Management of Length of Lactation and Dry Period to Increase Net Farm Income in a Simulated Dairy Herd

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(ABSTRACT)

A computerized dairy herd simulation was developed to evaluate the economic impact of changing length of lactation relative to length of dry period in a dairy herd. It created weekly production for individual cows in a typical herd. Cows were dried off early if they were producing below a designated daily milk yield. They were replaced with fresh cows to produce more daily milk and increase profit while maintaining a constant number of cows in milk (98 to 102).

A two by four factorial of dry off strategies was designed using rates of lactation decline of 6% and 8% and early dry off at 8, 13, 18, and 23 kg. Cows producing less than this for 2 wk consecutively were dried off. There were 100 cows in each herd and each of the eight scenarios was run 10 times (10 herds) for 80 herds total.

Dry cow groups at 8, 13, 18, and 23 kg dry off were 14, 17, 23, and 32% of total herds, respectively. Average daily milk (kg) increased for the four dry kg: 30.4, 31.2, 32.3, and 33.7 kg/d per milking cow, whereas RHA decreased.

Three different milk-feed income scenarios, (+20%, average, -20%) were combined with three dry cow costs, (+20%, average, and -20%). Nine combinations were analyzed statistically at each rate of decline. Net cash income changed $3561, $1571, and $-3051 from 8 to 13 to 18 to 23 kg dry kg under a normal economic situation. Net farm income under the same scenario changed $3170, $2945, and $-1154. Under the best economic situation, net cash income increased with each successive dry kg, $5086, $4248, and $921. Net farm income also increased by $4695, $5621, and $2819. Net cash income and net farm income were largest at 13 and 18 kg when milk–feed income was low and dry cow cost was high, the worst economy scenario. Only in the most optimistic economic situations does it appear practical for a dairy business to adopt early dry off beyond 13 kg/d per cow given the small gains and the yearly variability. Strategies of dry off at

larger dry kg, although not greatly profitable, nevertheless were not extremely unprofitable either.

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Table of Contents

MANAGEMENT OF LENGTH OF LACTATION AND DRY PERIOD TO INCREASE NET FARM INCOME IN A SIMULATED DAIRY HERD .... **I**

ABSTRACT .... **II**

ACKNOWLEDGEMENTS .... **IV**

TABLE OF CONTENTS .... **V**

LIST OF TABLES .... **VII**

LIST OF FIGURES .... **IX**

INTRODUCTION **1**

- OBJECTIVE 2

REVIEW OF LITERATURE **3**

- CURRENT MANAGEMENT PRACTICES 3
- DAIRY SIMULATIONS 3
- SIMULATION BY CONGLETON 3
- SIMULATION BY O'CONNER AND OLTENACU 6
- MILK PRODUCTION 9
- LACTATION CURVES 10
- DAYS OPEN 13
- CULLING 14
- DRY PERIOD 17
- HEALTH DISORDERS 18
- CONCLUSION 20

MATERIALS AND METHODS **21**

- SIMULATION 21
- SIMULATION SOFTWARE 21
- GENERATING RANDOM VARIATION 24
- BASE VALUE 25
- REPRODUCTION 26
- LACTATION CYCLE 28
- TRIALS 28
- GENERATING THE INITIAL HERD 29
- PERCENT DRY 30
- MILK PRODUCTION 32
- VISUAL BASIC AND MACROS 35
- BALANCING THE SIMULATION 43
- COUNTS 44
- STATISTICAL ANALYSIS 50

Sensitivity Analysis 50
RESULTS AND DISCUSSION 52
Cull Rates 52
Lactation Periods 52
Milk Yields 53
Mixed Model ANOVA's 62
Trends of Increasing Milk at Dry Off 62
Effect of Dry off at Each Lactation Decline 74
Sensitivity Analysis 75
Net Cash Income and Milk–Feed Income 75
Net Cash Income and Dry Cow Cost 76
8% Decline versus 6% Decline 76
Net Farm Income 77
Other Possibilities 83
CONCLUSIONS 83
REFERENCES 86
APPENDIX 89
VITA 100

List of Tables

Table 1: Opportunity losses in total net returns ($) for drying off practice in the field and recommended drying off policy (26). 8
Table 2. Lactational incidence risks, disease-specific risk of culling, and day by which 25% of the cows had been culled for each disease in 7523 Holstein dairy cows. 20
Table 3. Characteristic of uniform and normal random numbers in Excel. 24
Table 4. Probability of n heats and days between heats for cows that become pregnant. 28
Table 5. Differences in initial herd (wk 1 and 2) for dry kg scenarios. 30
Table 6. Rates of decline and peak milk for three lactations. 33
Table 7. Quantity of feed (kg/d per cow, as fed) for various milk yields. 49
Table 8. Price of feed in ration ($/d per cow) for various milk yields. 49
Table 9. Means and standard deviations for 8 kg dry and 6% lactation decline (10 herds). 54
Table 10. Means and standard deviations for 13 kg dry and 6% lactation decline (10 herds). 55
Table 11. Means and standard deviations for 18 kg dry and 6% lactation decline (10 herds). 56
Table 12. Means and standard deviations for 23 kg dry and 6% lactation decline (10 herds). 57
Table 13. Means and standard deviations for 8 kg dry and 8% lactation decline (10 herds). 58
Table 14. Means and standard deviations for 13 kg dry and 8% lactation decline (10 herds). 59
Table 15. Means and standard deviations for 18 kg dry and 8% lactation decline (10 herds). 60
Table 16. Means and standard deviations for 23 kg dry and 8% lactation decline (10 herds). 61
Table 17. Test of fixed effects. 65
Table 18. Mean income 6%. 66
Table 19. Mean expenses 6%. 67

Table 20. Mean herd variables 6%. 68
Table 21. Mean investments 6%. 69
Table 22. Mean income 8%. 70
Table 23. Mean expenses 8%. 71
Table 24. Mean herd variables 8%. 72
Table 25. Mean investments 8%. 73
Table 26.Tests of dry kg differences (P-values). 74
Table 27. Significance (P>F) of sources of variation in net income for nine income-dry cost scenarios. 78

List of Figures

Figure 1. Dairy Herd Simulation. 253
Figure 2. Parameters of the simulation for generating the basic 8 kg dry-off herd. 25
Figure 3. Reproduction cycle and weeks open. 27
Figure 4. Macros to generate random numbers. 37
Figure 5. Macros to create of the herd. 38
Figure 6. Macros and sub macros to make management decision. 39
Figure 7. Macros for heifer management. 42
Figure 8. Count variables. 45
Figure 9. Economic parameters. 48
Figure 10. Schemes to test sensitivity to price change. 51
Figure 11. Net cash income by change in milk-feed income and dry cow cost at 6% decline (L = Linear, Q = Quadratic).. 79
Figure 12. Net farm income by change in milk-feed income and dry cow cost at 6% decline (L = Linear, Q = Quadratic).. 80
Figure 13. Net cash income by change in milk-feed income and dry cow cost at 8% decline (L = Linear, Q = Quadratic).. 81
Figure 14. Net farm income by change in milk-feed income and dry cow cost at 8% decline (L = Linear, Q = Quadratic).. 82

Introduction

Daily, herd managers are faced with decisions that influence the economic success of their program. Management teams should set goals, and use goals to guide day to day decisions. These goals should consider cows that leave the herd and cows that remain. Valuable resources, such as, time, labor, and breeding expense should be used first for those cows remaining in the herd. Management should avoid extremely long and extremely short calving intervals. Faust (12) explains farm management as a combination of economic analysis and business control, and the management of biological processes within the context of a changing technical, legal and human environment.

There are four major management decisions regarding the disposition of individual cows: to treat, breed, cull, or dry off. Extensive research has been conducted on proper breeding techniques and treatment of cow ailments. The dairy manager follows established protocols to achieve economic stability. Culling decisions have an important influence on the economic performance of the dairy but are often made in a nonprogrammed fashion and based partly on the intuition of the decision-maker. It is difficult to make a major error in culling, and culling one cow will not have significant financial impact on a dairy operation. Length of dry period has been examined extensively through lactation records to settle on a standard of 40 to 70d to optimize production in the next lactation. These recommendations are tied to standard breeding practices. Although producers have guidelines to follow to maximize lactation records for the herd, individual farm circumstances will dictate ultimate profit.

Current practices have allowed producers to strategically manage their herds to increase cash flow, mostly by increasing production and cow numbers. A predominant trend in the dairy industry has been toward fewer herds and fewer cows, but more cows per herd. Pressure to maintain and increase farm profits have resulted in larger herds in addition to increased milk production per cow. Two major factors affect the profit of the operation, the price for the product and the cost of producing the product. Rapid advances in the annual productivity of dairy cows have kept milk supplies from dwindling. Advancements in technologies have made milk production more efficient and cows more productive. In the past 20 yr, the Virginia dairy industry has experienced extensive change. In 1983 there were 1678 Grade A dairy farms with a herd size of approximately 85 cows/farm. Since this time producers have tried to diminish costs per cow by increasing the number of cows per farm. The increase in cow numbers per herd reflects the decrease in the number of farms remaining in Virginia. In 1999 the number of dairy farms had decreased to 996 and the average herd size had increased to 123 cows (39).

One management strategy to enhance the economic position of the dairy farm might be to manipulate length of lactation. A fresh cow usually will produce more milk per day than a cow several months into lactation. This suggests there is an increase in cash flow if the ratio of fresh cows to late lactation cows is greater. A larger percentage of fresh cows, in theory, produce more daily milk and increase cash flow while the operation remains at its current number of cows in milk. As a result, however, there will be more dry cows than normal. If the fresh cows can produce enough milk to sustain their cost as well as the cost of extra dry cows, there is an increase in economic efficiency.

Objective

The objective of this research was to evaluate alternatives concerning length of lactation relative to length of dry period. First, a computerized dairy herd simulation was developed to create weekly production for a typical herd of cows. Second, the simulation was used to determine the economic impact of shortening length of lactation to increase daily milk yield from a constant number of cows in milk.

Review of Literature

Current Management Practices

Management involves the creation of an environment in which people can use available resources to reach stated goals of the dairy operation. Dairying requires implementation of five functions of management - planning, organizing, staffing, directing, and controlling. Proper management can identify priorities, improve financial position, and reach set goals. Subsequently, the size and organization of the dairy drives the daily implementation of the decisions.

Modern managers need to be goal-oriented with regard to their herd and the overall profit of the dairy operation. The majority of net farm income is derived from lactating cows; thus emphasis is placed on milk production and health of those cows. Successful managers pay attention to their cows, and they do not lose track of what is important.

Dairy Simulations

Simulation is a management science tool that models situations with random variation, but does not typically generate an optimal solution to a problem. Although the results of the simulation represent the solution of a system, the results should not be considered to be optimal in the same sense as the solution to a linear programming problem. Dairy cattle simulations developed in the 1960's were used primarily for dairy genetics research or for instructional purposes. Genetic simulations have evolved from single trait dairy cattle breeding to multiple trait beef, dairy and swine simulations (40).

Simulation by Congleton

Congleton (3), in 1984, developed a simulation using the General Activity Simulation Program (GASP IV) simulation package to investigate general dairy management strategies. The program dealt with the relationship of herdlife to annual income of individual cows. The major objective of this work was validation of the model through comparison to survey information. Also included in the model were economic and production information, as well as simulation of discrete (calving, breeding, culling) and continuous (milk yield, feed consumption) variables. There were six subroutines in modular form for breeding, drying off, freshening, milk yield, culling, and replacement. Interactions between model components were included in the subroutines. He attempted to identify interactions between variables in model development such as an increase in milk yield resulted in increased health costs. The purpose was to create some factors that would determine output for others. The model was verified for validity by comparing two Northeast dairy farm survey summaries for performance and economic information.

Congleton's simulation tracked a cow moving through a cycle from freshening through reproduction and lactation. Individual animal records were kept in two files, one for lactating cows, and the other for replacements. Repetitious processes such as milk yield were calculated and recorded daily. However, because the simulation was using GASP IV these updates were performed in blocks of time. After a significant event (conception, calving) the cow was passed to a subroutine to calculate characteristics related to breeding, milk yield, and current lactation. No consideration was given to effects of subclinical mastitis on milk yield or to the fact that treatment and lost milk costs could vary depending on the severity of the mastitis case and daily milk yield of the cow. Incidences of reproductive diseases or conditions that occurred during the lactation were calculated at freshening. Dystocia, retained placenta, metritis, cystic follicles, luteal cysts, and twinning were all simulated. Most of the diseases and conditions were contingent on the age of the cow and previous occurrences.

Another subroutine was used for calculation of daily milk yield and feed energy consumption. Daily milk yield was calculated from a Gamma function that included effects of age of the cow and days in milk. Included in the estimation of yield were breeding value of the cow, a permanent environmental effect, and the effect of gene segregation, calculated when the animal was selected as a replacement.

Energy requirements were calculated depending on daily milk yield, maturity of the cow, length of gestation, body weight, age at freshening, and daily weight gain of the cow. In addition to calculating milk yield and feed consumption, a subroutine also calculated and stored feed cost, health cost, fixed cost, body size and growth traits, mortality, and determined if drying off or culling was necessary for each time increment.

Fertility was treated as discrete events so that 120d milk yield could be used in calculating days open and calculated the breeding cost. Infertile cows were culled when dried off and replacement cows were available when cows were culled or died. Gestation period for all cows was 280 d, with no variation in length. Pregnant cows were dried off when daily milk yield was less than 4.5 kg/d, or the cow was less than a specified number of days from her next calving. The optimum numbers of days dry varied according to lactation number and number of days open in the current lactation. Open or infertile cows were sold when their milk yield was less than 6.8 kg/d.

Culling also occurred through mortality of cows, culling of infertile cows, or culling of fertile cows when they went dry for other than reproductive purposes. Cows were culled when their cost per unit of production fell below a level set by the operator. Otherwise, the cow was kept, lactation yield and cost variables were set to zero. If a cow was culled, a replacement was selected from the replacement herd, which was stored in a file separate from the milking herd. Replacements were selected on their age and pedigree index value. However, if the number of replacements was greater than 75% of the number of cows, then replacements of breeding age could be sold.

The simulation accounted for many of the biological characteristics and relationships between biological systems of the cow throughout its life. Executing the model for 30 simulated years performed validation of the simulation. The first 5yr were used to obtain stabilization, with 25 yr of data collected for statistical analyses. Most measures calculated from the simulation compared well with the data from the Northeast dairy herd surveys. The largest discrepancy was for milk yield, where the simulation was significantly higher. As well, feed cost and net cash income were higher in the simulation. Higher reproductive culling was attributed to the culling policy that required more than 4 services or greater than 180 d open to be classified as a reproduction cull.

Simulation by Foster

In 1988, Foster (14) evaluated the effect of several management practices on timeliness of herd profit. Magnitude of change in profit as a result of change in management was recorded at specific intervals of time. He developed a simulation to evaluate effects of all combinations of two levels of involuntary culling, heifer rearing, and sire selection against dystocia in heifers on timing and magnitude of net income from dairy cows. The simulation operated on a microcomputer for future flexibility and distribution. Variables measured profit on a cow and herd basis, which required separate evaluations. Net income was accumulated monthly, and expressed per day of life and per day to 96 mo of life. Twenty herds of 80 cows were simulated for 20 yr with 8 scenarios. More than 1000 cows with complete individual lactation records were simulated for each scenario, with no voluntary culling.

The mean time from birth to payoff for an individual cow was 60 mo, ranging from 55 to 70 mo, depending on age at calving. Mean net income for cows surviving 96 mo was \$0.36/d per cow, including salvage value. Milk yield per cow averaged 6838 ± 858 kg/yr and net income per cow was \$671 ± \$193/yr (14). Differences in response variables due to sire dystocia were minimal. Earliest time to payoff (54 mo) and highest net income (\$.485/d) was with 26 mo age at first calving, 11% involuntary culling, and random mating. Differences did not exist in time to payoff between levels of involuntary culling and for selection against dystocia. Heifer rearing was most important in this study due to large differences in time to pay off and net income as age at first calving changed. Sire selection against dystocia in heifers was least important because of the mating program used.

Simulation by O'Conner and Oltenacu

The decision to dry off a cow impacts the current and subsequent lactation. The objective of O'Conner and Oltenacu (26) was to determine the optimum drying off policies for cows with various characteristics. They developed a mathematical model of drying off decisions, which included all major factors affecting the outcome. Optimum time of drying off was subsequently determined using computer simulation techniques. The decision model contained factors affecting milk yield in the current lactation, parity, month of freshening as determined by the time of conception in the current lactation, and length of the dry period at the onset of the lactation.

Length of the dry period at the onset of lactation has a significant effect on milk yield. Adjustment factors were considered and were used in the main analysis, along side sensitivity of the optimal decision with respect to the other adjustment factors also investigated (26). Calculation of feed cost included a total mixed ration based on a 50-50 corn silage-hay crop silage forage mix on a dry matter basis, with the rations balanced using corn grain, 48% soybean meal, and a vitamin mineral premix. Cows were fed using three feeding groups for milking cows and one group for dry cows. Total net return from milk over feed and labor costs was determined over the number of days in the time frame appropriated for the decision.

The opportunity loss concept was used in the study to compare the optimum time of drying off against the drying off practice and against a policy similar to that generally recommended by dairy extension specialists. Economic impacts from implementing an optimal dry off policy can be significant (Table 1). Opportunity losses are considerably higher for cows freshening in summer and fall. Sensitivity analysis showed that the dry off decision was not very sensitive to the days open adjustment factors used, but was sensitive to the days dry adjustment factors, pointing toward the need for more accurate estimates of the effect of length of dry period on yield in subsequent lactations (26).

Table 1: Opportunity losses in total net returns ($) for drying off practice in the field and recommended drying off policy (26).

		Prevailing drying off practice		Recommended drying off policy	
Month of calving	Days Open	Lact 1[1]	Lact>3	Lact 1	Lact>3
Jan	40	8.2[2]	2.4	7.1	6.2
	70	1.2	0.0	5.0	2.2
	100	1.2	0.0	3.8	0.4
	130	11.4	0.1	3.7	1.1
	160	15.5	1.0	0.7	0.7
	190	23.5	1.0	0.1	0.2
Apr	40	9.9	3.2	5.7	5.1
	70	1.7	0.0	3.7	1.4
	100	0.5	0.2	2.4	1.5
	130	8.3	0.6	2.2	1.4
	160	9.5	2.1	0.0	1.1
	190	13.3	0.2	0.2	0.0
Jul	40	8.4	2.5	11.3	11.5
	70	1.0	0.5	10.4	7.3
	100	3.5	5.2	10.7	3.2
	130	25.0	8.0	13.2	0.3
	160	44.7	6.7	10.2	2.1
	190	74.3	20.1	9.5	1.4
Oct	40	11.7	3.4	8.9	11.6
	70	2.1	0.2	7.8	8.1
	100	1.8	5.9	7.3	3.7
	130	18.9	10.3	8.8	0.5
	160	34.2	9.7	5.2	2.0
	190	58.2	26.2	3.9	1.3

1 = Lactation
2 = Units ($)

With the accuracy and flexibility of computer simulations, O'Conner and Oltenacu concluded the optimum time of drying off is similar for first lactation and for older cows with 70 or fewer days open. For more than 70 d open, older cows need to be dried off earlier in lactation, resulting in longer dry periods than first lactation cows.

Milk Production

As milk production is the foundation of the dairy operation, estimating effects of change on lactation has become increasingly important. Pecsok et al. (29) determined the relationship between the genetic and environmental effects on herd production. A total of 3967 Holsteins on Minnesota dairies was sampled. Environmental factors included nutrition, reproduction, and lactation health. Nutritional variables included grain, forage, and dry matter intake (DMI). Nutrition was a significant component of the environmental effect. The study concluded that an improved management practice could alter a herd characteristic (days open). The direct result of the transformed herd characteristic could be a change in average herd milk production (prediction) as well as the rate of change in herd size greatly affected management practices and income.

Aishett (1) reported among 305 d lactations there was a strong correlation between lactation yield and lactation length. Increases in 305 d yields were associated biologically with longer lactation. The biological association between lactation yield and length is strengthened further by management practices of culling and selection. Low yields typically were associated with lactations where daily yield became low shortly after calving. Typically, first lactation yield has determined the cow’s longevity in the herd.

Gill and Allaire (18) used age at calving, milk production, fat percent, number of days in milk, number of breeding services, and body weight, to detect increased milk yields in first lactation associated with physical or physiological characteristics. Both long and short dry periods have been associated with loss of production. Optimal length of dry period, to maximize returns depended on the variables stated above.

A simulation conducted by Van Arendonk (37) determined relative herd life, total lifetime profit, total lifetime profit adjusted for opportunity costs, and profit per day of herd life. Relative value of herdlife was overestimated by 260% when opportunity costs of postponed replacements were not considered. In the model, involuntary culling, conception, and lactation production were treated as stochastic variables. State variables of the cow were lactation number, stage of lactation, time of conception, and milk production, present and previous lactation. For total lifetime profit, the value of one additional day of herdlife was equal to an additional 14.5 kg milk production in first lactation. When variation in production among cows was taken into account, the economic weight was 50% higher than in a situation without variation in production. Cash value of a dairy cow was determined by the animal's projected net income over remaining herdlife plus her salvage value. Lactation producing ability and milk prices had the largest effect on cash value. Significant interactions between the characteristics of the animal and its economic environment influenced cash value as well, such as mastitis, voluntary culling, and lifetime production. Foster (14) reported an increase in milk production usually resulted in an increase in net income through improved efficiency of production. Differing levels of dry off should have an effect on income and expenses.

