. The magnitude of seasonal influence did not change from 1958-60 to 1962-64. Comparisons were made between the pasture and drylot herds and between quartiles of the 198 herds ranked on the DHIA herd average of milk for 1960 to 1964. The drylot herds showed more variation with season than did the pasture herds. For 1958-60 the greatest seasonal variation occurred in the first quartile herds, whereas the least occurred in the fourth. During 1962-64 seasonal variation was largest in the first quartile herds, intermediate in the second, and least in the third and fourth. Seasonal effects differed some among the quartiles and between pasture and drylot herds.

Interactions of age with season were present in that the total change associated with season was about 250 lb less for two-year-olds than for three-year-olds, while three-year-olds in turn varied 60 lb less than cows four years or older. July-August was much more detrimental to yield of the two older groups than to two-year-olds, whereas March-April calvings were distinctly more favorable to the two older groups. Cows of all ages yielded least following July-August calvings, while maximum yields were associated with January-February calvings for the three-year-olds and November-December calvings for the others. Although the seasonal pattern was similar, age x season interactions varied among the quartiles and between the pasture and drylot herds, indicating herd x age x season interactions may be an important source of variation. Age x season interactions seemed to be largest in the lower producing herds.

Age constants varied widely among the sets of herds. For the 198 herds during 1958-64 the three-year-old constant was largest and the four years or older constant smallest.

An analysis of variance within herd and year, within sire-season groups, between sire groups within season, between seasons within sire, and between different sires in different seasons was unable to partition seasonal differences into genetic and environmental components because of excessive variation among paternal sisters within season.

Interactions of herds with age, season, and age x season appeared large enough to be a source of errors in the ranking of bulls tested in a limited number of herds.

LITERATURE CITED

ALLAIRE, F. R., and GAUNT, S. N. 1965. First Lactation Contemporary Comparisons as Indicators of Environmental Influences on Daughter Records Used for Sire Evaluation. J. Dairy Sci. 48:454.

ALLAIRE, F. R., and HENDERSON, C. R. 1966. Selection Practiced Among Dairy Cows. I. Single Lactation Traits. J. Dairy Sci. 49:1426.

ANNIS, D. J., ERB, R. E., and WINTERS, W. R. 1959. Influence of Month and Season of Calving on Yields of Milk and Fat. Wash. Agr. Exp. Sta. Bull. 606.

ARNOLD, P. T. DIX, and BECKER, R. B. 1935. The Effect of Season of the Year and Advancing Lactation Upon Milk Yield of Jersey Cows. J. Dairy Sci. 18:621.

AULERICH, C. C. 1965. Differences in Extending Terminal and Non-Terminal Incomplete Lactations to 305 Days. M.S. Thesis, Michigan State University Library, East Lansing, Michigan.

BARKER, J. S. F., and ROBERTSON, A. 1966. Genetic and Phenotypic Parameters for the First Three Lactations in Friesian Cows. Anim. Prod. 8:221.

BARR, G. R. 1962. Selecting Young Dairy Bulls on Differences Between Relatives and Their Contemporaries. Ph.D. Thesis, Iowa State University Library, Ames, Iowa.

BERESKIN, B. 1963. Effects of Genetic and Environmental Variance on Dairy Sire Evaluation. Ph.D. Thesis, Iowa State University Library, Ames, Iowa.

BERESKIN, B., and FREEMAN, A. E. 1965. Genetic and Environmental Factors in Dairy Sire Evaluation. I. Effects of Herds, Months, and Year-Seasons on Variance Among Lactation Records; Repeatability and Heritability. J. Dairy Sci. 48:347.

BRANTON, C., STONE, E. J., and MILLER, G. D. 1958. Heritability and Repeatability of Milk-yield Records of Holstein-Friesian Cows in Louisiana with and without Certain Environmental Corrections. (Abstr.) J. Dairy Sci. 41:746.

CANNON, C. Y. 1933. Seasonal Effect on Yield of Dairy Cows. J. Dairy Sci. 16:11.