Lactation Curves

One of the most common lactation curve equations has been a gamma curve. A regression of ln(Y) on an additive function of t gives estimates of a, b, and c. Wood (1969) used this model to fit curves to 859 British Friesian cow lactations (15)

$Y_t = at^b e^{-ct}$

Where:

Y_t = Daily milk yield in month t

t = Month in lactation

e = Base of natural logarithm

t_m = Month of maximum production

t_f = Final month of production

r = Monthly rate (%) of decline in production, (negative)

$c = (r/100)(t_f+t_m)/(t_f-t_m)$

$b = ct_m$

M_m = Maximum daily yield

$a = M_m(ce/b)^b$

A summary of Wood's lactation equation by Pesock (28) states that this lactation curve takes the exponential form $Y_t=at^be^{-ct}$, where Y_t is the average daily yield in the t^{th} day from the start of the lactation, and e is the base of the natural logarithm. Parameters a, b, and c are to be estimated from a graph of the cow's daily milk production. This would show the curve increasing until 45 to 60 d into lactation and then slowly leveling off and declining linearly. The first coefficient, a, will not change the shape of the curve, but will increase the total production of the cow. The second coefficient, b, is an index of the cow's capacity to utilize energy for milk production, and c is the rate of decline in production over time. The ratio of b to c explains the day of peak lactation.

Many of the factors that affect the lactation curve of a cow were factors that DHI accounts for in extending test day averages to a standardized 305 d lactation period. It is not efficient to measure daily milk production, thus the lactation curve, based on sampling points, has provided a useful estimate of total production of the lactating animal.

Lactation curves describe persistency by linear regression of milk production on time, after peak yield. Schneeberger (34) estimated lactation curves for milk and fat yield for 159,541 Brown Swiss cows. The increase of the curve at the beginning and the decrease after the peak, measured by equation b and c, had more of an effect in shifting the curve as lactation number increased. Lactation curves of cows calving in the winter had a more marked increase of production at the beginning and a steeper decrease after the peak, than those of the summer season cows (34). Data obtained on 137 completed lactations from Holstein dairy herds in Canada, showed significant differences in lactation curves with varying ages of cows and other factors such as genetic potential, production of milk, and body tissue (34). The objective of Freeze and Richards (16) was to add breeding and feeding variables to the incomplete gamma model and establish lactation curve parameters for milk production, fat percent, protein percent, and body weight change by a simultaneous, rather than simple equation technique. The results indicated climatic factors affect milk production both by increasing milk production at peak and the time in which peak lactation occurs. Milk production attained maximum when cows reached 6.5 yr. Body weight was positively correlated with milk production.

Profitability, accumulated over all cows in a herd, is imperative for the survival of the dairy enterprise. The application of the lactation curve can have an impact on optimizing profits. Ferris et al. (13) observed individual lactation curves for 5927 first lactation Holsteins in 557 herds from Michigan DHI. Data were restricted to monthly records in first lactation, adjusted 305 d yield, and lactation curve characteristics for age of freshening by a regression approach. The greatest gain for milk besides selecting for milk directly was selecting for peak yield. Selecting for a delay of time to peak resulted in much lower gain of 305 d milk yield (13). Guidelines based from lactation curves can evaluate production, so decision making can become more accurate.

Mathematical formulas that describe the shape of the lactation curve are to predict future lactation yield from lactations in progress and to estimate the effect of days open on yield of milk and fat. DeBoer et al (8) determined cows in first parity reach peak yield later than cows in second parity, time of peak yield for each phase was later for first parity than for second. According to Rogers et al., (31) cows with longer calving intervals yield more milk of higher fat content. Younger cows are more persistent, so the increase in milk yield and fat percent with increased current calving intervals are longer for younger cows than older cows. An increase in milk yield resulted in a slightly higher optimum culling rate. This implies that selection for higher milk yield will not and should not lead to longer average productive life, unless other factors such as maturity rate are changed. Included in Faust's (12) economic decision making are goals for calving intervals that consider total milk production during the current and subsequent lactations, and the shape of the lactation curve. Typically, shape of the lactation curve dictates "timing" of milk production. Bovine Somatotrophin (bST) supplementation (17) has the potential for altering the lactation curve and the delayed pregnancy effect on persistency of milk yield. From the data the increased persistency of milk yield observed in bST-treated cows may allow pregnant animals to be milked longer and open cows to be retained in the herd longer before culling.

Days Open

Knowledge of the relationship between milk yield and days open is important for effective control of the dairy operation. Both Oltenacu et al. (27) and Ripley et al. (30) reported evidence that days open should be considered in the evaluation of dairy production records. Oltenacu et al. (27) estimated relationships between days open and cumulative milk yield at several intervals from parturition for several lactation numbers, season of freshening, and production from Holsteins in New York. The correlation between days open and cumulative milk yield is nonlinear and nonsymmetrical for the production of cows open over 100 d. The trend for the open period for each cumulative yield was summarized as a quadratic equation. The relationship for first lactation with days open is essentially linear for cumulative milk yield.

Gill and Allaire (18) studied 933 Holstein cows to determine the relationship of profit function and performance traits to determine levels at which specific management variables maximized economic returns. The statistical approach was to quantify the relationship of lifetime production traits with age at first calving, days open, days dry, and herd life by polynomial regression curves. From this research, profit per day of life was associated more closely with herdlife than was milk per day of life with herdlife. Profit per day of herdlife was maximum for cows first calving at 25 mo of age with 124 d open and 42 d dry . Marti and Funk (24) studied five production variables and days open with 611,680 records from 348,243 cows in 5694 herds in Wisconsin on the DHI program. The purpose was to estimate variance components for production records and adjust for days open at several levels of herd production. They found days open decreased from 148 d for herds with a mean production of 5910 kg/cow, to 125 d for herds with a mean production of 10,455 kg/cow. However, this increased to 129 d for herds with a mean greater than 10,455 kg/cow. The relationship between production and days open is not consistent at different levels of herd production. An unpublished study by Galton, using bST (17), found that bST needs to be used on a continuous basis throughout lactation to maximize the bST milk production response and extend the calving interval. The use of bST early in lactation was essential to improve the persistency throughout lactation to realize maximum profit. Cattle with longer calving intervals may have better overall health and longer herd life.

Culling

Culling is the act of removing cows from the herd, usually cows of low profit. Realistically, relative cull rates increase with each lactation (7). According to Van Horn and Wilcox (38), a low profit cow is determined by the nonproductive dry period, and the following 305 d lactation. Cows are considered low profit when their next lactation test day production is below a value that is 60% of the herd's average. Other factors such as mastitis, reproductive inefficiency, udder conformation, feet and leg conformation, and lack of facility space influence culling decisions. Most herds have cows that are not returning a profit. When a cow ceases to produce a profit, a decision must be made. This cow can be turned dry, hoping to make a future profit, or can be removed from the herd. Either economic or health reasons, Culling removes some animals from the herd, meaning the remaining animals must offset expenses of all cows before a profit can be realized (14).

Culling rate is a measure of cows removed relative to herd size. For each cow that leaves, a reason should be recorded. Both the number of cows and the percent culled over the past twelve months should be kept up to date. Percent of herd is calculated using the number culled as the numerator and the average herd inventory as the denominator. Although time of culling usually occurs later than the actual problem or failure that prompted the culling decision, the culling percentage should only include cows that left the herd in the past calendar year (38). The 1998 Virginia culling rate was 35%. Within the usual 45 cows (35%) that were culled, 9% were culled for dairy reasons, 13% for low production reasons, 17% for reproduction, 22% for disease or injury, 16% for death, 16% for mastitis or udder problems, and 7% for feet and leg problems (39). All of these factors have some influence on the profitability of the herd. The application of traditional index techniques does not consider consequences of those culling decisions on the herd cash flow. Congleton and King (5) stated that long-term economic consequences of keeping the cow depended on having animals that could potentially replace her in the herd, and the income streams that might be generated by those replacement animals.

Congleton et al. (4) reviewed Maximum Average Monthly Return Index (MaxAMR), developed at Wisconsin. It was used to project income and costs of individual cows from milk, feed, value of calf, cow appreciation, and interest on beef value of the cow over the rest of current lactation and ten months into the next lactation. Congleton et al., in a simulation, added a long-range profit projection to the shorter MaxAMR to attain a two-stage culling criterion for individual cows. The long-term cash flow peaked in lactations two through five, then declined. Their simulation achieved more profit by removing cows in mid-lactation, rather than waiting to late lactation, as commonly practiced in commercial herds.

Rogers et al. (32) designed a dynamic programming model to consider replacement heifer costs, variation in yield, involuntary culling probabilities and costs, genetic improvement, conception probabilities, insemination costs, and interest. Optimum culling decisions were sensitive to changes in replacement heifer prices. The average mature equivalent milk yield, milk price, a feed price had small effect on culling. The situation resulting from optimum decisions was used to evaluate the consequences of the optimum replacement and insemination decisions. Cow productive life and culling strategies had major effects on overall net income. As an example, increasing productive life of the average cow from 2.8 to 3.3 lactations increased profits. The annuity for rearing a replacement heifer over the entire planning horizon was $443. Rates of voluntary and involuntary culling were 8.6 and 16.5%. Voluntary replacements represented 35% of all replacements in the first lactation, and average time for voluntary culling of all cows was 263 d in lactation. Older cows were voluntarily culled later in lactation than younger cows because of their higher production. A decline in the feed price of 20% resulted in more voluntary culling of the younger cows, which resulted in a slight increase of 0.7% in the overall rate of culling. According to Ducrocq et al. (10), culling rate was higher in first lactation cows.

Culling often necessitates associated costs for replacement heifers that account for approximately 20% of the dairy budget. Lehenbaur and Oltjen (22) suggested a paradigm shift from viewing culling management as a retrospective analysis of voluntary and involuntary removal categories to considering culling as an economic decision. To make the culling decision successful, the manager needs to examine the important economic elements of the decision, review progress in the development of the culling decision support system, and discern some of the potentially rewarding areas for future research of culling models.

On commercial dairy operations, factors such as beef price, milk yield, and milk price influence the culling rate. With large dairy operations as in the west, predominately Arizona, California and New Mexico, optimal profitability and efficiency are frequently sought. Several dynamic programming models have been used to determine optimal culling policies. Dynamic programming is a mathematical technique that divides a multistage problem into a series of independently solvable single-stage problems. In a study conducted by Stewart et al. (36), using a dynamic programming model, the objective was to define the culling rate in terms of milk sales, beef sales, feed costs, cow depreciation costs, replacement costs, and salvage value over a ten-year planning horizon. From this study it was found that out of the 2695 decisions 2570 of them did not change regardless of the milk price, beef price, feed price, or interest rate (36). The number of decisions influenced by changes decreased for second and third lactation cows.

Dentine et al. (9) studied reasons for disposal of cows in grade and registered Holstein herds. In grade herds 22% of cows were culled voluntarily, whereas 18% were culled involuntarily. Culls for reproduction represented 3.8% of the herd; 2% died.

It must be recognized that a dairy cow is a business asset that is owned and operated for a profit. A cow at a particular age should be kept in the herd as long as her projected annual profit is larger than the expected average profit per year of herd life of a typical replacement cow. Cows would be expected to generate increasing annual income up to their fourth or fifth lactation, increasing the probability that she will remain in the herd (7).

Dry Period

The alternative to culling is to dry the cow and hope she will make a profit for the dairy operation in subsequent lactations. In reality, each calving is a health risk. The lactating cows need to provide enough income for themselves as well as the dry cows. These concerns about length of lactation and dry period plus many more need to be addressed to maintain an optimal dairy operation.

During the dry period the cow is not generating income, so the shorter the dry period the quicker the cow returns to lactation. One goal of a dry period is to attain an economic balance between the gains in production and profit from extending the current lactation with any losses in production and profit in the following lactation as a result of fewer days dry. It has become more common to stop the cow's lactation when her daily production declines to 8 to 13 kg of milk. Data suggest reducing milk production to less than 11.4 kg per day before drying off because there is a smaller chance of udder-related complications during her dry period, and the cow is potentially producing at or above a breakeven milk weight (7).

O'Connor and Oltenacu (26) determined optimum dry period for first lactation in summer and fall to be 47 to 49 d for cows open between 40 and 160 d, and 50 to 53 d dry for cows open more than 160 d. For winter and spring, the optimal dry off period was 50 to 53 d when open between 40 and 130 d, and 53 to 63 d when open more than 130 d. These periods were determined by a binary search, which was performed to identify the day of dry off associated with the highest net return per year. Using decision analysis and computer simulations, they considered the effect of parity, month of freshening, length of dry period prior to lactation, and the length of the open period during the current lactation. Within lactations, older cows tended to have longer previous dry periods than did younger cows.

Schaeffer and Henderson (33) obtained DHI records from New York to study the effects of days dry and days open on Holstein milk production. In their study, dry periods of 50 to 59 d gave the highest average production in the following lactation. Days dry of 40 to 49 and 60 to 69 d were not greatly different on a practical basis. Age and month of calving also contributed a small amount of variation to days dry. The effect of the dry period on production depended partially on the body condition of the cow at the beginning of the dry period and on the feeding practice during the dry period.

Hillers et al. (21) found a reduction in optimal days dry as lactation number or age increased. Milk production during lactation decreased following a dry period greater than 59 d relative to milk production by other cows with a 50 to 59 day dry period. Lower producing cows were dried off earlier before next calving than average producing cows. A study by Sorensen and Enevoldsen (35) indicated a loss in milk production when dry period length decreased to 4 wk for 366 Danish Black and White and Red Danish cows. Increasing length of dry period increased milk production in subsequent lactations. In a study conducted by Coppock et al. (6), cows with dry periods from 30 to 50 d produced as much as cows with 50 d dry or more. In that study, 65 New York DHI herds were sampled to evaluate the effects of length of the dry period on disorders at calving and subsequent milk production. There was a slight trend of decreased ketosis with a shorter dry period and the dry period length had no effect on the number of retained placenta. There was no relationship between length of the preceding dry period and days open in succeeding lactation. However, dairy managers in the study were reluctant to impose short dry periods a second time.

Health Disorders

Mastitis is a costly disease for the dairy industry. Enevoldsen and Sorensen (11) found that mastitis treatments were more frequent after dry periods of 4 wk versus 7 wk. The risk of mastitis was highest for those cows with the lowest yield prior to their dry period. Complications around and after dry off occurred least frequently with a dry period of 7 wk. No clear effect of dry period length was found on clinical disorders or on the occurrence of mastitis around and after dry off.

Another factor related to profitability in cattle is dystocia or calving difficulty. As a consequence of dystocia, cows generally have higher reproductive health costs, more reproduction problems, produce less milk, take more time to return to normal cycling activity, and exhibit lower conception rates and sterility. Grohn et al. (20) focused on the effect of several disorders (milk fever, retained placenta, displaced abomasum, ketosis, metritis, ovarian cysts, and mastitis) on culling. Health disorders may have different effects on culling depending on when they occur and when the effect on culling is observed (Table 2). The study consisted of 7523 Holstein cows from 14 herds in New York. The models consisted of 2 parts: a baseline hazard function that was common to all observations, and a vector of covariates for each individual observation. Cows with milk fever or displaced abomasum were more than twice as likely to be culled than were healthy cows. Cows with retained placenta were culled in later lactation more than were cows without retained placenta. Ketotic cows were more likely to be culled throughout lactation than were non-ketotic cows. The effect of ovarian cysts on culling depended on conception status.

Table 2. Lactational incidence risks, disease-specific risk of culling, and day by which 25% of the cows had been culled for each disease in 7523 Holstein dairy cows.

	Incidence risk by lactation						
Disease	All	1	2	3	4	5	>6
				(%)			
Milk fever	0.9	0.1	0.4	0.7	3.1	4.0	6.1
Retained placenta	9.5	6.8	9.3	12.3	13.3	8.8	18.0
Displaced abomasum	5.3	5.5	4.6	6.4	6.0	4.3	3.1
Ketosis	5.0	4.2	3.9	6.0	8.3	6.1	7.7
Metritis	4.2	5.9	3.4	2.6	3.5	2.1	3.1
Ovarian cysts	10.6	11.2	11.5	9.1	10.3	7.3	8.0
Mastitis	14.5	11.5	13.8	16.7	20.1	20.1	19.9
No treatment	61.7	64.5	63.3	59.4	53.8	61.4	51.0

Conclusion

Dairy managers must be flexible and creative in new situations and new markets as the farm business is subjected to a continuous stream of changing circumstances. There are a number of cost concepts that are important when making decisions with economic consequences. Opportunity cost is fundamental to economic decision making. Managers should consider the profit maximizing time to cull and replace cows if the facility is full. Economic returns for management decisions differ. When dairy producers and managers understand the elements that influence economics for cattle performance, they can make more decisions that are informal about adopting technologies and management practices that benefit their dairy operations. Faust (12) found it necessary to study combinations of lactations to devise management strategies for groups of cows and make the best use of farm resources such as time, labor, and finances.

Materials and Methods

A "typical" herd of cows was modeled by computer to simulate weekly milk production and estimate the economic impact of drying off cows early to increase the freshness of the milking string. Net income was estimated for various kilograms of milk required to retain a cow in the milking string under two rates of decline in lactation.

The simulation modeled four milk kilograms of dry off, 8, 13, 18, and 23 kg/d, and two rates of decline, 6 and 8%. The size of the milking herd was kept constant at 98 to 102 cows, although the number of cows dry could vary. In the simulation cows replicated normal lactation events of calving, milk production, and dry period while being subjected to the possibility of being culled or dried earlier than scheduled for a normal dry period. When the milking herd dropped below 98 cows, heifer replacements were purchased and entered the milking herd. They too followed a normal lactation schedule.

Simulation

Dynamic simulation transforms estimates of rates of process and probability of events into computer language that can describe or simulate changes in a system. Events that change characteristics of a cow are lactation number, weeks open, weeks of lactation, weeks dry, and culling, both involuntary and voluntary. The computer code describes events (freshening, lactation length, drying off, culling, and replacements joining the herd) in a continuous process synchronized with milk production that is in a separate component of the model.

Simulation Software

The simulation was developed using a spreadsheet (Microsoft Excel version 7.0, Microsoft Corp.) on a microcomputer. Excel was chosen to take advantage of its row-column data storage, macro language, functions, and number parameters, as well as to enable future changes by a user familiar with spreadsheets. Although the formulas in the spreadsheet and the macros are complex, a user able to read Visual Basic should be able to alter and successfully run the simulation. An advantage of using Excel was that it will run on modern Windows-compatible and Apple computers. The simulation contained several worksheets, each of which contained its own set of formulas that were linked to the main worksheet. Weekly management decisions were implemented with a set of macros. The amount of time it takes to generate a herd and simulate four years varies depending on computer capacity (RAM) and speed. Figure 1 is a diagram of the dairy herd simulation and its components.

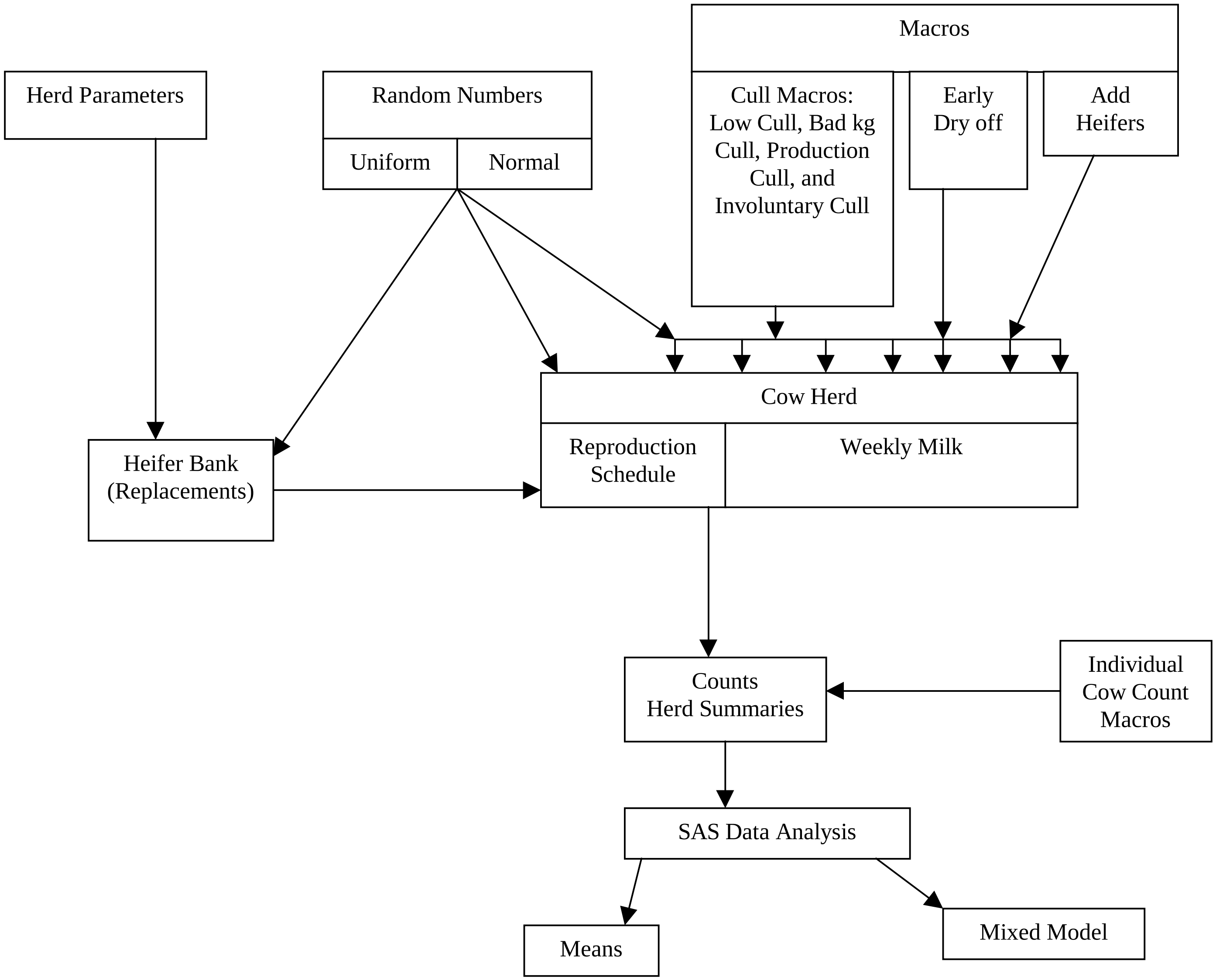

Figure 1. Dairy Herd Simulation.

Verification

Verification that each individual equation performed properly was done by setting random variation to zero and observing accuracy of the results. Equations that included random variation were also hand-calculated for verification.

Generating Random Variation

For the research to be representative of real life, random variation was included for each cow in each herd. For any distribution, random numbers can be generated in a spreadsheet by two procedures, individual functions that recalculate continuously, or a random number generator that creates fixed arrays of random numbers. However, when the simulation "runs," each cow needs several random numbers, so it is efficient to generate an entire set of numbers that does not change at every recalculation. Distributions used most frequently in this simulation are normal and uniform random numbers. Uniform numbers are drawn with equal probability from all values in the specified range, usually from 0 to 1. Random normal numbers are drawn from a normal distribution, the numbers ranging from -6 to +6 standard deviations with a mean of 0. Characteristics of uniform and normal random numbers are in Table 3.

Table 3. Characteristic of uniform and normal random numbers in Excel.

	Type of Distribution	
Characteristic	Uniform	Normal
Cell Function	=rand()	=norminv(rand())
Generation Tool	random number, uniform	random number, normal
Mean	0.5	0
Variance	1/12	1

Characteristics of the simulated cows in the herd were specified by parameters on the parameter sheet. Not only did macros generate the initial herd as well as the replacement heifers, they were designed to make management decisions. Macros will be discussed later in further detail. Parameters are defined in Figure 2.

Figure 2. Parameters of the simulation for generating the basic 8 kg dry-off herd.

Parameter	Base Value	Explanation
% First Calf Heifers	33	Arbitrary number
# Cows in Herd	115	The integer of the number of milk cows (100) divided by (1-fraction of dry cows). Varies by dry kg scenario.
% Cows Dry	13	Percent of cows in the dry herd, depending on simulation run.
# Cows in Milk	100	Arbitrarily selected
# Heifers	345	Used for random number generation, 3 times the herd size. This is a bank of heifers from which purchases will be made.
Peak Milk Yield First Lactation Second Lactation Third Lactation	 32 ± 5.0 39 ± 6.2 41 ± 7.0	Derived from DHI and standard deviations from a previous field study (kg). The peaks will vary by percent decline of lactation. Reference (25,41)
% Rate weekly decline First Lactation Second Lactation Third Lactation	 0.96 ± 0.97 1.90 ± 1.22 2.06 ± 1.21	Monthly rate from field study turned into a weekly %. Corresponds to monthly rates of 3.9, 7.8, and 8.5%. (25)
Wk of Maximum Yield	6	Number of weeks to peak milk yield (2)
Root Milk MSE (kg/d) First Lactation Second Lactation Third Lactation	 2.58 3.55 4.01	Random variation of weekly milk yield for a cow, from Nebraska nutrition data. (19)
Repeatability of milk	0.5	Correlation between consecutive peak yields of the same cow; set equal to lactation repeatability
First possible service	50d	Minimum voluntary waiting period is 50d, from average VWP–SD, (60-10).
Heat Cycle length (d)	21 ± 1.2	Length of heat cycle. (2)
Gestation Length (d)	280 ± 6	Length of gestation. (14)
% Reproduction Culls	10	From DHI. (39)
Probability of a Male Calf	0.52	Probability of a male calf
Involuntary culls (death) at calving (%)	4.0	Percent of involuntary culls (including death) at calving. (39)
Relative chance of Involuntary Cull at 3+ Lactation	2.5	Older cows (3+ lactations) are 2.5 times more likely than younger cows to be culled. (39)
Death at calving (%)	3.7	From DHI. (39)
[Involuntary-death at calving-ReproCulls] (%)	12	Annual percent of involuntary culls, not from reproduction or death at calving. (39)

Involuntary Culling % Weekly First Lactation Second Lactation Third Lactation	 0.002 0.002 0.005	Weekly percent chance of involuntary cull, not reproduction or death at calving (%). Derived from the annual culling percentage. (39)
Total Involuntary Culls (%)	26	DHI average. (39)
Low kg dry (kg/d)	8	If a pregnant cow drops below this milk kg for two consecutive weeks, she will be forced dry. Varies with scenario, 8, 13, 18, and 23 kg runs.
Low Bad Milk (kg/d)	10	If no open cow is available to cull then it looks at the pregnant cows and selects one below 10 kg/d regardless of due date.
Weeks in milk for cull	21	Earliest week of lactation a cow can be culled for low production.
Peak milk random number for voluntary culls	0.0	If the cow is open, greater than 21 wks in milk, and has a permanent peak milk below average (dev<0.0), then she is eligible to be culled when needed.
Lactation Distribution for initial herd (%) First Lactation Second Lactation Third Lactation	 33 22 45	Percentage of cows in each lactation in initial herd. (39)
Days Dry (d)	56 ± 5	Established from DHI records and rounded to the next week. (39)

Reproduction

Simulated cows were moved weekly through time based on reproductive events of calving, heats, breedings, pregnancy, and dry-off. Reproduction schedules were estimated on a lactation basis. Through several macros, the computer generated the appropriate weeks for each event for cows in the initial herd. Assuming variables are normally distributed the mean plus a standard deviation (SD) times a N (0,1) random deviate, creates variation. The reproductive status of each cow each week was determined by voluntary waiting period (VWP), number of heats until bred, and pregnancy rate (PR), including random variation about the mean for each of these. The average Virginia DHI herd had a VWP of 60d. The simulation incorporated an average of 50 d plus a SD (0,1) to determine days to first possible service. Days to first service (60 d) were slightly longer than VWP (50 d). A typical reproductive timeline would look like this: (H = Heat)

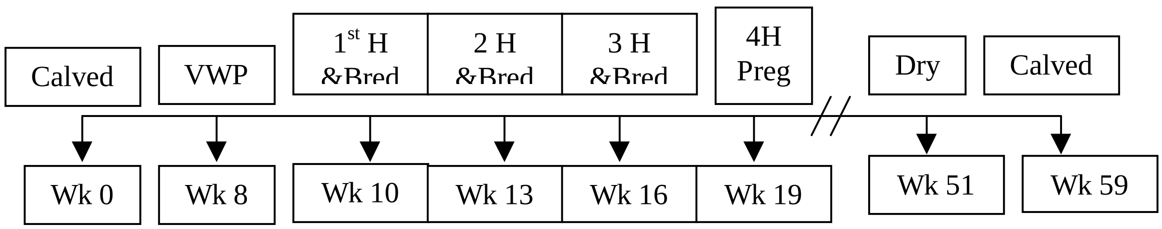

Figure 3. Reproduction cycle and weeks open.

Number of heats to pregnancy also determined the reproductive cycle and weeks open (Fig. 3). Cows were bred for up to nine potential estrus cycles. Therefore, for the simulation, each cow was assigned to one of nine reproduction sequences. This saved time because the only important event was the week of pregnancy. A consecutive heat probability was derived from one minus the cumulative pregnancy rate. The cumulative probability of pregnancy was based only on the cows that eventually became pregnant. It excluded the fraction of cows (22%) that would have been culled as open cows after nine heat periods if nothing else detrimental happened to them.

The reproductive cycle for each cow consisted of days to first breeding added to days between pregnancy and first breeding. These days were from Table 3 for each estrus cycle up to nine. Twelve percent of the cows would become pregnant at the first estrus after VWP. They represented 14% of the fertile cows (12/78). For an individual cow, days to first breeding were generated. That was added to her number of days open after first breeding by randomly locating her number of estrus periods in Table 3 and reading the number of days plus a [standard deviation times a N(0, 1) random deviate]. If the uniform random number was 0.75, then it selected five estrus periods for the cow. If the N(0,1) was 1.5 and the days to first breeding were 95, then days open would be [95 + 84 + (2.45)*(1.5) = 183 d]. The 22% of the cows that never became pregnant were culled after nine potential estrus periods [(days to first estrus) + (147 ± 3.24) d], or culled at 237 d on average.

Table 4. Probability of n heats and days between heats for cows that become pregnant.

Cumulative Probability of n Estruses[1]	Estrus number n[2]	Days from VWP to Estrus n[3]	Std Dev Days[4]	Conception Probability[5]	Estrus Detection Probability[6]	Pregnancy Probability[7]
0.14	1	0	0	0.40	0.30	0.12
0.36	2	21	1.22	0.40	0.55	0.22
0.53	3	42	1.73	0.40	0.55	0.22
0.66	4	63	2.12	0.40	0.55	0.22
0.77	5	84	2.45	0.40	0.55	0.22
0.85	6	105	2.74	0.40	0.55	0.22
0.91	7	126	3.00	0.40	0.55	0.22
0.96	8	147	3.24	0.40	0.55	0.22
1.00	9	168	3.46	0.40	0.55	0.22

[1]Cumulative probability of n heats determined the percent of cows that would be bred through the nth heat after the VWP. The formula was percent of cows pregnant by that heat divided by the total percent of cows pregnant at the end of 9 heats, or: $[1-(1-\text{Preg\_rate})^{n}]/[1-(1-\text{Preg\_rate})^{9}]$

[2]The number of potential heats of the cow, nine maximum.

[3]After each heat, 21 additional days have passed.

[4]Standard deviation for one cycle was 1.22 d (2). Therefore, standard deviation for n independent cycles would be : (1.22) Sqrt(n-1), where n = cycle number.

[5]Probability of conception when a cow was bred.

[6]Probability of estrus detection during one cycle period. From DHI records, probability of estrus detection was less for the first observed estrus (39).

[7]Pregnancy rate determined from typical Virginia DHI numbers was the product of heat detection and conception for each specific service number.

Lactation Cycle

Weeks to first possible breeding were the minimum mean VWP ± SD* N (0,1) random deviate. Minimum weeks to first breeding was minus one SD. Days to first possible breeding had a mean of 50 d with a SD of 10 d. Average weeks to first breeding was then 12.3 wk or 86 d. This is 26 d longer than average VWP due to imperfect estrus detection.

Trials

A two by four factorial was designed using rate of decline at 6% and 8% and early dry off at 8, 13, 18, and 23 kg/d (for two consecutive weeks). There were 100 cows in each herd and each combination (8 scenarios) was run 10 times (10 herds) for a total of 80 herds.

Each scenario required distinct changes on the parameter page, which impacted the herd. Milk yield peaks (kg) and rates of decline (kg) were different between 6% and 8%. Other changes, such as number of cows in the herd at wk 1, total cows, and cows in the dry herd after wk 1, were influenced by the dry kg scenario. Additional differences were percent of cows dry, maximum weeks dry for the initial herd, and what percent of the original 100 cows was required for wk 1 (Table 5).

Generating the Initial Herd

Management decisions vary from herd to herd and region to region. The simulation used average numbers unless otherwise stated. Generating the initial herd involved macros and copying of IF statements. All reproductive possibilities for individual cows were calculated on the parameter page (Table 4). After establishment of milking cows (100), rate of decline (8%) and kilograms for dry off (13 kg), the formulas on the parameter page determined initial numbers for wk 1 of the simulation. Number of milking cows in wk 1 was calculated from the percent dry and corresponding dry off kilograms. Extra milking cows were needed at the expense of dry cows in wk 1 due to force dries and low culls in wk 2 (e.g. 3% will be forced dry immediately at the 18 kg scenario). Percent of cows starting dry was set in the same manner. Target dry percent (Table 5) was obtained in wk 2 by reducing dry percent in wk1 while increasing milking cows in wk 1 (relative cows in milk, Table 5). Reproduction parameters as well as lactation parameters were then selected (Table 4) from the random numbers that were generated. Percent first calf heifers in the milking herd corresponded to the lactation distribution table on the parameter page. The macro first produced enough milking cows for wk 1 of the simulation and generated each cow's reproduction schedule and lactation variables. Next, it added the dry cows and their reproduction schedules and lactation variables.

Table 5. Differences in initial herd (wk 1 and 2) for dry kg scenarios.

Dry off Kg/d	Percent Dry	Maximum Weeks Dry	Relative Cows in Milk
8	13	10	1.00
13	17	14	1.03
18	24	18	1.10
23	33	24	1.20

Starting Week of Lactation:

The simulation started at no particular season of the year. Each cow had a different starting week of lactation at calendar wk 1. Because the cow’s lactation length was known, her week in lactation at calendar wk 1 was selected at random, with each week equally likely. Those cows that were initially dry had a different formula for start week of lactation. Maximum length of dry period for the initial herd was 10, 14, 18, and 24 wk depending on the kilograms at which the cows were to be dried off, 8,13, 18 or 23 kg. This minimized longer dry periods for scenarios where cows would be dried off early. Weeks dry at calendar wk 1 were generated at random for each dry cow. By inspection it was determined that 3, 10, and 20% of cows were dried off or culled in wk 2 for 13, 18, and 23 kg scenarios, so the initial herd was established with that percentage more cows in milk at the expense of dry cows. Then when low-producing cows were dried off in wk 2, the herd had 100 cows in milk and the appropriate number of dry cows for the scenario.

Lactation Number:

A table on the parameter sheet designated the probability of first, second, or third and greater lactation cows. Probability for a first lactation cow was 33%. The probability of a second lactation cow was 33% of 67%, or 22%. Third and greater lactations were the remainder of 100%.

To determine the cow's lactation number in the initial herd, a uniform random number was assigned to each cow. If the random number was less than 0.33, she was in lactation 1, larger than 0.55, she was in lactation 3, and otherwise in lactation 2.

Infertility:

The limit of unsuccessful breeding was nine potential estrus cycles. Table 2 describes days to first service, estrus detection, conception and the cycle length. The probability pregnancy on first service was 14% with a conception rate of 40% and an estrus detection of 30%. On the second estrus, the estrus detection rate increased to 55% with a conception of 40% and a cumulative probability of 36%. After each heat, 21 additional days passed. If the cow reached nine estruses, she would have been open for at least 168 days beyond first potential breeding.

Involuntary Culling:

Cows could be removed from the herd involuntarily for: death at calving (4%/lactation), infertility (10%/lactation), and health difficulties (12%/lactation) (39). Note that the total was 26% and that infertility was determined when the cow entered the herd, but not implemented until her nine potential heats expired. Percentage of health difficulties was then converted to a weekly basis. A cull equation determined the status of the cow. If a random uniform number was less than 0.10, the cow was culled for reproduction reasons, meaning the cow was not pregnant after nine estrus cycles. If a different random uniform number was less than 0.04, the cow died at calving. Otherwise, the cow was designated pregnant for that particular lactation. Percent involuntary culling also depended on the cow's current lactation, where cows with 3 or more lactations had a greater chance to be culled for health reasons (17.9% versus 7.2%). To have between 98-102 milking cows, death at calving was eliminated during the first week of the simulation. However, reproduction culling was still in effect.

Weeks Open:

If the cow died at calving, weeks open were zero. Otherwise, they were the days to first breeding plus the additional days to pregnancy, both with random variation. Additional days to pregnancy were from Table 2 using a uniform random deviate. This equation was then converted from days to weeks. Average weeks open was programmed to be 19.3 wk or 135 d.

Lactation Length:

If the cow had been culled for reproductive reasons, her lactation length was the duration of her weeks open (33 wk) as she automatically surpassed the maximum number of unsuccessful breedings. If she died at calving, she did not continue with the simulation. If pregnant, weeks open was added to weeks of gestation, both adding a random normal number multiplied by the respective SD. Because gestation length also included dry period, dry period mean plus a different random normal deviate multiplied by the dry period SD was subtracted from the calving interval to yield length of lactation. Gestation length was 280 d ± 6 d and dry period was 56 d ± 5 d (parameter page). Lactation length varied due to random deviates for reproduction and the two SD's from gestation and dry period.

Calving Interval:

Calving interval is the time between each calving. This formula depended on weeks open, lactation length, and the dry period. The calving interval was determined for each lactation at the start of the simulation. However, the simulation defined weeks cumulatively. The cumulative calving interval number minus the previous cumulative calving interval number defined the number of weeks between calvings. If the cow had been culled for infertility or died at calving, she did not calve again and was eliminated from the simulation; R or C represented these conditions.

The calving interval number from the parameter page was only a guideline or average. Each cow was slightly different. The specific calving interval for each cow provided randomization and later assisted in the milk yield calculation. Weeks open, weeks in lactation, and calving interval weeks were cumulative from lactation to lactation and provided a timeline for each cow.

Milk Production

Wood's equation was used to determine a cow's milk yield per day at weekly intervals. However, several preliminary parameters had to be established before the equation could be calculated. For the Wood's equation, an estimate of a cow's lactation peak production (at 6 wk) was needed. First lactation was 32 kg, second 39 kg and third or greater 41 kg (39). A SD for peak milk yield was 5.0, 6.2, 7.0 kg/d, respectively (25).

Rate of monthly decline after peak was estimated to average 7%, or 3.9, 7.8, and 8.5%/mo for lactation 1, 2, and greater (25). Using weekly compounding, these were converted to weekly percentages. The simulation used monthly decline of 6% and 8% in two scenarios as detailed in Table 6. To maintain the same lactation production for 6% and 8% monthly declines, peak milk was adjusted upward for 8% and downward for 6%.

Table 6. Rates of decline and peak milk for three lactations.

		Lactation		
Decline (%/mo)	Variable	1	2	3
6	Monthly (%)[1]	3.34	6.69	7.29
	Weekly (%)[2]	0.83	1.63	1.77
	Peak Milk (kg)[3]	31.3	37.5	39.4
7	Monthly (%)[1]	3.90	7.80	8.50
	Weekly (%)[2]	0.96	1.90	2.06
	Peak Milk (kg)[3]	32.0	39.0	41.0
8	Monthly (%)[1]	4.46	8.91	9.71
	Weekly (%)[2]	1.10	2.16	2.34
	Peak Milk (kg)[3]	32.7	40.5	42.6
All	Std. Dev. (mo,%)[4]	5.50	6.40	6.40
	Std. Dev (wk,%)[2]	0.97	1.22	1.21

[1](25).
[2]Calculated from monthly.
[3](39), adjusted within lactation to create identical lactation totals among different percent declines.
[4](25).

The milk yield equation encompassed several components.

Wood Equation: $Y_t = at^b e^{-ct}$

Where:

$Y_t =$ Daily milk yield at time t, weeks

t = Week in lactation

e = Base of natural logarithm

t_w = Week of maximum production

t_f = Final week of production

$b = ct_w$

$c = r/100[(t_f+t_w)/(t_f-t_w)]$

r = Weekly rate (%) of decline in production, after peak

$a = M_m(ce/b)^b$

M_m = Maximum daily yield

A separate worksheet contained Y, r, a, b, and c. Each of these components was generated by a formula with a random component added for each cow and each lactation. For simplicity this worksheet created weeks of milk yield with no consideration of culling.

M, Maximum Daily Yield:

If the cow was new to the simulation, even if it was lactation number 2, 3, or greater, the equation added the peak yield to the corresponding SD multiplied by a normal random number. If the cow previously had a lactation in the simulation, the second random number for peak yield was correlated with the first by the equation. $R_n = \rho * R_{(old)} + Sqrt(1-\rho^2) * R_{(new).}$ Where R was a N (0,1) random deviate and ρ was the correlation between peak yields in consecutive lactations (0.5). Therefore, the repeatability of peak yields in consecutive lactations was 0.5. This assured that high-producing cows tended to remain high producing in subsequent lactations. The last random deviate in the equation is related to root MSe.

r, Weekly Rate (%) of Decline in Production:

For first lactation cows, this was rate of weekly decline plus the SD of rate weekly decline multiplied by a random normal number unrelated to r.

% Weekly Decline:

Monthly decline was converted to weekly decline: $r_w = [(e^{\ln(1+r_m/100)}/4-1]*100$

SD % Weekly Decline:

This entailed a conversion similar to monthly to weekly decline. Parameters a, b, and c, have specific functions related to the lactation curve. The a is the parameter controlling production at the beginning of the lactation. The b controls the rise to peak production, and c controls the post-peak decline. The formulas must be calculated backwards, c, b, then a when incorporated in Wood's equation. Maximum daily yield, rate of decline and parameters a, b, and c, were generated for four lactations on each cow.

c, control of post peak decline:
Variation in c was provided by the randomness of r, that varied by lactation number and scenario.

b, rise to peak daily yield:
Variation in b came through c.

a, height of lactation curve:
Variation in a was provided through b, c, and M_w, where M_w's were correlated across lactations.

Visual Basic and Macros

The simulation operated through two different computer languages, Excel and Visual Basic (VB). Using Excel, IF statements were developed to generate each cow's starting week of lactation, cull status, weeks open, weeks of lactation, and weeks of calving interval for all four years. IF statements also generated the same conditions for the replacement heifers. Visual Basic generated the number of milking cows, number of dry cows, their reproduction and lactation parameters, culled any cows that met the constraints, and added replacement heifers when needed.

A macro is a visual basic program, recorded or written. Visual Basic is an object-oriented programming language, which means that it performs tasks by manipulating objects. An object can be almost anything in Excel, from a single cell or worksheet to the Excel application itself. Because VB is a Windows development language, some familiarity with the Windows environment is necessary.

Once a macro has been created, it can be executed later. Macros are typically written for tasks that are repetitively run. When a macro is recorded, the macro recorder stores Excel commands in the form of VB by writing the code. However, VB programming can also be written by a user to execute a series of commands to carryout specific tasks. The VB statements are edited the same way text is edited in a word processing program. As a programming language, VB code would often include IF statements to implement decisions and DO statements to implement loops. Procedures, therefore, can be repeated through cows and weeks of the herd.