CASTLE, O. M. 1953. Memo on Age Corrections in Sire Survey Work in New Zealand. (Mimeo.).

DEATON, O. W., and McGILLIARD, L. D. 1964. First, Second, and Third Records of a Cow to Estimate Superiority of Her Daughters. J. Dairy Sci. 47:1004.

FAIRCHILD, T. P., TYLER, W. J., BARR, G. R., and CORLEY, E. L. 1966. Estimating Transmitting Abilities of Artificial Insemination Dairy Sires. J. Dairy Sci. 49:1416.

FOSGATE, O. T., and WELCH, H. K. 1960. Effect of Certain Environmental Factors Upon Milk Production in Georgia. (Abstr.). J. Dairy Sci. 43:442.

FREEMAN, A. E. 1960. Genetic Relationships Among the First Three Lactations of Holstein Cows. J. Dairy Sci. 43:876.

FRICK, G. E., MANN, A. I., and JOHNSON, S. 1947. The Relation of Season of Freshening to Milk Production. J. Dairy Sci. 30:631.

GRAVIR, K., and HICKMAN, C. G. 1966. Importance of Lactation Number Age and Season of Calving for Dairy Cattle Breed Improvement (Based on Canadian Record of Performance). Pub. 1239, Canada Dept. of Agric.

HAMMOND, J., and SANDERS, H. G. 1923. Some Factors Affecting Milk Yield. J. Agric. Sci. 13:74.

HENDERSON, C. R. 1949a. Estimation of Changes in Herd Environment. (Abstr.). J. Dairy Sci. 32:706.

HENDERSON, C. R. 1949b. Numerical Example of Estimation of Changes in Herd Environment. (Mimeo.). Dept. of Animal Husbandry, Cornell Univ., Ithaca, New York.

HENDERSON, C. R. 1956. Cornell Research on Methods of Selecting Dairy Sires. New Zealand Soc. Anim. Prod. Proc. 16:69.

HENDERSON, C. R. 1958. Estimates of Environmental Trends and Biases Resulting from Errors in Age Factors and Repeatability. J. Dairy Sci. 41:747.

HENDERSON, C. R., KEMPTHORNE, O., SEARLE, S. R., and vonKROSIGK, C. M. 1959. The Estimates of Environmental and Genetic Trends from Records Subject to Culling. Biometrics 15:192.

HICKMAN, C. G., and HENDERSON, C. R. 1955. Components of the Relationship Between Level of Production and Rate of Maturity in Dairy Cattle. J. Dairy Sci. 38:883.

HOFMEYR, J. 1955. A Study of Danish and Swedish Progeny Testing Methods for Dairy Bulls. Ann. Royal Swedish Agr. Coll. 22:425.

JARVIS, W. E. 1960. Adjusting Milk Production Records for Age at Calving in Western Canada. M.S. Thesis, Michigan State University Library, East Lansing, Mich.

JOHANSSON, I. 1961. Genetic Aspects of Dairy Cattle Breeding. University of Illinois Press. Urbana, Illinois.

KENDRICK, J. F. 1955. Standardizing Dairy-Herd-Improvement-Association Records in Proving Sires. United States Dep. Agr., Bur. Dairy Ind. Pub. ARS-52-1.

LAMB, R. C., and McGILLIARD, L. D. 1960. Variables Affecting Ratio Factors for Estimating 305-Day Production from Part Lactations. J. Dairy Sci. 43: 519.

LEE, J. E., FOSGATE, O. T., and CARMON, J. L. 1961. Some Effects of Certain Environmental and Inherited Influences Upon Milk and Fat Production in Dairy Cattle. J. Dairy Sci. 44:296.

LUSH, J. L. 1949. Animal Breeding Plans. Iowa State University Press. Ames, Iowa.

MAHADEVAN, P. 1951. The Effect of Environment and Heredity on Lactation. I. Milk Yield. J. Agric. Sci. 4:80.

McDANIEL, B. T., and CORLEY, E. L. 1966. Environmental Influences on Age Correction Factors. (Abstr.). J. Dairy Sci. 49:736.

McDOWELL, J. C. 1922. Influence of Season of Freshening on Production and Income from Dairy Cows. United States Dep. Agr. Bull. 1071.

MILLER, R. H. 1964. Biases in the Estimation of the Regression of Milk Production on Age. J. Dairy Sci. 47:855.

MILLER, R. H. 1967. Personal Communication.

MILLER, R. H., HARVEY, W. R., TABLER, K. A., McDANIEL, B. T., and CORLEY, E. L. 1966. Maximum Likelihood Estimates of Age Effects. J. Dairy Sci. 49:65.

MORRISON, F. B. 1956. Feeds and Feeding. 22nd Ed. Morrison Publishing Co., Ithaca, New York.

MORROW, K. S., KEENER, H. A., and HALL, C. N. April, 1945. Analysis of Certain Factors Involved in Dairy Herd Management in New Hampshire. New Hampshire Agr. Exp. Sta. Tech. Bull. 86.

OLOUFA, M. M., and JONES, I. R. 1948. The Relation Between the Month of Calving and Yearly Butterfat Production. J. Dairy Sci. 31:1029.

PLUM, M. 1935. Causes of Differences in Butterfat Production of Cows in Iowa Cow Testing Associations. J. Dairy Sci. 18:811.

RENDEL, J. M., and ROBERTSON, A. 1950. Estimation of Genetic Gain in Milk Yield by Selection in a Closed Herd of Dairy Cattle. J. Genetics 50:1.

RENDEL, J. M., ROBERTSON, A., ASKER, A. A., KHISHIN, S. S., and RAGAB, M. T. 1957. The Inheritance of Milk Production Characteristics. J. Agric. Sci. 48:426.

ROBERTSON, A., and BARKER, J. S. F. 1966. The Correlation Between First Lactation Milk Production and Longevity in Dairy Cattle. Anim. Prod. 8:241.

SANDERS, H. G. 1927. The Variations in Milk Yield Caused by Season of the Year, Service, Age, and Dry Period, and Their Elimination. J. Agric. Sci. 17:339.

SEARLE, S. R. 1961. Part Lactations. I. Age-Corrected Factors for Monthly Milk Fat Yields. J. Dairy Sci. 44:104.

SEARLE, S. R., and HENDERSON, C. R. 1959. Establishing Age-Correction Factors Related to the Level of Herd Production. J. Dairy Sci. 42:824.

SMITH, V. R. 1959. Physiology of Lactation. 5th Ed. Iowa State University Press. Ames, Iowa.

SUNDARESAN, D., and FREEMAN, A. E. 1961. Variation in Milk Fat Production in State-Owned Herds in Iowa. J. Dairy Sci. 44:151.

SYRSTAD, O. 1965. Studies on Dairy Herd Records. II. Effect of Age and Season of Calving. Acta Agric. Scand. 15:31.

TUCKER, W. L., and LEGATES, J. E. 1962. Effective Use of Herd-Mates in Dairy Sire Evaluation. (Abstr.). J. Anim. Sci. 21:976.

TUCKER, W. L., and LEGATES, J. E. 1965. Seasonal Division of Herd-Mates in Sire Evaluation. J. Dairy Sci. 48:234.

TUCKER, W. L., LEGATES, J. E., and FARTHING, B. R. 1960. Genetic Improvement in Production Attributable to Sires Used in Artificial Insemination in North Carolina. J. Dairy Sci. 43:982.

VANVLECK, L. D., WADELL, L. H., and HENDERSON, C. R. 1961. Components of Variance Associated with Milk and Fat Records of Artificially Sired Holstein Daughters. J. Anim. Sci. 20:812.

WILCOX, C. J., and YOUNG, H. W. February 25, 1965. Season of Freshening Affects Yield. Hoard's Dairyman, 110(4):207.

WOODWARD, T. E. 1945. Some Studies of Lactation Records. J. Dairy Sci. 28:209.

WYLIE, C. E. 1925. The Effect of Season on the Milk and Fat Production of Jersey Cows. J. Dairy Sci. 8: 127.