The macros developed for this simulation worked off several worksheets, although the results were shown only on the cow and week worksheet, B. Cows were rows, were as weeks were columns. This worksheet contained every cow's reproductive schedule and milk yield by week, through four possible lactations.

Random numbers were generated first in the simulation (Fig.4). Each random number macro first cleared the previous numbers on the page and generated a new array according to the size desired, distribution, mean, and variance. The simulation could optionally retain the current random numbers, recreate an old set from a seed integer, or randomly generate a new seed and new numbers.

Figure 4. Macros to generate random numbers.

RandomMain	This macro ran all appropriate random macros. Before each random macro there was a command to clear the previous set of numbers.
RandomNormal	Generated a worksheet of random normal numbers, N (0,1). Rows of normal numbers corresponded to the number of initial milking cows in the herd.
Uniform	Several uniform (0,1) numbers were generated for every cow.
RandomInvol (Cows and Heifers)	These were random uniform numbers. One number was assigned to each cow each week and used in the involuntary cull.
LacRandom and HlacRandom (Cows and Heifers)	Normal random numbers, N (0,1), were generated for variation in milk yield parameters, peaks and slopes.
Zero, ZeroHLacR,ZeroLacR,ZeroUniform	These four macros zeroed the previous random number pages. These can be used as a verification tool to see if calculations are working properly.

A second set of macros (Fig. 5) created the initial herd. After random numbers had been generated, the seven macros ran automatically. Some of the macros used random numbers directly or from another worksheet that had used a random number.

Figure 5. Macros to create of the herd.

AddCows	Created a specific number of cows and their weeks open, lactation length and calving interval.
Dry_Cows	Changed the start week of lactation to a negative number to have the correct size of dry herd the first week of the simulation
MilkYield	This calculated weeks in milk for all cows in the initial herd for 208 weeks. It followed the reproductive schedule for each cow and generated daily milk yields for each week.
RCCull	Any cow that had been culled for reproduction or death at calving had been left with blank milk until this point. This macro replaced the blank cells either with an R for reproduction cull or with a C for death at calving. These cows were no longer in the herd at that point.
DryOff	Between lactations, each cow had a specific number of weeks dry. The macro identified the end of her lactation and the beginning of the next one, and placed the word “Dry” in those weeks.
HLacParameters	Established parameters for milk yield for the heifer. There were three times as many heifers as the size of the initial herd. Heifers were also numbered differently, beginning at 1001.
AddHeifers	Made a worksheet for heifers similar to the AddCows macro.

Management 2 macro (Fig.6) implemented weekly management decisions. It invoked the macros Involuntary Culls, Low Production, Early_Dry and Heifer Management before moving to the next week. Some macros passed through other macros, meaning they were called from a different macro to perform specific functions, but allowed the original macro to continue to run. Cull Low Cows and Early Dry called six other macros. However, the names of those six need not appear in the Management 2 macro because they were being passed through the two main macros.

Figure 6. Macros and sub macros to make management decision.

InvolCull	This macro looked at all the live cows in a specific week. Through a series of statements, the macro determined whether each cow's involuntary random number for that particular week and her lactation number was less than the probability of being culled involuntarily. If so, she was culled. An "I" indicated this decision.
LowCullCows	If the milking herd was larger than 102, the maximum number of cows in milk, and there were no pregnant cows that qualified to be dried off, and the cow was in milk that week, the macro called Cull_Status. If there were no open cows to cull, the Preg_Cull was called. After it called Cull_Status and Find_Min_Index, the cow with the lowest milk yield was designated with an "L" replacing the milk yield. Then Ext_Low_Cull was called to extend the "L" through her remaining weeks of lactation.

Cull_Status	This macro determined whether the cow had been open for 21 wk or longer and had a negative random number for her peak yield. It then stored the cow's lactation number and called Find_Min_Index
Preg_Cull	If herd size was too large and there were no open cows to cull, Preg_Cull was called. Under this macro, the cow had to be pregnant and have a negative random number for her peak yield. Like Cull_Status, the lactation number was established and Find_Min_index was called. All other procedures were the same from this point forward.
Find_Min_Index	Depending on the lactation number from Cull_Status , Find_Min_Milk stored the cow who had the minimum ratio of her peak milk yield divided by average peak yield of her current lactation number. The lowest index and associated cow were returned back to the low cull cows macro.
Ext_Low_Cull	This macro placed an "L" for a low production cull cow for the duration of her weeks in the simulation.
EarlyDry	If the milking herd was too large that week, this macro either forced a cow to be dry or culled her from the herd. This is different from LowCullCow because the LowCullCow macro has a series of constraints to meet before culling. The macro first selected an open cow that had a

	milk yield lower than the indicated low kg scenario for two consecutive weeks. If this was true a “Bcull” was indicated and the cow was culled due to bad production. The macro then selected pregnant cows that were more than 21 wk in milk and had a low milk yield like above, they were indicated by “Pcull” for poor production. If the simulation still had too many cows that week, the macro found pregnant cows with low milk yields and force - dried those cows. “Fdry” indicated that procedure.
Dry_Status	After a specific cow was selected to be force - dried, “Fdry” was placed in the weekly cells until it reached an “R”, “C”, “I” or “Dry” cell. It then ran the Heifer Management macro.

If heifers were needed to reach the minimum number of cows in milk (98), the Heifer Management series of macro was run (Fig.7). Once it was determined a heifer was needed that particular week, heifers were added to the milking herd worksheet by copying and pasting the information from the heifer bank worksheet, where all heifers had been stored. Once a heifer was added, it was processed through another series of macros before the next heifer was added.

Figure 7. Macros for heifer management.

HefMY	Once a heifer was added to the milking herd, her milk yield was calculated in the same manner as the cows. Random numbers and milk yield parameters specific to that heifer were used.
HRCCull	Same as RCCull for cows
HDOff	Same as Dry Off for cows

The sequence of macros was as follows: RandomMain generated normal, uniform, involuntary and heifer involuntary, lactation random, and heifer lactation random numbers. The next macro was Management. It created the appropriate number of milking cows with their four predetermined lactations. It automatically calculated each cow's milk yield for all lactations and then implemented RCCull and DryOff. After those were completed, the initial herd had been established. Heifer Lactation Parameters and Add Heifers ran next. This built the heifer bank for future use. Summary of herd creation:

- Create random numbers
- Create cows and reproduction parameters
- Create dry cows
- Generate all weekly milk yields
- Designate those cows that died at calving and were cull for reproduction
- Designate all dry periods with the word “Dry” in appropriate cells
- Create bank of heifers and their parameters

The next macro that automatically ran was Management 2. This again called several macros to perform these tasks. Cows were processed one week at a time through Involuntary Culls, Low Cull Cows, Early_Dry, and then finally HeiferManagement, that added heifers each week if needed. A heifer was added with its four lactations, followed by macros for Milk Yield, RCCull, and DryOff. Management 2 then went through the herd from week to week until it reached 208 wk. Summary of management decisions each week:

- Determined involuntary culls
- Determined, if necessary, low production cows

- Determined, if necessary, Bad milk (kg) cull, Production (kg) cull, and Force dry
- Created replacement heifers, as needed, on milk cow worksheet

To obtain accurate lengths of all complete lactations and dry periods, the simulation was divided into three calendar years. The first year began on simulation wk 20 and went for 52 wk, followed by the second and third years, ending on simulation week 176. This calendar versus simulation week difference enabled analysis of three complete lactations from the initial herd, regardless which week the cow initially started.

Data generation stopped at 208 wk, enough time for a cow in the initial herd to have three complete lactations. The numbers for all cows from each herd were placed in a separate worksheet where formulas obtained a variety of weekly and yearly averages and counts.

One last macro was designed to calculate a count of weeks in milk, weeks dried off early (Fdry), and weeks dry (Dry) for each revised calendar year (starting with simulation wk 20). If the cow started with a milk yield the first year, the count did not begin until a Fdry or Dry was detected. This ensured a complete lactation. The counts for lactation weeks, forced dry weeks, dry weeks, and total dry weeks were all recorded in the year the period ended. Furthermore, an average for weeks in milk was taken on the last week of each year.

Balancing the simulation

The simulation presented formidable problems of balance in two areas, culling and dry off. Most dairy herds reach equilibrium in cow numbers relative to culls, calvings, and dry – offs. Culls are often driven by raised heifers calving into the herd. Because this simulation “bought” springing heifers as needed and did not restrict number of dry cows, there was not the normal pressure to cull cows. Culls depended on involuntary reasons and very poor production. Trying to maintain 100 cows in milk each week caused frequent purchase of heifers to fill a vacancy, only to have a dry cow calve the next week, forcing another cow to be dried of prematurely. Finally, with scenarios that dried off cows at higher milk yields, there was a disproportional number of cows in the herd initially that were below the dry off milk kg at the start. They were dried off immediately causing problems first, the need to purchase several heifers, and second, a glut of both dry cows and of heifers that were all due to cycle through their lactations in synchrony. Those led to surges of calvings, dry offs, and further purchases.

One solution to these problems was to allow 98 to 102 cows in milk at once to reduce frequent purchases, dry offs, and culls. Another was to increase the size of the milking herd in wk 1, at the expense of the dry herd, such that after the dry offs in week two, the milking and dry herd sizes would be as desired, without purchasing replacement heifers. Different percentages of dry cows were specified for each scenario (Table 5.). Moreover, the final solution was to start the research at the wk 20 of the simulation so some equilibrium could be reached.

Counts

After the simulation generated the herd data for 208 wk, the data were then transferred to a new workbook. That workbook counted and averaged specific variables on a weekly basis. Counts for reproduction culls, death at calving, low production culls, force dry culls and involuntary culls were all formulated by a COUNTIF statement. A COUNTIF statement counted the specific characteristic that week, which was cumulative. Therefore, the count from the previous week was subtracted from the current week to obtain a count of activities for that week only. The count of cows force dried was programmed by a macro. Because force dries came in and out of the herd, the macro prevented inaccurate negative numbers, force dries split between two calendar years, and cumulative counts. There was a row that calculated the total number of culls sold (all the culls minus death at calving) and one that calculated the culling percent per week. There was a total number of milk cows and dry cows each week and the number of heifers that entered the herd that week. All counts in the Count workbook were averaged on a yearly basis, 1 to 3, and maximum and minimum values were expressed for each year. Several other variables expressing income and expenses were also calculated on a yearly basis (Fig.8). Essentially, for each variable, nine averages or numbers were associated with it. All count variables were analyzed through SAS (23).

Figure 8. Count variables.

Variable	Explanation
Repro Culls (n)	The sum of all reproduction culls each year.
Death at Calving (n)	Sum of cows that died at calving
Force Dries (n)	Number of new force dries each year
Low Production Culls (n)	Number of cows culled due to low production
BadCulls (n)	Sum of open cows culled for low production
Pculls (n)	Number of early stage pregnant cows culled for low production
Involuntary Culls (n)	Sum of involuntary culls per year
Total Culls Sold (n)	Total culls, not including death at calving, sold each year
Total Culling (%)	100* (Death at calving + total culls sold)/(# milk cows + # dry cows)
Milk Cows (n)	Average number of milking cows per year. Between 98 and 102 cows.
Dry Cows (n)	Average number of dry cows
First Calf Heifers (n)	Average number of first calf heifers including replacement heifers.
Older Lactation Cows (n)	Average number of cows that are 2+ lactation
First Calf Heifers (%)	100* First calf heifers / (milking cows + dry cows)
Dry Cows (%)	100* # dry / (dry cows + milking cows)
Average Milk (kg)	Average milk produced each week.
Total Milk (100 kg)	Sum total of milk produced/100, for each year
First Lactation Calved (n)	Sum of all replacement heifers that calved per year.
Older Lactation Calved (n)	Sum of all other lactations calving per year
Calves Sold (n)	Sum of first lactation and 2+ lactation calved.
Lactation Days (n)	Average weeks in milk * 7 each year
Average DIM (n)	Average weeks in milk at end of year * 7

Average Fdry (wk)	Average Fdry weeks ending in each calendar year
Average Dry (wk)	Average normal dry weeks that ended in each year
Total Fdry and Dry (wk)	Average of actual dry period that ended each year.
Fdry (%)	100 * Count Fdry/Count Dry Percent of dry periods that started with a force dry.
Rolling Herd Average (kg)	365*Total milk for the year / (sum of (milk cows + dry cows) across all days)
Milk Income ($)	Total milk (kg) * Mail box milk price
Cull Income ($)	Total culls * Cull price
Calf Income ($)	A weighted calf value, adjusted for price of male calves * first and 2+ lactation calved
Feed Exp for Milking Cows ($)	Maintenance cost + cost of feed / kg of milk * average milk * milking cows * 365
Feed Exp for Dry Cows ($)	Dry cow cost/d * avg dry cows/d * 365
Other Exp for Dry Cows ($)	Dry cow labor/d * avg dry cows/d * 365
First Lactation Purchases ($)	First lactation calved * heifer price
Cattle Invest. Begin ($)	Sum of the beginning milking cow numbers and dry cow numbers * heifer price.
Cattle Invest. End ($)	Sum of ending milking cow numbers and dry cow numbers * heifer price.
Change in Cattle Invest. ($)	Cattle investment beginning minus cattle investment ending, each year.
Interest on Cattle Average ($)	Sum of beginning and ending cow numbers / 2 * interest, each year.

Total Income ($)	Sum of milking income, cull income, and calf income.
Total Cash Expenses ($)	Sum of feed expense for milking herd, feed expense for dry herd, feed expense for other and first lactation purchases.
Net Cash Income ($)	Total income minus total cash expenses
Interest – Invest. Change ($)	Interest of cattle minus change in cattle investment.
Net Farm Income ($)	Net cash income minus interest minus investment change.

There were several economic parameters associated with the Count worksheet. Each cost or price of a variable was entered into a reference sheet, where any could be changed for different analyses. The parameters described various economic influences in the dairy industry (Fig. 9).

Figure 9. Economic parameters.

Parameter	Base	Explanation
Maintenance Cost	$ 0.819	Intercept for the regression of feed cost (kg/d) on milk production (kg/d).
Cost of feed per kg of milk	$ 0.057	Feed cost per kg of milk produced ($/kg milk).
Dry Cow Feed Cost/d	$ 1.25	Typical feed cost for a dry cow ($/d).
Mailbox Milk Price/100 kg	$30.00	Average price, converts to $13.61 / cwt
Dry Cow Cost/d (labor, etc.)	$ 0.50	Standard value; fixed cost to maintain a dry cow ($/d); did not include feed cost.
Calf Death Loss	5%	Standard value (2), calves born dead (%); could not be sold.
% Male Calves	52%	Standard value
Bull Calf Value	$40.00	Average price ($/head).
Heifer Calf Value	$150.00	Average price ($/head).
Wtd Calf Value (w/ loss)	88.16	(Male calves * bull value + (1- male calves) * heifer value) * (1- death loss); ($/ calf born).
Price for Heifers Bought	$ 1200	Average price ($/head)
Cull Weight (kg)	620	Average weight of cull cow (1364 lb.).
Cull Prices/kg	$ 0.70	Average price ($/kg), ($ 0.32 / lb.).
Cull Prices (1350#)	$434.00	Cull weight * cull price ($/head).
Interest Rates	8%	Standard value

Feed costs for maintenance and milk production as shown in Figure 8 were derived from regressing feed cost on milk yield for six milk yields. Rations were formulated for 20 to 45 kg of milk per day. Quantity of ration ingredients (as–fed) are in Tables 7, whereas costs of dry ingredients are in Table 8.

Table 7. Quantity of feed (kg/d per cow, as fed) for various milk yields.

		Milk (kg/d per cow)					
Feed Prices	$/1000 kg	20	25	30	35	40	45
Corn Silage	33	15.28	9.63	6.15	13.62	28.13	40.23
Alfalfa Silage	44	23.06	28.00	31.88	29.40	19.79	12.25
Ground Corn	110	2.56	4.67	6.47	6.58	5.98	5.60
SBM	220	0.00	0.00	0.00	0.44	1.65	2.73
Mineral	363	0.32	0.36	0.41	0.49	0.56	0.63
Trace Mineral	1100	0.04	0.04	0.05	0.05	0.06	0.06

Table 8. Price of feed in ration ($/d per cow) for various milk yields.

		Milk (kg/d per cow)					
Feed Prices	$/1000 kg	20	25	30	35	40	45
Corn Silage	33	0.50	0.32	0.20	0.45	0.93	1.33
Alfalfa Silage	44	1.01	1.23	1.40	1.29	0.87	0.54
Ground Corn	110	0.28	0.51	0.71	0.72	0.66	0.62
SBM	220	0.00	0.00	0.00	0.10	0.36	0.60
Mineral	363	0.12	0.13	0.15	0.18	0.20	0.23
Trace Mineral	1100	0.04	0.05	0.05	0.06	0.06	0.07
Total		1.96	2.24	2.52	2.80	3.09	3.38

Statistical Analysis

Data from three years for each of the eight scenarios were analyzed using Proc Mixed of SAS (23) with the following model:

$$Y_{ijkl} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + H_{(ij)k} + \gamma_l + (\alpha\gamma)_{il} + (\beta\gamma)_{jl} + (\alpha\beta\gamma)_{ijl} + E_{ijkl}$$

Where:
Y_{ijkl} = An observation from one year of one scenario.
μ = Overall mean.
α_i = Fixed effect of the i^{th} dry kg (I = 8, 13, 18, or 23 kg/d).
β_j = Fixed effect of j^{th} rate of decline (j = 6 or 8% mo).
$(\alpha\beta)_{ij}$ = Fixed effect of interaction of dry kg and rate of decline (a scenario).
$H_{(ij)k}$ = Random effect of herd k within scenario ij (k = 1 to 10).
γ_l = Fixed effect of year l (l = 1, 2, or 3).
$(\alpha\gamma)_{il}, (\beta\gamma)_{jl}, (\alpha\beta\gamma)_{ijl}$ = Fixed effect of interactions among scenarios and years.
E_{ijkl} = Random residual.

Years were assumed correlated, and designated so in the analysis with the option AR(1) for first order auto regressive relationship. The AR(1) was confirmed more descriptive of the covariance structure among years in these data than the CS relationship (by Schwarz' Bayesian Criterion, SBC closest to zero). AR(1) specifies first order auto regression, indicating a correlation between successive years. CS specifies compound symmetry, where each year has same variance but years are uncorrelated. Orthogonal polynomial contrast were designated to test linear, quadratic, and lack of fit (cubic) trends among the four dry kg scenarios (8, 13, 18, 23 kg). These coefficients were [-3 –1 +1 +3] for linear, [+1 –1 –1 +1] for quadratic, and [-1 +3 –3 +1] for lack of fit (cubic). Because of the arbitrary choice of number of herds, P<=0.10 was selected as the criterion for statistical significance.

Sensitivity Analysis

Because it was anticipated that changes in net cash and net farm income due to dry kg would be very sensitive to the difference between milk price and feed cost, as well as dry cow costs, these costs were changed in a designed manner. They were increased and decreased by 20%, creating nine data sets for comparison. Milk price minus feed cost was widened and narrowed 20% by shifting each 10% in opposite directions. Both dry fixed costs and dry feed costs were changed by 20%. The same 80 herds were reanalyzed nine times with the mixed model described previously. The middle price scheme (no change in price) was an exact duplication of the original data on the 80 herds. The nine price schemes are in Figure 10.

Figure 10. Schemes to test sensitivity to price change.

	Low	Milk Feed Income	High
High	-10% Milk Price +10% Feed Cost +20% Dry Cow Cost	0% Milk Price 0% Feed Cost +20% Dry Cow Cost	+10% Milk Price -10% Feed Cost +20% Dry Cow Cost
Dry Cow Costs	-10% Milk Price +10% Feed Cost 0% Dry Cow Cost	Normal Prices	+10% Milk Price -10% Feed Cost 0% Dry Cow Cost
Low	-10% Milk Price +10% Feed Cost -20% Dry Cow Cost	0% Milk Price 0% Feed Cost -20% Dry Cow Cost	+10% Milk Price -10% Feed Cost -20% Dry Cow Cost

Results and Discussion

Seventeen variables that were not financial were selected and their means and standard deviations were obtained by dry kg, percent decline, and year. Each table is an overall average of the ten herds for that particular scenario. Tables 9 through 16 indicate the variation among the three years as well as differences among intensities of dry kg and percent decline. These tables also serve as verification against the original parameter page in the simulation.

Cull Rates

Most cull rates did not change between rates of decline. The first year for all cull rates appeared to be an adjustment period, although the simulation started at 20 wk. Percent reproduction culls was close to but slightly lower than the desired average of 10%/yr. Reproductive culls were generated indirectly in that 22% of cows would never be pregnant. Other culling reduced the percentage from 22% to about 9%. Death of cows at calving occurred half as frequently as desired (4%/yr). The reason is unknown. As expected, low milk cull and bad milk cull percentages increased as dry kg increased, both being largest at 23 kg dry kg. Cows not pregnant at the dry kg milk yield were culled. Weekly involuntary cull percent was as predicted on an annual basis, and was designed to be 2.5 times as intense on cows beyond second lactation. Total involuntary cull percent was equal to the specified sum of 26% from the parameter page. However, it decreased about 2 units at 18 and 23 dry kg because more cows were culled for low milk. Total culls incorporated all culls and averaged 30 to 32%, though slightly lower at 8% decline in years 2 and 3.

Lactation Periods

Percent first lactation cows did not differ from the means on the parameter page. The percentage was largest in year 1. As dry kg increased there were fewer first lactation cows in the herd, due to a steady increase in dry cows from early dry off. As these numerous dry cows calved, fewer heifers were needed. The proportion of dry cows was steady at 14% across years for 8 kg dry, but was about 17%, 23% and 31% for dry kg of 13, 18, and 23 kg. The stability of dry herd size across years was difficult to achieve when designing the simulation. There were more calves sold at 18 and 23 kg. These numbers corresponded to the number of cows that calved each year.

Lactation length was about the same for 6 and 8% decline. As expected from increasing dry kg, lactation length shortened by 20, 30, and 40 d moving from 8 to 13, 18, and 23 dry kg. By the 23 kg run, lactation was shorter because the dry off and culling restraints increased. Consequently, early dry period weeks increased as dry off milk yield increased. As more cows were forced dry, the early dry weeks increased. Normal dry period in weeks remained constant each year for both rates of decline. There was no difference because dry period was set at 56 d on the parameter page, although because days were rounded up, it functionally became 9 wk.

The percentage of cows dried off early was slightly higher for 8% decline. The change in percentage was sustained as dry kg increased. From about 8% early dry off at 8 kg dry, it increased to 27, 50, and 72% for 13, 18, and 23 dry kg. The percent of dry cows also increased slightly each year.

Milk Yields

Daily milk yield per cow increased 1 kg at each higher dry off up to 18 dry kg. From 18 to 23 dry kg, it increased 1.5 kg. This was due to a larger percentage of cows being replaced by higher producing (fresher) cows. Fresh cows were less frequently heifers at 23 dry kg (26% heifers versus 31% heifers for others) because of the larger dry herd at 23 kg dry. Rolling herd average (RHA) decreased 500 to 800 kg/yr per cow from years 1 to 3. It also decreased 400 and 700 kg/yr per cow for the 18 and 23 dry kg runs. The RHA was constant between 8 and 13 dry kg. These decreases are a function of the definition of RHA, that prescribes total milk yield for the herd to be divided by total number of cows milking and dry. Larger dry herds had smaller RHA. However, it also serves as an example that financial position is not optimized through maximum RHA.

Table 9. Means and standard deviations for 8 kg dry and 6% lactation decline (10 herds).

	Years							
	1		2		3		All	
Variable	x	SD	x	SD	x	SD	x	SD
Repro Culls (%)	11.4	2.9	9.1	2.4	8.7	2.3	9.7	2.7
Died (%)	2.0	1.1	1.7	1.4	2.2	1.1	2.0	1.2
Bad kg Milk Culls (%)	0.0	0.0	0.0	0.0	0.1	0.3	0.0	0.3
Low Milk (kg) Culls (%)	3.8	3.3	4.2	2.8	4.0	3.1	4.0	3.0
Production Cull (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Weekly Involuntary Culls (%)	16.8	4.2	12.3	3.5	16.1	3.9	15.1	4.3
Total Involuntary Cull (%)	30.2	4.9	23.1	4.2	27.0	4.5	26.8	5.3
Total Culls (%)	33.9	6.2	27.4	3.7	31.0	3.9	30.8	5.3
Lactation 1 (%)	41.1	3.3	28.5	2.6	23.8	2.6	31.1	7.9
Dry Cows (%)	13.3	0.9	13.8	0.5	14.2	0.7	13.8	0.8
Calves Sold (n)	120	4	119	4	121	4	120	4
Lactation Length (d)	302.8	6.9	334.2	6.3	332.3	6.3	323.1	15.9
Days in Milk, 12/31 (d)	160.6	11.4	164.3	8.6	163.4	12.3	162.8	10.6
Early Dry Period (wk)	5.3	4.4	7.7	2.6	9.7	3.0	7.6	3.8
Normal Dry Period (wk)	9.2	0.1	8.9	0.1	8.7	0.1	8.9	0.2
Total Dry Period (wk)	9.3	0.2	9.3	0.2	9.8	0.3	9.5	0.3
Dry Early (%)	2.7	2.9	6.1	3.0	11.9	3.1	6.9	4.8
Milk Yield (kg/d per cow)	30.9	0.5	30.0	0.4	29.4	0.4	30.1	0.8
RHA Yield (kg/yr per cow)	9788	219	9436	165	9205	133	9476	297

Table 10. Means and standard deviations for 13 kg dry and 6% lactation decline (10 herds).

	Years							
	1		2		3		All	
Variable	x	SD	x	SD	x	SD	x	SD
Repro Culls (%)	9.5	3.1	8.7	2.0	8.6	2.0	8.9	2.4
Died (%)	2.9	1.9	1.7	1.2	1.4	1.1	2.0	1.5
Bad kg Milk Culls (%)	0.3	0.4	0.7	0.5	0.3	0.4	0.4	0.5
Low Milk (kg) Culls (%)	3.9	2.2	6.9	2.0	5.4	3.0	5.4	2.7
Production Cull (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Weekly Involuntary Culls (%)	16.1	4.0	14.6	1.9	15.9	2.5	15.5	2.9
Total Involuntary Cull (%)	28.7	4.5	24.9	2.8	25.9	3.5	26.4	3.9
Total Culls (%)	32.6	4.0	32.4	2.7	31.5	4.7	32.2	3.8
Lactation 1 (%)	40.4	2.0	28.8	2.2	23.9	2.3	31.0	7.4
Dry Cows (%)	15.6	0.8	16.7	1.1	16.8	0.6	16.4	1.0
Calves Sold (n)	124	4	127	4	125	3	125	4
Lactation Length (d)	278.0	16.6	316.6	5.6	316.4	7.6	303.7	21.3
Days in Milk, 12/31 (d)	156.1	13.1	148.9	14.2	152.8	11.5	152.6	12.9
Early Dry Period (wk)	7.6	2.0	10.0	1.3	10.1	1.5	9.2	2.0
Normal Dry Period (wk)	9.2	0.1	8.9	0.1	8.7	0.1	8.9	0.2
Total Dry Period (wk)	10.3	0.4	11.7	0.6	12.3	0.6	11.4	1.0
Dry Early (%)	14.6	3.0	27.5	5.0	35.6	5.1	25.9	9.8
Milk Yield (kg/d per cow)	30.9	0.7	30.8	0.7	30.5	0.6	30.8	0.7
RHA Yield (kg/yr per cow)	9534	262	9371	305	9275	237	9393	282

Table 11. Means and standard deviations for 18 kg dry and 6% lactation decline (10 herds).

	Years							
	1		2		3		All	
Variable	x	SD	x	SD	x	SD	x	SD
Repro Culls (%)	7.8	2.5	9.4	2.2	8.4	2.8	8.6	2.5
Died (%)	2.8	1.0	1.9	1.1	1.6	1.2	2.1	1.2
Bad kg Milk Culls (%)	0.0	0.0	0.4	0.4	1.2	1.0	0.5	0.8
Low Milk (kg) Culls (%)	8.0	3.4	5.5	5.1	4.9	3.7	6.1	4.3
Production Cull (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Weekly Involuntary Culls (%)	13.5	3.3	14.9	2.4	14.0	1.9	14.1	2.6
Total Involuntary Cull (%)	24.0	3.4	26.2	4.2	24.0	2.7	24.8	3.5
Total Culls (%)	32.1	5.0	32.1	6.2	30.2	2.9	31.4	4.8
Lactation 1 (%)	40.4	2.9	27.5	3.4	23.7	3.0	30.5	7.9
Dry Cows (%)	19.5	1.2	21.7	1.8	23.2	1.2	21.5	2.1
Calves Sold (n)	126	5	136	7	137	5	133	7
Lactation Length (d)	258.0	13.6	289.5	7.7	279.4	7.8	275.5	16.6
Days in Milk, 12/31 (d)	145.1	10.1	144.1	8.9	148.5	9.1	145.9	9.3
Early Dry Period (wk)	10.6	1.6	13.0	0.9	14.7	0.9	12.8	2.0
Normal Dry Period (wk)	9.1	0.1	8.9	0.1	8.7	0.1	8.9	0.2
Total Dry Period (wk)	12.5	0.5	15.2	1.0	17.5	1.1	15.1	2.2
Dry Early (%)	32.5	4.0	48.3	5.8	59.6	5.9	46.8	12.5
Milk Yield (kg/d per cow)	32.0	0.7	32.0	0.7	31.3	0.6	31.8	0.7
RHA Yield (kg/yr per cow)	9393	261	9160	288	8766	268	9106	372

Table 12. Means and standard deviations for 23 kg dry and 6% lactation decline (10 herds).

	Years							
	1		2		3		All	
Variable	x	SD	x	SD	x	SD	x	SD
Repro Culls (%)	10.2	3.1	10.7	3.7	6.8	2.8	9.2	3.6
Died (%)	3.0	1.0	2.1	1.1	1.6	0.5	2.2	1.1
Bad kg Milk Culls (%)	0.2	0.4	0.9	0.8	1.8	1.4	0.9	1.1
Low Milk (kg) Culls (%)	5.8	3.0	5.5	3.0	6.9	3.0	6.1	2.9
Production Cull (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Weekly Involuntary Culls (%)	13.6	1.9	12.7	2.4	11.6	1.5	12.6	2.1
Total Involuntary Cull (%)	26.8	3.1	25.4	3.6	20.0	3.2	24.1	4.4
Total Culls (%)	32.8	3.6	31.8	4.4	28.7	4.7	31.1	4.5
Lactation 1 (%)	34.6	3.6	23.7	2.3	20.7	2.8	26.4	6.7
Dry Cows (%)	27.8	1.8	30.7	1.7	33.1	2.1	30.6	2.9
Calves Sold (n)	146	7	154	4	157	6	152	7
Lactation Length (d)	216.7	15.5	248.9	9.8	239.0	8.8	234.9	17.8
Days in Milk, 12/31 (d)	129.3	6.7	130.5	6.2	127.5	11.3	129.1	8.2
Early Dry Period (wk)	12.7	1.4	18.3	1.0	19.5	1.1	16.8	3.2
Normal Dry Period (wk)	9.1	0.1	8.9	0.05	8.7	0.08	8.9	0.2
Total Dry Period (wk)	16.3	1.1	21.7	1.2	23.9	1.2	20.6	3.4
Dry Early (%)	56.6	6.2	69.9	4.8	77.9	4.2	68.1	10.2
Milk Yield (kg/d per cow)	33.4	0.5	33.3	0.4	32.9	0.7	33.2	0.6
RHA Yield (kg/yr per cow)	8795	332	8424	257	8036	390	8418	448

Table 13. Means and standard deviations for 8 kg dry and 8% lactation decline (10 herds).

	Years							
	1		2		3		All	
Variable	x	SD	x	SD	x	SD	x	SD
Repro Culls (%)	12.5	1.9	9.2	3.2	10.0	2.8	10.6	2.9
Died (%)	2.2	1.6	2.2	1.7	1.0	1.0	1.8	1.5
Bad kg Milk Culls (%)	0.0	0.0	0.0	0.0	0.3	0.4	0.1	0.3
Low Milk (kg) Culls (%)	4.3	2.6	5.4	4.7	6.9	5.1	5.5	4.2
Production Cull (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Weekly Involuntary Culls (%)	14.0	1.5	16.1	4.0	14.2	3.7	14.8	3.3
Total Involuntary Cull (%)	28.7	2.9	27.5	6.2	25.3	6.1	27.1	5.3
Total Culls (%)	32.9	3.6	32.8	3.7	32.2	4.8	32.6	4.0
Lactation 1 (%)	43.5	3.2	29.2	2.5	26.4	2.5	33.0	8.1
Dry Cows (%)	13.2	0.5	14.2	0.5	14.2	0.8	13.9	0.7
Calves Sold (n)	119	3	124	5	120	5	121	5
Lactation Length (d)	310.1	10.2	330.8	6.6	329.7	4.4	323.5	12.0
Days in Milk, 12/31 (d)	166.6	11.3	159.9	13.6	161.4	13.5	162.6	12.7
Early Dry Period (wk)	4.1	1.9	6.6	1.8	8.3	1.9	6.4	2.5
Normal Dry Period (wk)	9.2	0.1	8.9	0.1	8.7	0.0	8.9	0.2
Total Dry Period (wk)	9.34	0.1	9.5	0.3	10.2	0.6	9.7	0.5
Dry Early (%)	4.2	1.6	9.3	3.5	17.7	3.8	10.4	6.4
Milk Yield (kg/d per cow)	30.9	0.6	30.5	0.4	29.8	0.5	30.4	0.7
RHA Yield (kg/yr per cow)	9778	183	9552	147	9327	205	9552	256

Table 14. Means and standard deviations for 13 kg dry and 8% lactation decline (10 herds).

	Years							
	1		2		3		All	
Variable	x	SD	x	SD	x	SD	x	SD
Repro Culls (%)	10.2	2.9	7.4	1.5	9.5	2.6	9.0	2.6
Died (%)	2.8	1.1	1.9	0.9	0.7	0.9	1.8	1.3
Bad kg Milk Culls (%)	0.0	0.0	0.5	0.6	0.6	0.7	0.4	0.6
Low Milk (kg) Culls (%)	6.1	3.6	6.9	3.3	4.9	3.0	6.0	3.3
Production Cull (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Weekly Involuntary Culls (%)	14.0	3.5	15.9	3.5	18.0	4.5	16.0	4.1
Total Involuntary Cull (%)	27.0	4.6	25.2	3.1	28.1	5.6	26.8	4.6
Total Culls (%)	33.1	4.7	32.6	4.5	33.6	4.1	33.1	4.3
Lactation 1 (%)	40.6	2.9	30.2	2.2	26.5	2.6	32.4	6.6
Dry Cows (%)	15.9	0.9	16.6	1.1	17.8	0.9	16.8	1.2
Calves Sold (n)	123	4	127	6	128	4	126	5
Lactation Length (d)	295.2	8.2	312.8	5.2	307.5	6.5	305.2	9.9
Days in Milk, 12/31 (d)	149.1	15.3	150.6	7.1	146.6	9.2	148.8	10.9
Early Dry Period (wk)	7.4	1.4	9.3	1.6	11.3	1.1	9.4	2.1
Normal Dry Period (wk)	9.2	0.1	8.9	0.1	8.7	0.1	8.9	0.2
Total Dry Period (wk)	10.7	0.6	11.6	0.7	13.4	0.6	11.9	1.3
Dry Early (%)	19.8	6.8	28.3	4.5	41.6	5.1	29.9	10.6
Milk Yield (kg/d per cow)	31.6	0.5	31.3	0.6	30.6	0.7	31.2	0.7
RHA Yield (kg/yr per cow)	9691	225	9524	262	9199	237	9471	312

Table 15. Means and standard deviations for 18 kg dry and 8% lactation decline (10 herds).

	Years							
	1		2		3		All	
Variable	x	SD	x	SD	x	SD	x	SD
Repro Culls (%)	9.5	2.6	7.5	2.7	8.1	2.7	8.4	2.7
Died (%)	2.6	1.1	2.1	0.8	1.5	1.0	2.1	1.1
Bad kg Milk Culls (%)	0.3	0.5	0.9	1.0	1.3	0.6	0.8	0.8
Low Milk (kg) Culls (%)	4.6	1.6	6.2	3.0	5.9	2.2	5.6	2.4
Production Cull (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Weekly Involuntary Culls (%)	15.8	2.9	11.8	1.6	14.2	4.4	13.9	3.5
Total Involuntary Cull (%)	27.9	3.9	21.4	2.7	23.9	6.4	24.4	5.2
Total Culls (%)	32.8	3.4	28.4	4.3	31.1	5.1	30.8	4.6
Lactation 1 (%)	39.5	2.5	27.5	1.7	22.4	2.3	29.8	7.6
Dry Cows (%)	21.0	1.5	23.6	1.4	24.8	1.0	23.1	2.1
Calves Sold (n)	132	5	135	5	141	5	136	6
Lactation Length (d)	258.7	14.4	280.9	11.3	273.2	8.2	270.9	14.6
Days in Milk, 12/31 (d)	140.8	8.2	140.7	13.0	136.1	4.7	139.2	9.2
Early Dry Period (wk)	9.6	1.5	12.8	1.5	14.2	0.9	12.2	2.4
Normal Dry Period (wk)	9.2	0.1	8.9	0.0	8.7	0.1	8.9	0.2
Total Dry Period (wk)	13.2	0.8	15.9	1.1	18.6	0.6	15.9	2.4
Dry Early (%)	42.1	4.9	55.4	7.2	69.2	2.3	55.6	12.3
Milk Yield (kg/d per cow)	32.7	0.6	32.3	0.4	32.1	0.3	32.3	0.5
RHA Yield (kg/yr per cow)	9431	279	8989	187	8804	165	9075	339

Table 16. Means and standard deviations for 23 kg dry and 8% lactation decline (10 herds).

	Years							
	1		2		3		All	
Variable	x	SD	x	SD	x	SD	x	SD
Repro Culls (%)	10.4	2.2	5.6	2.5	8.3	2.7	8.1	3.1
Died (%)	2.2	1.2	1.9	1.2	1.3	1.0	1.8	1.2
Bad kg Milk Culls (%)	0.3	0.4	0.7	0.6	1.4	0.9	0.8	0.8
Low Milk (kg) Culls (%)	6.3	3.6	7.7	2.6	7.3	2.6	7.1	2.9
Production Cull (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Weekly Involuntary Culls (%)	12.0	2.6	12.0	1.9	10.9	2.5	11.6	2.3
Total Involuntary Cull (%)	24.6	3.5	19.6	4.0	20.52	4.3	21.6	4.4
Total Culls (%)	31.2	3.3	27.9	5.1	29.2	3.8	29.4	4.2
Lactation 1 (%)	33.3	1.8	22.9	2.1	18.1	1.8	24.8	6.7
Dry Cows (%)	29.9	1.0	33.3	1.9	34.1	2.1	32.4	2.5
Calves Sold (n)	150	4	158	7	159	6	156	7
Lactation Length (d)	221.4	14.0	236.8	7.9	227.3	13.3	228.5	13.3
Days in Milk, 12/31 (d)	122.0	13.1	118.9	12.9	128.9	10.5	123.3	12.5
Early Dry Period (wk)	13.4	1.1	17.4	1.1	19.5	1.3	16.8	2.8
Normal Dry Period (wk)	9.12	0.06	8.90	0.07	8.71	0.10	8.91	0.19
Total Dry Period (wk)	17.8	1.0	22.3	1.1	24.6	0.8	21.6	3.0
Dry Early (%)	64.4	3.8	76.9	2.4	81.9	3.0	74.4	8.1
Milk Yield (kg/d per cow)	33.7	0.4	33.8	0.3	33.4	0.6	33.7	0.5
RHA Yield (kg/yr per cow)	8634	154	8233	239	8039	346	8302	355

Mixed Model ANOVA's

Table 17 lists significance of fixed effects. There were no interactions of dry kg and rate of decline except relating to the dry herd (% dry, % forced dry, interest on cattle, dry cow costs, and feed income). There was also no significance for cull income and heifer purchases, except for dry kg. Rate of decline interacted with year and dry kg by year for net farm income, but not net cash income, due to change in interest minus investment. Rate of decline did not affect RHA because the simulation was designed to equalize total milk for 6% and 8% decline by assigning a higher peak yield for 8% decline.

Trends of Increasing Milk at Dry Off

Tables 18 through 25 list annual and overall least squares means for income, expenses, net income, and production variables. Means are for dry off kilograms of 8, 13, 18, and 23 kg/d. Standard errors are included, as are tests of significance for linear, quadratic, and cubic orthogonal polynomials. These determined the existence of trends as dry kg was changed from 8 to 23 kg/d. The tables contain many means, making them difficult to interpret except as explanatory information for the more important net income measures. The discussion of Tables 18 – 25 will be limited to summary remarks on several of the variables.

At 18 kg and 23 kg for 8% decline, percent dry cows was greater, as expected, because more cows were required to have shorter lactations to meet the program constraints. Likewise, there was an increase in force dries to meet herd size constraints. More total weeks dry at 8% was due to the higher percentage of cows force dried at 23 kg.

There was no significant difference in lactation days between 6% and 8% decline. The estimates for linear significance at 6% and 8% decline were negative, meaning the mean was greater at 8 kg than at 23 kg. The estimate was also negative at both rates of decline for the quadratic trend, indicating that lactation days decreased more rapidly as dry kg advanced. Lactation length dropped 20, 30, and 40 d for 13, 18, and 23 dry kg, ending at 235 d.

Milk (kg) was greater each year at 23 kg for both rates of decline. However, milk at 8% decline was greater because as level of dry off increased and herd size remained the same, those cows remaining in the herd produced more milk. With higher daily milk but longer dry periods and more dry cows, RHA decreased as level of dry off increased, especially at dry kg of 23 kg. Linear significance showed that 8 kg dry kg had a higher mean RHA than 23 kg.

Income was linear and quadratic with regards to level of dry kg. Income increased due to an increase in milk production. Income was higher at 8% than 6% due to higher peak milk production resulting in greater milk production per day. Calf income for rates of decline was similar across level of milk dry off because the number of milking cows in the herd remained constant (98 to 102). Total income for 6% and 8% was linear and quadratic, and had a sharp upward increase at 18 kg and 23 kg. Total income increased as dry off level increased due to an increase in cull and milk income. As the production level increased, feed expense also increased. Feed expense was greater at 8% decline compared to 6% due to increased milk production.

At 6% decline, feed expense was linear, quadratic and cubic (lack of fit), and linear and quadratic for 8% decline. As expected, this difference was due to the dry cow restrictions between the two declines. There was a larger difference in expense between 6% and 8% at 18 kg and 23 kg. Year 3 had the largest expense because there were more dry cows in the herd than any other year. Decline of 8% had a large overall expense at 23 kg for the same reason, more dry cows in the herd.

Heifer purchase followed the same trend as number of cows culled. If the milking herd number was below 98 the appropriate number of heifers was added. More heifers were purchased at 23 kg at 6% decline than 23 kg at 8%, as culling demand was greater and there was a need for more cows.

Total expenses increased more at 23 kg due to the largest increase in dry cows at 23 kg. Investment changes were very erratic as denoted by of lack of fit at year 2, due to culling rate, heifers entering and leaving the herd. Because there was a need for more cattle as dry kg increased, more money was invested in cattle, especially at dry kg of 23 kg. This was the interest expense or the cost of having money invested in cows and not invested in the bank at the specified interest rate (8%/yr).

Net cash income is total income minus total cash expenses. For dry kg of 8, 13, and 18 kg, milk income, cull income, and calf income offset the increase in feed cost and dry cow cost. Thus, net cash income increased for both rates of decline. However, at 23 kg there were increased expenses, mostly from heifer purchases and dry cow costs, which diminished any benefit from income, resulting in a downward turn in net cash income.

Interest and investment changes were erratic through the years depending on how much money was invested in the cows at the beginning of the calendar year and how much at the end. Non-cash interest costs minus change in investment mirrored interest costs alone because investment changes were initially small. Comparing combined years at 6% and 8% decline, net farm income was higher at 8% and reached a peak at dry kg of 18 kg. Those cows left in the herd at 8% decline were the highest producers from the 10 herds analyzed. Decline at 8% produced the same amount of milk with a higher peak for the 8 kg runs. At 23 kg, lactation length was shorter, but at 8% the peak milk was still high, thus milk per day was higher. Due to the decrease in lactation curve persistency, more cows had dropped below the dry off limit and were dried earlier. Between 8 kg and 23 kg at 6% decline there was an increase of $3395 in net farm income, not significant. At 8% decline between 8 kg and 23 kg, there was an increase of $4961 in net farm income.

Table 17. Test of fixed effects.

Source	NDF[1]	DDF[2]	Milk Income	Cull Income	Calf Income	Total Income	Feed Exp. (Milking Cow)	Feed Exp. (Dry Cows)	Other Exp. (Dry Cows)	Heifer Purchase	Total Expenses
			Variable Analyzed								
Drykg	3	72	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Decline	1	72	0.01	0.21	0.02	0.01	0.01	0.01	0.01	0.38	0.01
Drykg * Decline	3	72	0.78	0.27	0.38	0.94	0.81	0.01	0.01	0.32	0.96
Year	2	144	0.01	0.23	0.01	0.01	0.01	0.01	0.01	0.62	0.66
Drykg * Year	6	144	0.02	0.58	0.01	0.03	0.03	0.01	0.01	0.85	0.04
Decline * Year	2	144	0.94	0.16	0.97	0.75	0.91	0.47	0.47	0.31	0.44
Drykg * Decline *Year	6	144	0.12	0.18	0.04	0.02	0.13	0.33	0.33	0.61	0.46

[1]Numerator degrees of freedom
[2]Denominator degrees of freedom

Table17. continued.

Source	% Dry	% Fdry	Total Dry wk	Lactation Days	Milk (kg)	RHA	Invest. Change	Int. on Cattle	Net Cash Income	Int. – Invest. Change	Net Farm Income
	Variable Analyzed										
Drykg	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.07	0.05	0.03
Decline	0.01	0.01	0.01	0.11	0.01	0.97	0.38	0.01	0.04	0.60	0.02
Drykg * Decline	0.03	0.04	0.10	0.13	0.66	0.26	0.53	0.02	0.89	0.58	0.67
Year	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Drykg * Year	0.01	0.01	0.01	0.10	0.01	0.07	0.05	0.01	0.92	0.02	0.02
Decline * Year	0.58	0.24	0.14	0.01	0.97	0.77	0.01	0.03	0.74	0.01	0.05
Drykg * Decline *Year	0.31	0.15	0.21	0.43	0.08	0.11	0.03	0.06	0.73	0.02	0.08

Table 18. Mean income 6%.

	Dry off Milk Yield (kg)					Contrast[1]		
Variable	8	13	18	23	SE	L	Q	LF
				Year 1				
Milk Income	334451	334860	346394	360273	1952	0.01	0.07	0.32
Cull Income	15796	15147	15667	17751	701	0.04	0.05	0.90
Calf Income	10553	10897	11152	12845	137	0.01	0.01	0.01
Total Income	360802	360903	373214	390869	2054	0.01	0.01	-0.46
				Year 2				
Milk Income	324438	333599	346306	359440	1952	0.01	0.31	0.72
Cull Income	12803	15884	16492	18358	701	0.01	-0.39	0.24
Calf Income	10473	11223	11972	13603	137	0.01	0.02	0.15
Total Income	347714	360707	374770	391401	2054	0.01	0.38	0.87
				Year 3				
Milk Income	318317	330851	337981	355332	1952	0.01	0.22	0.08
Cull Income	14452	15581	16015	17360	701	0.04	0.88	0.61
Calf Income	10659	11002	12078	13832	137	0.01	0.01	-0.93
Total Income	343428	357434	366073	386524	2054	0.01	0.12	0.06
				All Years				
Milk Income	325736	333103	343561	358348	1337	0.01	0.07	0.84
Cull Income	14351	15537	16058	17823	382	0.01	0.45	0.27
Calf Income	10562	11041	11734	13427	82	0.01	0.01	0.04
Total Income	350648	359681	371353	389598	1364	0.01	0.01	0.52

[1]L = Linear, Q = Quadratic, LF = Lack of Fit

Table 19. Mean expenses 6%.

Variable	Dry off Milk Yield (kg) 8	13	18	23	SE	Contrast[1] L	Q	LF
				Year 1				
Feed Exp. (Milking Cows)	93075	93182	95393	97921	378	0.01	0.02	-0.29
Feed Exp. (Dry Cows)	6940	8339	10989	17421	343	0.01	0.01	0.10
Other Exp. (Dry Cows)	2776	3335	4395	6968	96	0.01	0.01	0.10
Heifer Purchase	45120	46200	48960	58080	2158	0.01	0.06	-0.63
Total Expenses	147911	151056	159737	180390	2128	0.01	0.01	0.50
				Year 2				
Feed Exp. (Milking Cows)	91189	92954	95316	97766	378	0.01	0.37	-0.76
Feed Exp. (Dry Cows)	7232	9060	12513	20004	343	0.01	0.01	0.12
Other Exp. (Dry Cows)	2893	3624	5005	8001	96	0.01	0.01	0.12
Heifer Purchase	41280	46680	51720	59520	2158	0.01	0.58	0.75
Total Expenses	142594	152318	164553	185291	2128	0.01	0.01	0.53
				Year 3				
Feed Exp. (Milking Cows)	90063	92442	93728	96991	378	0.01	0.24	0.07
Feed Exp. (Dry Cows)	7480	9148	13662	22406	343	0.01	0.01	0.37
Other Exp. (Dry Cows)	2992	3659	5465	8962	96	0.01	0.01	0.37
Heifer Purchase	42840	44760	50160	56880	2158	0.01	0.27	0.82
Total Expenses	143374	150009	163015	185240	2128	0.01	0.03	0.77
				All Years				
Feed Exp. (Milking Cows)	91442	92859	94812	97559	258	0.01	0.01	0.82
Feed Exp. (Dry Cows)	7217	8849	12388	19944	241	0.01	0.01	0.05
Other Exp. (Dry Cows)	2887	3539	4955	7977	68	0.01	0.01	0.05
Heifer Purchase	43080	45880	50280	58160	1190	0.01	0.04	0.72
Total Expenses	144627	151128	162435	183641	1205	0.01	0.01	0.35

[1]L = Linear, Q = Quadratic, LF = Lack of Fit

Table 20. Mean herd variables 6%.

	Dry off Milk Yield (kg)					Contrast[1]		
Variable	8	13	18	23	SE	L	Q	LF
				Year 1				
% Dry	13.3	15.6	19.5	27.8	0.4	0.01	0.01	0.14
% Fdry	2.7	14.6	32.5	56.6	1.4	0.01	0.01	0.96
Total Dry wk	9.3	10.3	12.5	16.3	0.25	0.01	0.01	0.83
Lactation Days	303	278	258	217	3.13	-0.01	-0.01	-0.07
Milk (kg)	30.9	30.9	32.0	33.4	0.12	0.01	0.01	-0.37
Rolling Herd Average	9788	9534	9393	8795	78.49	-0.01	-0.03	-0.11
				Year 2				
% Dry	13.8	16.7	21.7	30.7	0.4	0.01	0.01	0.28
% Fdry	6.1	27.3	48.3	69.9	1.4	0.01	0.94	0.82
Total Dry wk	9.3	11.7	15.2	21.7	0.25	0.01	0.01	0.12
Lactation Days	334	317	290	249	3.13	-0.01	-0.03	-0.78
Milk (kg)	30.0	30.8	32.0	33.3	0.12	0.01	0.21	-0.64
Rolling Herd Average	8436	9371	9160	8424	78.49	-0.01	-0.01	-0.28
				Year 3				
% Dry	14.2	16.8	23.2	33.1	0.4	0.01	0.01	-0.91
% Fdry	11.9	35.6	59.6	77.8	1.4	0.01	-0.05	-0.34
Total Dry wk	9.8	12.3	17.5	23.9	0.25	0.01	0.01	-0.15
Lactation Days	332	316	279	239	3.13	-0.01	-0.01	0.21
Milk (kg)	29.4	30.5	31.3	32.9	0.12	0.01	0.18	0.09
Rolling Herd Average	9205	9275	8766	8036	78.49	-0.01	-0.01	0.31
				All Years				
% Dry	13.8	16.4	21.5	30.6	0.3	0.01	0.01	-0.24
% Fdry	6.9	25.9	46.8	68.1	0.7	0.01	0.24	-0.75
Total Dry wk	9.7	11.4	15.1	20.6	0.16	0.01	0.01	0.87
Lactation Days	324	304	276	235	1.95	-0.01	-0.01	-0.66
Milk (kg)	30.9	30.8	31.8	33.2	0.09	0.01	0.02	0.87
Rolling Herd Average	9476	9393	9106	8418	56.49	-0.01	-0.01	-0.44

[1]L = Linear, Q = Quadratic, LF = Lack of Fit

Table 21. Mean investments 6%.

Variable	Dry off Milk Yield (kg) 8	13	18	23	SE	Contrast[1] L	Q	LF
				Year 1				
Investment Change	240	-2640	1080	5040	1944	0.04	0.08	-0.47
Interest on Cattle	10944	11318	12101	13200	105	0.01	0.07	-0.85
Net Cash Income	212890	209846	213477	210478	2805	-0.77	0.99	-0.20
Interest – Invest Change	10704	13958	11021	8160	1936	-0.22	-0.12	0.47
Net Farm Income	202186	195888	202456	202318	3097	0.62	0.32	-0.16
				Year 2				
Investment Change	1560	3360	240	3720	1944	0.70	0.67	0.19
Interest on Cattle	11016	11347	12154	13550	105	0.01	0.01	0.81
Net Cash Income	205120	208388	210217	206110	2805	0.70	-0.19	-0.72
Interest – Invest Change	9456	7987	11914	9830	1936	0.56	-0.87	-0.19
Net Farm Income	195664	200401	198303	196279	3097	-0.99	-0.28	0.62
				Year 3				
Investment Change	-840	3360	2520	10440	1944	0.02	0.34	0.12
Interest on Cattle	11045	11616	12264	14117	105	0.01	0.01	0.02
Net Cash Income	200054	207426	203059	201284	2805	-0.96	-0.11	0.26
Interest – Invest Change	11885	8256	9744	3677	1936	-0.09	-0.53	-0.15
Net Farm Income	188169	199170	193315	197607	3097	0.11	-0.28	0.05
				All Years				
Investment Change	320	1360	1280	6400	840	0.01	0.02	0.01
Interest on Cattle	11002	11427	12173	13622	90	0.01	0.01	0.34
Net Cash Income	206021	208554	208917	205957	1643	0.98	-0.10	-0.88
Interest – Invest Change	10682	10067	10893	7222	827	-0.01	-0.07	-0.11
Net Farm Income	195340	198486	198025	198735	1640	0.19	-0.46	0.52

[1]L = Linear, Q = Quadratic, LF = Lack of Fit

Table 22. Mean income 8%.

	Dry off Milk Yield (kg)					Contrast[1]		
Variable	8	13	18	23	SE	L	Q	LF
				Year 1				
Milk Income	334253	341883	352933	364544	1952	0.01	0.31	0.74
Cull Income	15233	15494	16362	17751	701	0.01	0.42	-0.98
Calf Income	10509	10808	11663	13189	137	0.01	0.01	0.85
Total Income	359995	368186	380958	395483	2054	0.01	0.13	-0.76
				Year 2				
Milk Income	330222	339146	348815	365608	1952	0.01	0.05	0.47
Cull Income	15364	15841	14799	16709	701	0.34	0.31	0.16
Calf Income	10949	11205	11884	13947	137	0.01	0.01	0.12
Total Income	356535	366192	375498	396264	2054	0.01	0.08	0.20
				Year 3				
Milk Income	322583	331462	346624	360923	1952	0.01	0.17	-0.41
Cull Income	15624	17230	16883	18141	701	0.02	-0.80	0.26
Calf Income	10544	11320	12475	14061	137	0.01	0.04	0.93
Total Income	348751	360011	375982	393126	2054	0.01	0.15	-0.70
				All Years				
Milk Income	329019	337497	349458	363692	1337	0.01	0.03	0.84
Cull Income	15407	16188	16015	17534	382	0.05	0.34	0.13
Calf Income	10667	11111	12007	13732	82	0.01	0.01	0.31
Total Income	355094	364796	377479	394958	1364	0.01	0.06	0.77

[1]L = Linear, Q = Quadratic, LF = Lack of Fit

Table 23. Mean expenses 8%.

	Dry off Milk Yield (kg)					Contrast[1]		
Variable	8	13	18	23	SE	L	Q	LF
				Year 1				
Feed Exp. (Milking Cows)	93070	94522	96536	98772	378	0.01	0.30	-0.84
Feed Exp. (Dry Cows)	6896	8569	11977	19240	343	0.01	0.01	0.17
Other Exp. (Dry Cows)	2759	3427	4791	7696	96	0.01	0.01	0.17
Heifer Purchase	47280	47280	52800	56520	2158	0.07	0.39	-0.45
Total Expenses	150005	153798	166105	182228	2128	0.01	0.04	-0.62
				Year 2				
Feed Exp. (Milking Cows)	92322	94015	95807	98971	378	0.01	0.05	0.45
Feed Exp. (Dry Cows)	7464	9052	13997	22606	343	0.01	0.01	0.84
Other Exp. (Dry Cows)	2986	3621	5599	9043	96	0.01	0.01	0.84
Heifer Purchase	45120	47040	45840	56400	2158	0.09	0.05	0.13
Total Expenses	147892	153728	16124	187020	2128	0.01	0.01	0.08
				Year 3				
Feed Exp. (Milking Cows)	90878	92511	95371	98047	378	0.01	0.17	-0.40
Feed Exp. (Dry Cows)	7478	9767	14889	23441	343	0.01	0.01	0.70
Other Exp. (Dry Cows)	2991	3907	5956	9377	96	0.01	0.01	0.70
Heifer Purchase	44760	48720	52200	57240	2158	0.01	0.80	0.83
Total Expenses	146107	154905	168417	188105	2128	0.01	0.01	0.88
				All Years				
Feed Exp. Milking Cows	92090	93683	95905	98597	257	0.01	0.04	-0.89
Feed Exp. (Dry Cows)	7279	9129	13621	21762	241	0.01	0.01	0.35
Other Exp. (Dry Cows)	2912	3652	5449	8705	68	0.01	0.01	0.35
Heifer Purchase	45720	47680	50280	56720	1190	0.01	0.06	0.55
Total Expenses	148001	154144	165255	185784	1205	0.01	0.01	0.41

[1]L = Linear, Q = Quadratic, LF = Lack of Fit

Table 24. Mean herd variables 8%.

	Dry off Milk Yield (kg)					Contrast[1]		
Variable	8	13	18	23	SE	L	Q	LF
				Year 1				
% Dry	13.2	15.9	21.0	29.9	0.4	0.01	0.01	0.41
% Fdry	4.2	19.8	42.1	64.4	1.4	0.01	0.02	-0.29
Total Dry wk	9.4	10.7	13.2	17.8	0.25	0.01	0.01	0.49
Lactation Days	310	295	259	221	3.13	-0.01	-0.05	0.14
Milk (kg)	30.9	31.6	32.7	33.7	0.12	0.01	0.33	-0.53
Rolling Herd Average	9778	9691	9431	8634	78	-0.01	-0.01	-0.30
				Year 2				
% Dry	14.2	16.6	23.6	33.3	0.4	0.01	0.01	-0.31
% Fdry	9.3	28.3	55.4	76.9	1.4	0.01	0.40	-0.03
Total Dry wk	9.5	11.6	15.9	22.3	0.25	0.01	0.01	-0.81
Lactation Days	331	313	281	237	3.13	-0.01	-0.01	0.90
Milk (kg)	30.4	31.3	32.3	33.8	0.12	0.01	0.03	0.52
Rolling Herd Average	9552	9524	8989	8233	78	-0.01	-0.01	0.42
				Year 3				
% Dry	14.2	17.8	24.8	34.1	0.4	0.01	0.01	-0.55
% Fdry	17.7	41.6	69.2	81.9	1.4	0.01	-0.01	-0.04
Total Dry wk	10.2	13.4	18.6	24.6	0.25	0.01	0.01	-0.32
Lactation Days	330	308	273	227	3.13	-0.01	-0.02	0.97
Milk (kg)	29.8	30.6	32.1	33.4	0.12	0.01	0.17	-0.44
Rolling Herd Average	9327	9199	88804	8039	78	-0.01	-0.01	-0.77
				All Years				
% Dry	13.9	16.8	23.1	32.4	0.3	0.01	0.01	0.70
% Fdry	10.4	29.9	55.6	74.4	0.7	0.01	-0.74	-0.05
Total Dry wk	9.7	11.9	15.9	21.6	0.17	0.01	0.01	-0.78
Lactation Days	324	305	271	229	1.95	-0.01	-0.01	0.38
Milk (kg)	30.4	31.2	32.3	33.7	0.09	0.01	0.03	-0.71
Rolling Herd Average	9552	9471	9075	8302	56	-0.01	-0.01	-0.81

[1]L = Linear, Q = Quadratic, LF = Lack of Fit

Table 25. Mean investments 8%.

	Dry off Milk Yield (kg)					Contrast[1]		
Variable	8	13	18	23	SE	L	Q	LF
				Year 1				
Investment Change	1440	-3360	-2040	10800	1944	0.09	0.01	0.54
Interest on Cattle	10992	11318	11995	13430	105	0.01	0.01	0.39
Net Cash Income	209990	214388	214854	213255	2805	0.42	-0.29	0.88
Interest – Invest Change	9552	14678	14035	2630	1936	-0.02	-0.01	-0.57
Net Farm Income	200438	199710	200818	210625	3097	0.02	0.09	0.62
				Year 2				
Investment Change	2640	3120	12000	11640	1944	0.01	-0.83	-0.04
Interest on Cattle	11155	11309	12394	14328	103	0.01	0.01	-0.86
Net Cash Income	208643	212464	214255	209244	2805	0.77	-0.12	-0.70
Interest – Invest Change	8515	8189	394	2688	1936	-0.04	0.50	0.40
Net Farm Income	200128	204275	213861	206556	3097	0.04	-0.07	-0.11
				Year 3				
Investment Change	-1560	2400	-600	-2160	1944	-0.58	-0.16	0.34
Interest on Cattle	11198	11530	12850	14707	105	0.01	0.01	-0.34
Net Cash Income	202644	205106	207565	205020	2805	0.45	-0.37	-0.69
Interest – Invest Change	12758	9130	13450	16867	1936	0.06	0.07	-0.31
Net Farm Income	189885	195976	194115	188153	3097	-0.61	-0.05	0.78
				All Years				
Investment Change	840	720	3120	6760	840	0.01	0.03	-0.73
Interest on Cattle	11115	11386	12413	14155	90	0.01	0.01	-0.92
Net Cash Income	207092	210653	212224	209173	1643	0.29	-0.05	-0.72
Interest – Invest Change	10275	10666	9293	7395	827	-0.01	-0.17	0.74
Net Farm Income	196817	199987	202932	201778	1640	0.02	-0.19	-0.60

[1]L = Linear, Q = Quadratic, LF = Lack of Fit

Effect of Dry off at Each Lactation Decline

Tests of effect of dry off for each rate of decline are in Table 26. With the exception of net cash income and net farm income, all variables were significantly different (P<= 0.10) for dry kg. Net cash income was not significant (P = 0.43) at 6% or at 8% (P = 0.16). Earlier tests also showed lack of significance between level of dry off and rate of decline that between 6% and 8% net cash income was very comparable. Net farm income at 6% decline lacked significance (0.44). However, at 8%, differences among dry kg were significant for net farm income at 0.06. This was due to an increase in net farm income in the third year at 8% decline that did not occur at 6% decline.

Table 26.Tests of dry kg differences (P-values).

	Decline in lactation (%/mo)	
Variables	6 %	8 %
Milk Income	0.01	0.01
Cull Income	0.01	0.02
Calf Income	0.01	0.01
Total Income	0.01	0.01
Feed Expense – Milk	0.01	0.01
Feed Expense – Dry	0.01	0.01
Other Expense – Dry	0.01	0.01
Heifer Purchase	0.01	0.01
Total Expense	0.01	0.01
% Dry	0.01	0.01
% Fdry	0.01	0.01
Total Dry wk	0.01	0.01
Lactation Days	0.01	0.01
Milk (kg)	0.01	0.01
RHA	0.01	0.01
Investment Change	0.01	0.01
Interest on Cattle	0.01	0.01
Net Cash Income	0.43	0.16
Interest – Investment Change	0.08	0.03
Net Farm Income	0.44	0.06

Sensitivity Analysis

Sensitivity analysis was run for nine combinations of income and expense; three incomes over feed cost by three dry cow costs (Appendix A1 to A18 and Figures 11 to 14). The combinations represented increases and decreases of income over feed of 20% (10% milk and 10% feed, in opposite directions), and increases and decreases in dry cow costs (both feed and fixed) of 20%. Low dry cow cost was represented by a –20%, high was +20%, and an average cost was 0% (no change). Milking cow feed costs were subtracted from milk income to emulate lucrative and detrimental economic conditions rather than allowing changes in the two variables to offset each other. For the nine income by dry cost scenarios, net cash income and net farm income were analyzed. For ease of interpretation, the analysis will concentrate on the net cash income and net farm income changes as depicted in the graphs (Figures 11 to 14) and emphasize significant trends in dry kg as indicated by the linear and quadratic orthogonal polynomials.

Net Cash Income and Milk–Feed Income

At high dry cow costs (first three sets of bars), when milk-feed income was reduced by 20%, lower income resulted at 23 kg. Dry kg of 8, 13, and 18 were about equal. Because milk-feed income was 20% lower and dry cost was higher, there were more dry cows in the herd. When milk-feed was increased (+20%), income dropped slightly at 8 kg and increased at 23 kg. Although more dry cows increased the cost, milk production was high enough at 23 dry kg to bring in more income.

At normal dry cow costs (middle three sets of bars), when milk-feed income was reduced (-20%), net income was smallest at 23 kg and largest at 13 kg dry kg. Lactation length was shortened as level of dry off increased. When milk-feed increased (+20%), there was a shift to a linear trend from lowest income at 8 kg to highest income at 23 kg. The larger dry herd at 23 kg was not so costly, allowing the higher milk production to take over. Net cash income increased by $6199 from 8 to 23 kg dry kg.

When dry cow cost was low (last three sets of bars) and milk–feed income was reduced (-20%), there was no advantage of any dry kg over any other dry kg. Any increase in milk production were offset by the low milk–feed price that could not be overcome by dry cow costs because they did not have as great an impact. When milk–feed income was increased (+20%), income became very linear. When high milk-feed income combines with low dry costs net cash income increased $7372 from 8 to 23 kg

Net Cash Income and Dry Cow Cost

At low milk–feed income 23 kg dry kg was at a disadvantage because its extra milk brought little income. When dry cow cost was also reduced (-20%), the net cash income from 23 kg dry kg increased slightly, leaving all four dry kg about equal. When dry cow cost increased +20%, there was very little change, except that 23 kg became more inferior than at normal dry cow costs. Not only was its superior milk of little relative value, but its large dry cow group was most expensive to feed.

When milk–feed income was average and dry cow cost was reduced, income at 23 kg rose above 8 kg, but 13 and 18 kg retained the highest incomes. There was no relative change when dry cow cost increased by 20%, just a little more inferiority of the 23kg.

At high milk–feed income when dry cow cost was reduced, income went from an 18 kg optimum to a 23 kg optimum. Income was significantly greater than that of any of the other eight combinations. Even if there were more dry cows at 23 kg, they cost less to feed and the 20% increase in milk–feed income increased total net cash income.

8% Decline versus 6% Decline

There was little change in patterns of net cash income for 8% decline in lactation compared to 6% decline. At high milk–feed income there was a slight increase in the advantage of the 23 kg dry kg, and the reverse at low milk–feed income. Those cows in the herd at 8% were the highest producers from the 80 herds analyzed. Decline of 8% was designed for the 8 kg runs to produce the same amount of milk with a higher peak. At 23 kg, lactation length was shorter, but at 8% decline, peak milk was high, thus milk per day was higher.

Net Farm Income

The only difference between net cash income and net farm income was non-cash interest cost on the average cattle inventory, and the change in inventory. The change in inventory was offset slightly by increased heifer purchases. The non-cash interest expense was much larger than inventory change and was important in equalizing the dry kg scenarios because each larger dry kg scenario required more dry cows.

With net farm income, all quadratic significances among the four dry kg disappeared, and half the sensitivity combinations did not differ significantly among dry kg. At high milk–feed income all three combinations were significantly linear, with advantages to the 23 kg dry kg, except when dry cow cost was high also (13, 18, and 23 kg equal). At normal milk–feed income, the only trend occurred with low dry cow costs, again an advantage to 23 kg. The only significant net farm income disadvantage for 23 kg was at low milk–feed income and high dry cow cost. Largest advantage for 23 kg was at 8% decline, high milk–feed income, and low dry cow costs. This combination was $13,135 superior in net farm income to the 8 kg run.

Table 27. Significance (P>F) of sources of variation in net income for nine income-dry cost scenarios.

			Milk-Feed Income[1]					
			+20% High		0 Average		-20% Low	
Source	DF	DFe	Net Cash	Net Farm	Net Cash	Net Farm	Net Cash	Net Farm
				Dry Cost[2] +20%				
DryKg	3	72	0.05	0.03	0.06	0.20	0.01	0.06
Decline	1	72	0.04	0.17	0.07	0.04	0.14	0.08
DryKg*Decline	3	72	0.93	0.75	0.94	0.76	0.96	0.76
Year	2	144	0.01	0.01	0.01	0.01	0.01	0.01
DryKg*Year	6	144	0.90	0.02	0.90	0.01	0.89	0.01
Decline*Year	2	144	0.77	0.08	0.76	0.06	0.75	0.04
DryKg*Decline*Year	6	144	0.68	0.12	0.73	0.10	0.76	0.07
				Dry Cost 0%				
DryKg	3	72	0.05	0.01	0.07	0.03	0.05	0.30
Decline	1	72	0.02	0.01	0.04	0.02	0.09	0.05
DryKg*Decline	3	72	0.88	0.69	0.89	0.69	0.91	0.69
Year	2	144	0.01	0.01	0.01	0.01	0.01	0.01
DryKg*Year	6	144	0.90	0.03	0.92	0.02	0.93	0.02
Decline*Year	2	144	0.74	0.07	0.74	0.05	0.73	0.04
DryKg*Decline*Year	6	144	0.68	0.11	0.73	0.08	0.78	0.06
				Dry Cost -20%				
DryKg	3	72	0.01	0.01	0.04	0.01	0.10	0.04
Decline	1	72	0.01	0.05	0.02	0.01	0.05	0.03
DryKg*Decline	3	72	0.82	0.61	0.82	0.61	0.83	0.61
Year	2	144	0.01	0.01	0.01	0.01	0.01	0.01
DryKg*Year	6	144	0.88	0.03	0.92	0.03	0.95	0.02
Decline*Year	2	144	0.72	0.07	0.71	0.05	0.70	0.04
DryKg*Decline*Year	6	144	0.69	0.10	0.73	0.08	0.78	0.06

[1]Milk-feed income includes high, average, low (10% milk and 10% feed) for milk income and milk feed expense variables.
[2]Dry cost increase dry, average, and low feed expenses and other dry cow expenses.

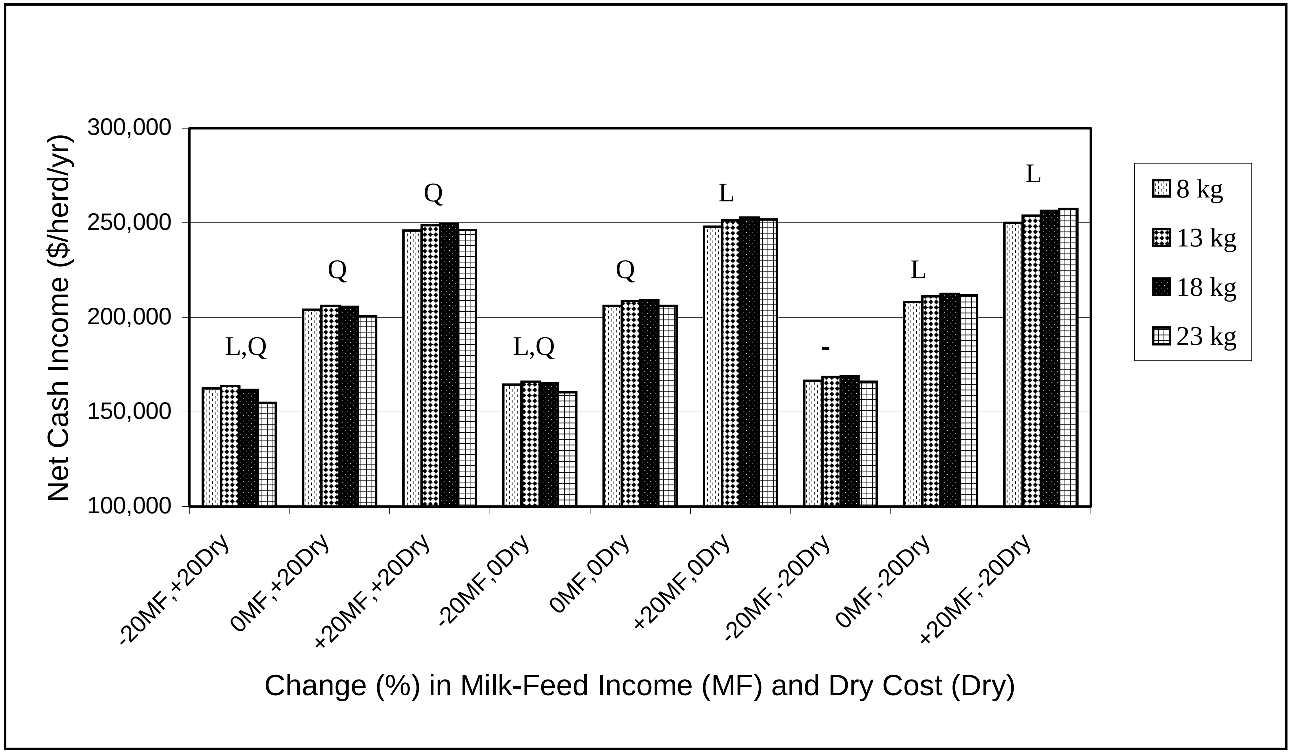

Figure 11. Net cash income by change in milk - feed income and dry cow cost at 6% decline (L = Linear, Q = Quadratic).

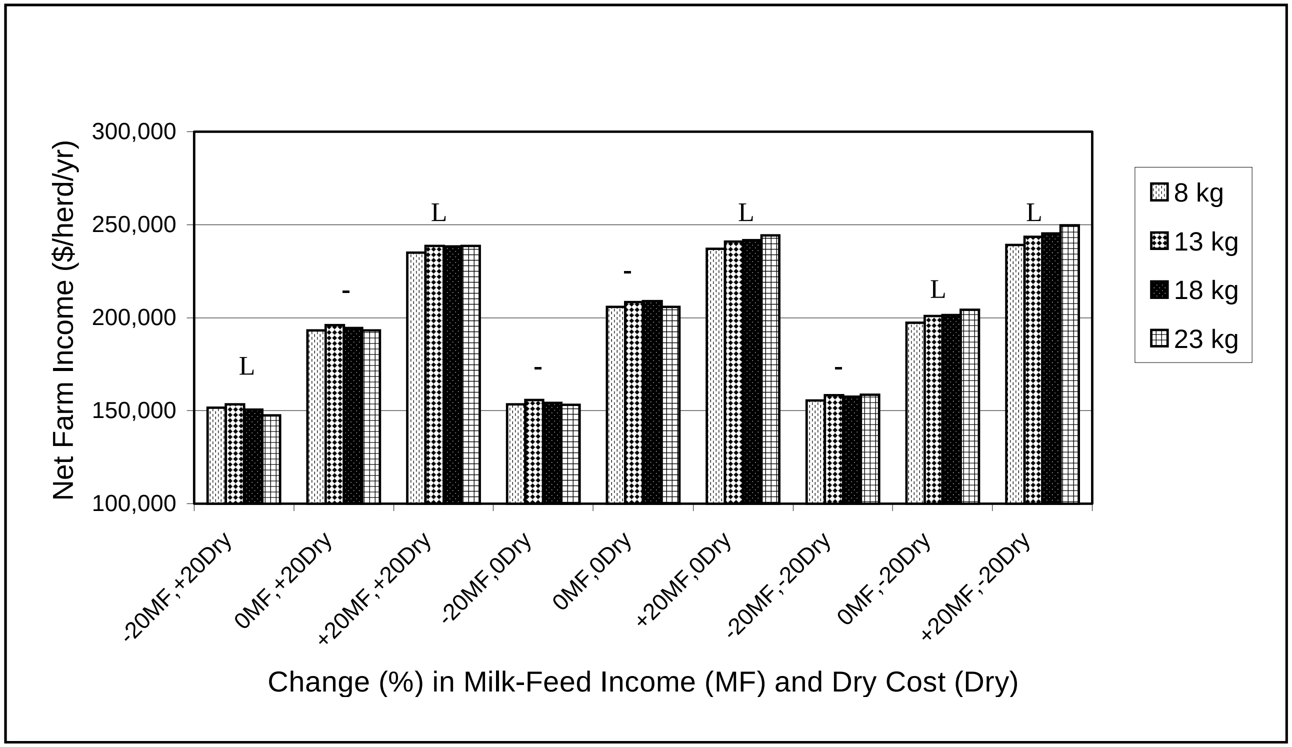

Figure 12. Net farm income by change in milk – feed income and dry cow cost at 6% decline (L= Linear, Q = Quadratic).

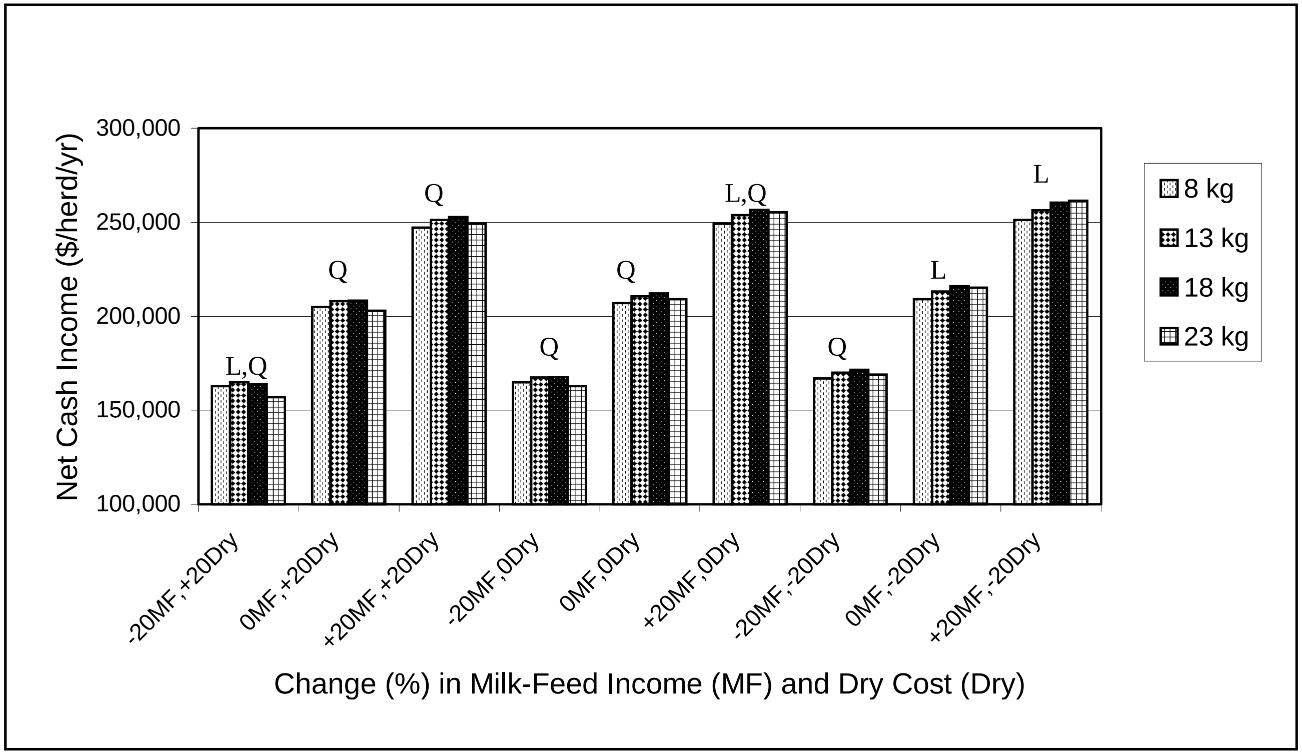

Figure 13. Net cash income by change in milk – feed income and dry cow cost at 8% decline (L = Linear, Q = Quadratic).

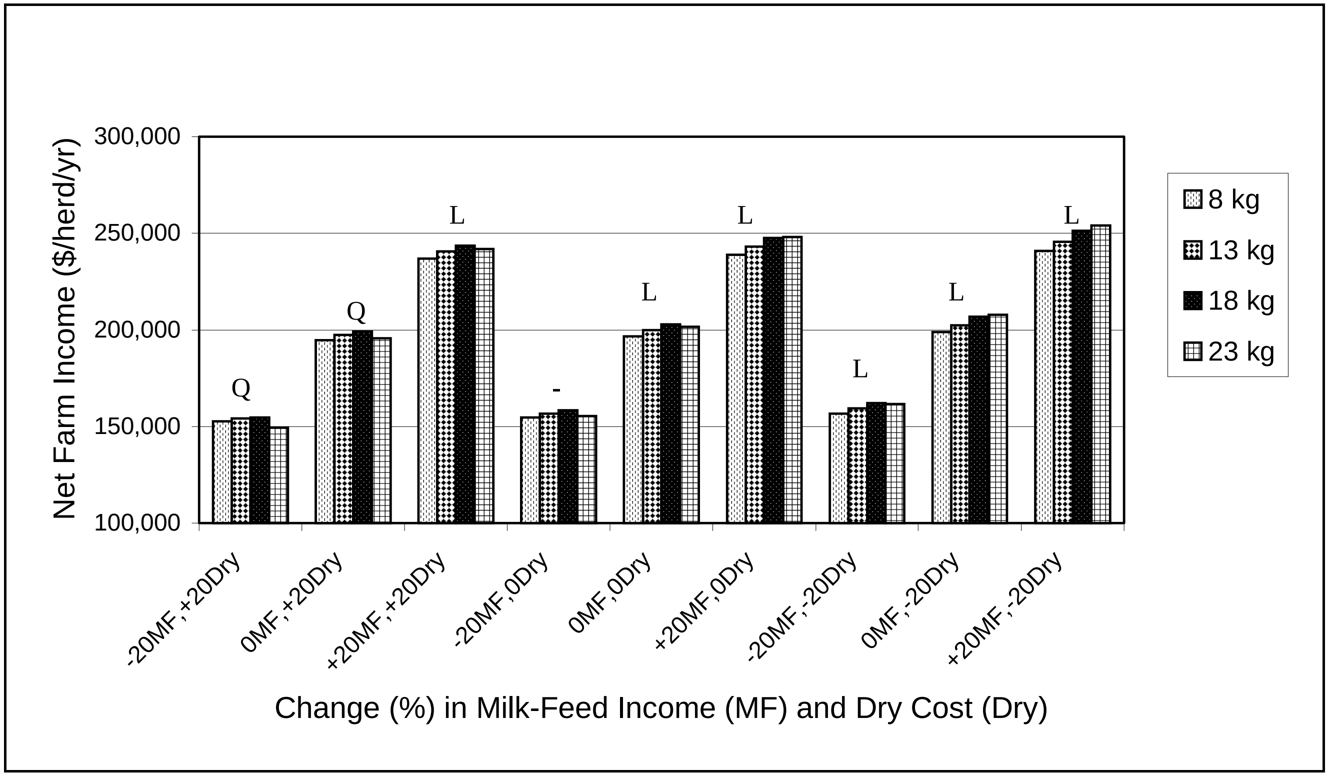

Figure 14. Net farm income by change in milk – feed income and dry cow cost at 8% decline (L = Linear, Q = Quadratic).

Other Possibilities

Several other combinations could have been analyzed because this was a simulation. The parameter page held the variables that could be easily changed. Changes in the sensitivity analysis were done under SAS software. Possible variables to change include rate of decline, simulating drug interaction (bST) to influence milk yield, peak milk yield, days dry, lengthening or shortening of lactation, timing of first possible service, number of heats before culled, culling percent, and many others. Changes in other variables such as herd size, dry matter intake, dairy facility size, and manure management can influence income and expenses. The simulation can be modified for a dairy using bST. The peak milk yield would have to be modified with an increase every 14 d followed by a drop 10 d after that, simulating a bST injection. A bST program would extend the lactation length, and if the herd size remained constant, benefits could be demonstrated with the simulation under scenarios of different production, calving intervals, dry off levels, and dry cow costs. The parameter page does not include any financial variables. The Count worksheet has a reference that contains the rations fed, milk price, and other price variables. The reference sheet could be changed as desired

Conclusions

There were a number of cost concepts that were important when considering the economic consequences of the scenarios investigated. Opportunity cost is fundamental to economic decision making. Here it was the opportunity to have a fresher cow in milk by drying off a more stale cow. The dairy farm as an enterprise is subject to a constant stream of fluctuating circumstances. The study simulated typical lactations in a herd. Management strategies were devised for drying off cows, and resulting net cash income and net farm income was determined. The simulation performed well. However, it was unable to account for extreme events or cycles that occurred periodically, such as clusters of dry cows.

As expected, percentage of dry cows and cows forced dry increased as dry kg increased. The percentages also increased over the three years. Dry cow groups at 8, 13, 18, and 23 kg were 14, 17, 23, and 32 % of total herds, respectively. Average daily milk (kg) increased for the four dry kg: 30.4, 31.2, 32.3, and 33.7 kg/d per milking cow, whereas RHA decreased, 9552, 9471, 9075, and 8302 kg/yr per cow. Length of lactation decreased as the percentage of cows forced dry increased. Lactation length (d) was 324, 305, 271, and 229 d for the four dry kg. Percent forced dry at 8, 13, 18, and 23 kg was 10, 30, 56, and 74 %. The increase in percent forced dry also increased total weeks dry. Weeks dry for 8, 13, 18, and 23 dry kg were 9.7, 11.9, 15.9, and 21.6 wk. Obviously, dry cow group sizes for 8, 13, 18, and 23 kg scenarios required increased costs for dry cow feed expense and fixed expenses. The larger herds, due to more cows dry, incurred additional expenses by non-cash interest charges on the extra cattle, reflected in net farm income.

Sensitivity analysis was run for three incomes over feed cost combined with three dry cow costs. Dry kg did not interact with decline at all, except through a year interaction. Dry kg interacted with years for net farm income, regardless of the sensitivity run, indicating difficulty in predicting outcomes for individual years. As milk-feed income was reduced, rate of lactation decline became more influential. Net cash income did not change with years or rate of decline, thus the interaction of net farm income was largely due to acquisition of more or fewer dry cows, changing investment numbers and interest on investment. When milk–feed income and dry cow costs were both high, both average, or both low, 8 and 23 kg dry kg were financially equal and inferior to 13 and 18 kg. However, when dry cow cost was high and milk–feed income was low, 23 kg dry kg was at a large disadvantage to 18 kg. Net cash income dropped $7023 from 18 kg to 23 kg. Net farm income decreased $5226. At low dry cow cost and at high milk–feed income, each successive step from 8 to 23 kg brought more net farm income. The 8% decline increased early dry offs, which was most advantageous at high milk–feed income as long as dry cow costs were not large.

At normal economy, with milk–feed income average and dry cow cost average, net cash income changed $3561, $1571, and $-3051 from 8 to 13 to 18 to 23 kg dry kg. Net farm income under the same scenario changed $3170, $2945, and $-1154. Under the best economic situation, high milk–feed income and low dry cow costs, net cash income increased with each successive dry kg, \$5086, \$4248, and \$921. Net farm income also increased \$4695, \$5621, and \$2819. Net cash income and net farm income were the largest at 13 and 18 kg when milk–feed income was low and dry cow cost was high, worst economic scenario. Then net cash income from 8, 13, 18, and 23 kg changed \$2015, \$-1104, and \$-7023, whereas net farm income changed \$1645, \$369, and \$-5226. Net farm income (interest and inventory) increased as dry kg and dry cow herd size increased. There was no purchase price paid for the extra dry cows required in the initial herds (18 kg and 23 kg dry, for instance) because it was assumed they could be sold in the end. However, interest was charged on the value of the larger cattle inventory.

Only in the most optimistic economic situations does it appear practically worthwhile for a dairy business to adopt early dry off beyond 13 kg/d given the small relative gains and the yearly variability. Strategies of dry off at larger dry kg, although not greatly profitable, nevertheless were not extremely unprofitable either.

As the economy changes and dairy management decisions change, this simulation can be revised to accommodate those changes. The flexibility to analyze different economic situations, herd characteristics, and management decisions provides the ability to determine optimum situations for the dairy enterprise.

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Appendix

Table A1. LS means and contrasts at 6% decline for dry cow cost +20% and milk-feed income –20%.

	Dry off Milk Yield (kg)					Contrast[1]		
Variable	8	13	18	23	SE	L	Q	LF
				Year 1				
Net Cash Income	168195	164708	166221	159781	2675	-0.05	-0.58	-0.28
Net Farm Income	157490	150749	155200	151621	2977	-0.32	0.59	-0.15
				Year 2				
Net Cash Income	161532	163196	162551	154788	2675	-0.08	-0.08	-0.69
Net Farm Income	152076	155209	150637	144958	2977	-0.05	-0.14	0.62
				Year 3				
Net Cash Income	157122	162535	156063	149778	2675	-0.02	-0.03	0.31
Net Farm Income	145237	154279	146319	146101	2977	-0.69	-0.12	0.06
				All Years				
Net Cash Income	162283	163480	161612	154782	1551	-0.08	-0.01	-0.79
Net Farm Income	151601	153412	150719	147560	1546	-0.04	-0.11	0.56

[1]L = Linear, Q = Quadratic, LF = Lack of Fit

Table A2. LS means and contrasts at 6% decline for dry cow cost +20% and milk-feed income 0%.

	Dry off Milk Yield (kg)					Contrast[1]		
Variable	8	13	18	23	SE	L	Q	LF
				Year 1				
Net Cash Income	210947	207512	210400	205600	2844	-0.30	-0.81	-0.27
Net Farm Income	200243	193554	199379	197440	3107	0.85	-0.45	0.15
				Year 2				
Net Cash Income	203095	205852	206713	200509	2844	-0.59	-0.12	-0.68
Net Farm Income	193639	197864	194800	190678	3107	0.39	0.18	-0.65
				Year 3				
Net Cash Income	197960	204864	199234	195011	2844	-0.26	-0.05	0.27
Net Farm Income	186075	196608	189490	191334	3107	-0.53	0.16	-0.06
				All Years				
Net Cash Income	204001	206076	205449	200373	1677	-0.13	-0.04	-0.82
Net Farm Income	193319	196009	194556	193151	1657	-0.79	-0.22	0.57

[1]L = Linear, Q = Quadratic, LF = Lack of Fit

Table A3. LS means and contrasts at 6% decline for dry cow cost +20% and milk-feed income +20%.

	Dry off Milk Yield (kg)					Contrast[1]		
Variable	8	13	18	23	SE	L	Q	LF
				Year 1				
Net Cash Income	253700	250316	254579	251420	3201	-0.85	0.97	-0.27
Net Farm Income	242996	236358	243558	243260	3249	0.58	0.33	-0.14
				Year 2				
Net Cash Income	244657	248507	250875	246229	3201	0.60	-0.16	-0.68
Net Farm Income	235201	240520	238962	236399	3249	0.89	-0.23	0.69
				Year 3				
Net Cash Income	238798	247194	242405	240243	3201	-0.97	-0.08	0.24
Net Farm Income	226913	238938	232661	236566	3249	0.12	-0.21	0.05
				All Years				
Net Cash Income	245718	248672	249286	245964	1808	0.87	-0.09	-0.84
Net Farm Income	235037	238605	238393	238742	1775	0.03	-0.13	0.59

[1]L = Linear, Q = Quadratic, LF = Lack of Fit

Table A4. LS means and contrasts at 6% decline for dry cow cost 0% and milk-feed income –20%.

	Dry off Milk Yield (kg)					Contrast[1]		
Variable	8	13	18	23	SE	L	Q	LF
				Year 1				
Net Cash Income	170138	167043	169298	164659	2637	-0.23	-0.77	-0.30
Net Farm Income	159434	153084	158177	156499	2969	-0.79	0.44	-0.17
				Year 2				
Net Cash Income	163557	165733	166054	160389	2637	-0.43	-0.14	-0.73
Net Farm Income	154101	157746	154140	150559	2969	-0.29	-0.23	0.58
				Year 3				
Net Cash Income	159216	165096	159888	156052	2637	-0.21	-0.07	0.29
Net Farm Income	147331	156840	150144	152375	2969	0.53	-0.22	0.06
				All Years				
Net Cash Income	164304	165957	165080	160367	1517	-0.07	-0.04	-0.85
Net Farm Income	153622	155890	154187	153144	1530	-0.65	-0.28	0.50

[1]L = Linear, Q = Quadratic, LF = Lack of Fit

Table A5. LS means and contrasts at 6% decline for dry cow cost 0% and milk-feed income 0%.

	Dry off Milk Yield (kg)					Contrast[1]		
Variable	8	13	18	23	SE	L	Q	LF
				Year 1				
Net Cash Income	212890	209846	213477	210478	2805	-0.77	0.99	-0.20
Net Farm Income	202186	195888	202456	202318	3097	0.62	0.32	-0.16
				Year 2				
Net Cash Income	205120	208388	210217	206110	2805	0.70	-0.19	-0.72
Net Farm Income	195664	200401	198303	196279	3097	-0.99	-0.28	0.62
				Year 3				
Net Cash Income	200054	207426	203059	201284	2805	-0.96	-0.11	0.26
Net Farm Income	188169	199170	193315	197607	3097	0.11	-0.28	0.05
				All Years				
Net Cash Income	206021	208554	208917	205957	1643	0.98	-0.10	-0.88
Net Farm Income	195340	198486	198025	198735	1640	0.19	-0.46	0.52

[1]L = Linear, Q = Quadratic, LF = Lack of Fit

Table A6. LS means and contrasts at 6% decline for dry cow cost 0% and milk-feed income +20%.

	Dry off Milk Yield (kg)					Contrast[1]		
Variable	8	13	18	23	SE	L	Q	LF
				Year 1				
Net Cash Income	255643	252651	257656	256298	2983	0.60	0.78	-0.28
Net Farm Income	244939	238693	246635	248138	3237	0.23	0.23	-0.16
				Year 2				
Net Cash Income	246682	251044	254379	251830	2983	0.16	-0.25	-0.73
Net Farm Income	237226	243057	242465	241200	3237	0.34	-0.33	0.65
				Year 3				
Net Cash Income	240892	249755	246230	246517	2983	0.32	-0.15	0.23
Net Farm Income	229007	241499	236486	242840	3237	0.01	-0.34	0.05
				All Years				
Net Cash Income	247739	251150	252755	251548	1774	0.10	-0.20	-0.90
Net Farm Income	237058	241083	241862	244326	1756	0.05	-0.66	0.53

[1]L = Linear, Q = Quadratic, LF = Lack of Fit

Table A7. LS means and contrasts at 6% decline for dry cow cost -20% and milk-feed income –20%.

	Dry off Milk Yield (kg)					Contrast[1]		
Variable	8	13	18	23	SE	L	Q	LF
				Year 1				
Net Cash Income	172081	169377	172375	169537	2602	-0.69	-0.98	-0.32
Net Farm Income	161377	155419	161354	161377	2964	0.66	0.31	-0.18
				Year 2				
Net Cash Income	165582	168270	169558	165990	2602	0.83	-0.23	-0.77
Net Farm Income	156126	160283	157644	156160	2964	-0.85	-0.34	0.55
				Year 3				
Net Cash Income	161310	167658	163714	162326	2602	0.94	-0.14	0.27
Net Farm Income	149426	159402	153970	158649	2964	0.10	-0.37	0.06
				All Years				
Net Cash Income	166324	168435	168549	165951	1485	0.88	-0.12	-0.91
Net Farm Income	155643	158368	157656	158728	1517	0.21	-0.59	0.44

[1]L = Linear, Q = Quadratic, LF = Lack of Fit

Table A8. LS means and contrasts at 6% decline for dry cow cost -20% and milk-feed income 0%.

	Dry off Milk Yield (kg)					Contrast[1]		
Variable	8	13	18	23	SE	L	Q	LF
				Year 1				
Net Cash Income	214834	212182	216554	215356	2770	0.63	0.79	-0.31
Net Farm Income	204130	198223	205533	207196	1625	0.23	0.22	-0.17
				Year 2				
Net Cash Income	207145	210925	213720	211711	2770	0.18	-0.30	-0.76
Net Farm Income	197689	202938	201807	201880	1625	0.41	-0.40	0.58
				Year 3				
Net Cash Income	202148	209987	206884	207558	2770	0.29	-0.20	0.24
Net Farm Income	190264	201731	197140	203881	1625	0.10	-0.45	0.05
				All Years				
Net Cash Income	208042	211031	212386	211542	1611	0.10	-0.24	-0.94
Net Farm Income	197361	200964	201493	204319	1149	0.04	0.81	-0.46

[1]L = Linear, Q = Quadratic, LF = Lack of Fit

Table A9. LS means and contrasts at 6% decline for dry cow cost -20% and milk-feed income +20%.

	Dry off Milk Yield (kg)					Contrast[1]		
Variable	8	13	18	23	SE	L	Q	LF
				Year 1				
Net Cash Income	257586	254986	260732	261175	2947	0.21	0.61	-0.30
Net Farm Income	246882	241027	249712	253015	3228	0.06	0.16	-0.17
				Year 2				
Net Cash Income	248708	253580	257882	257431	2947	0.02	-0.37	-0.75
Net Farm Income	239252	245593	245969	247601	3228	0.08	-0.47	0.62
				Year 3				
Net Cash Income	242986	252316	250055	252790	2947	0.04	-0.26	0.21
Net Farm Income	231102	244060	240311	249114	3228	0.07	-0.52	0.04
				All Years				
Net Cash Income	249760	253627	256223	257132	1742	0.02	-0.40	-0.96
Net Farm Income	239078	243560	245331	249910	1741	0.01	0.98	0.48

[1]L = Linear, Q = Quadratic, LF = Lack of Fit

Table A10. LS means and contrasts at 8% decline for dry cow cost +20% and milk-feed income –20%.

	Dry off Milk Yield (kg)					Contrast[1]		
Variable	8	13	18	23	SE	L	Q	LF
				Year 1				
Net Cash Income	165327	168348	166553	161537	2675	-0.27	-0.14	0.89
Net Farm Income	155775	150844	152518	158906	2977	0.32	0.59	0.15
				Year 2				
Net Cash Income	164298	166613	165873	156457	2675	-0.04	-0.03	-0.64
Net Farm Income	155783	158424	165480	153769	2977	0.05	-0.14	-0.62
				Year 3				
Net Cash Income	159204	159974	159197	152560	2675	-0.09	-0.17	-0.72
Net Farm Income	146445	150844	145747	135692	2977	-0.69	-0.12	0.06
				All Years				
Net Cash Income	162943	164978	163874	156851	1551	-0.07	-0.05	-0.67
Net Farm Income	152668	154313	154682	149456	1546	-0.18	-0.03	-0.56

[1]L = Linear, Q = Quadratic, LF = Lack of Fit

Table A 1. LS means and contrasts at 8% decline for dry cow cost +20% and milk-feed income 0%.

	Dry off Milk Yield (kg)					Contrast[1]		
Variable	8	13	18	23	SE	L	Q	LF
				Year 1				
Net Cash Income	205059	211989	211500	207868	2844	-0.93	-0.19	0.92
Net Farm Income	198507	197310	197465	205238	3107	-0.14	-0.15	-0.65
				Year 2				
Net Cash Income	206553	209929	210336	202915	2844	-0.41	-0.06	-0.70
Net Farm Income	198037	201740	209942	200227	3107	-0.29	0.03	0.11
				Year 3				
Net Cash Income	200550	202371	203396	198457	2844	-0.68	-0.24	-0.69
Net Farm Income	187791	193241	189945	181590	3107	0.11	0.03	-0.70
				All Years				
Net Cash Income	205054	208096	208411	203080	1677	-0.46	-0.01	-0.70
Net Farm Income	194779	197431	199118	195685	1657	0.55	-0.07	-0.58

[1]L = Linear, Q = Quadratic, LF = Lack of Fit

Table A12. LS means and contrasts at 8% decline for dry cow cost +20% and milk-feed income +20%.

	Dry off Milk Yield (kg)					Contrast[1]		
Variable	8	13	18	23	SE	L	Q	LF
				Year 1				
Net Cash Income	250791	255629	256447	254200	3021	0.41	-0.24	0.94
Net Farm Income	241240	240951	242412	251569	3249	0.03	0.15	0.68
				Year 2				
Net Cash Income	248807	253245	254798	249373	3021	0.81	-0.10	-0.76
Net Farm Income	240292	245056	254404	246685	3249	0.05	-0.06	-0.14
				Year 3				
Net Cash Income	241896	244768	247596	244354	3021	0.45	-0.31	-0.67
Net Farm Income	229138	235639	234146	227486	3249	-0.66	-0.04	0.85
				All Years				
Net Cash Income	247165	251214	252947	249309	1808	0.32	-0.04	-0.71
Net Farm Income	236890	240549	243654	241913	1775	0.02	-0.13	-0.59

[1]L = Linear, Q = Quadratic, LF = Lack of Fit

Table A13. LS means and contrasts at 8% decline for dry cow cost 0% and milk-feed income –20%.

	Dry off Milk Yield (kg)					Contrast[1]		
Variable	8	13	18	23	SE	L	Q	LF
				Year 1				
Net Cash Income	167258	170747	169906	166924	2637	-0.87	-0.22	0.85
Net Farm Income	157706	156069	155872	164293	2969	0.14	0.09	0.59
				Year 2				
Net Cash Income	166388	169148	169793	162787	2637	-0.39	-0.07	-0.64
Net Farm Income	157873	160959	169399	160099	2969	0.26	-0.04	-0.08
				Year 3				
Net Cash Income	161298	162708	163366	159123	2637	-0.62	-0.29	-0.73
Net Farm Income	148539	153579	149916	142256	2969	-0.09	-0.03	0.72
				All Years				
Net Cash Income	164981	167535	167688	162945	1517	-0.38	-0.02	-0.71
Net Farm Income	154706	156869	158396	155549	1530	0.56	-0.11	-0.59

[1]L = Linear, Q = Quadratic, LF = Lack of Fit

Table A14. LS means and contrasts at 8% decline for dry cow cost 0% and milk-feed income 0%.

	Dry off Milk Yield (kg)					Contrast[1]		
Variable	8	13	18	23	SE	L	Q	LF
				Year 1				
Net Cash Income	209990	214388	214854	213255	2805	0.42	-0.29	0.88
Net Farm Income	200438	199710	200818	210625	3097	0.02	0.09	0.62
				Year 2				
Net Cash Income	208643	212464	214255	209244	2805	0.77	-0.12	-0.70
Net Farm Income	200128	204275	213861	206556	3097	0.04	-0.07	-0.11
				Year 3				
Net Cash Income	202644	205106	207565	205020	2805	0.45	-0.37	-0.69
Net Farm Income	189885	195976	194115	188153	3097	-0.61	-0.05	0.78
				All Years				
Net Cash Income	207092	210653	212224	209173	1643	0.29	-0.05	-0.72
Net Farm Income	196817	199987	202932	201778	1640	0.02	-0.19	-0.60

[1]L = Linear, Q = Quadratic, LF = Lack of Fit

Table A15. LS means and contrasts at 8% decline for dry cow cost 0% and milk-feed income +20%.

	Dry off Milk Yield (kg)					Contrast[1]		
Variable	8	13	18	23	SE	L	Q	LF
				Year 1				
Net Cash Income	252723	258029	259801	259587	2983	0.10	-0.36	0.91
Net Farm Income	243171	243350	245765	256956	3237	0.03	0.09	0.65
				Year 2				
Net Cash Income	250897	255780	258717	255702	2983	0.20	-0.19	-0.76
Net Farm Income	242382	247591	258323	253014	3237	0.04	-0.11	-0.14
				Year 3				
Net Cash Income	243990	247503	251765	250917	2983	0.06	-0.47	-0.66
Net Farm Income	231232	238373	238315	234050	3237	0.56	-0.08	0.84
				All Years				
Net Cash Income	249203	253770	256761	255402	1774	0.08	-0.10	-0.73
Net Farm Income	238928	243105	247468	248007	1756	0.01	-0.30	-0.61

[1]L = Linear, Q = Quadratic, LF = Lack of Fit

Table A16. LS means and contrasts at 8% decline for dry cow cost -20% and milk-feed income –20%.

	Dry off Milk Yield (kg)					Contrast[1]		
Variable	8	13	18	23	SE	L	Q	LF
				Year 1				
Net Cash Income	169189	173147	173260	172311	2602	0.42	-0.35	0.81
Net Farm Income	159637	158468	159225	169680	2964	0.02	0.05	0.56
				Year 2				
Net Cash Income	168478	171682	173712	169116	2602	0.74	-0.14	-0.64
Net Farm Income	159963	163493	173318	166428	2964	0.03	-0.08	-0.08
				Year 3				
Net Cash Income	163392	165443	167535	165687	2602	0.44	-0.45	-0.73
Net Farm Income	150633	156314	154085	148820	2964	-0.56	-0.07	0.71
				All Years				
Net Cash Income	167020	170091	171502	169038	1485	0.26	-0.07	-0.74
Net Farm Income	156744	159425	162210	161643	1517	0.01	-0.29	-0.61

[1]L = Linear, Q = Quadratic, LF = Lack of Fit

Table A17. LS means and contrasts at 8% decline for dry cow cost -20% and milk-feed income 0%.

	Dry off Milk Yield (kg)					Contrast[1]		
Variable	8	13	18	23	SE	L	Q	LF
				Year 1				
Net Cash Income	211921	216787	218207	218642	2770	0.08	-0.43	0.84
Net Farm Income	202369	202109	204172	216012	1625	0.02	0.05	0.59
				Year 2				
Net Cash Income	210733	214998	218174	215574	2770	0.15	-0.22	-0.71
Net Farm Income	202217	206809	217780	212886	1625	0.02	-0.13	-0.11
				Year 3				
Net Cash Income	204738	207841	211734	211584	2770	0.05	-0.56	-0.70
Net Farm Income	191979	198711	198285	194717	1625	0.57	-0.10	0.77
				All Years				
Net Cash Income	209130	213209	216039	215267	2770	0.04	-0.14	-0.74
Net Farm Income	198855	202543	206746	207872	1149	0.01	-0.43	-0.62

[1]L = Linear, Q = Quadratic, LF = Lack of Fit

Table A18. LS means and contrasts at 8% decline for dry cow cost -20% and milk-feed income +20%.

	Dry off Milk Yield (kg)					Contrast[1]		
Variable	8	13	18	23	SE	L	Q	LF
				Year 1				
Net Cash Income	254653	260428	263154	264974	2947	0.01	-0.50	0.87
Net Farm Income	245101	245749	249119	262344	3228	0.02	0.05	0.62
				Year 2				
Net Cash Income	252987	258314	262636	262032	2947	0.02	-0.32	-0.77
Net Farm Income	244472	250126	262243	259344	3228	0.01	-0.19	-0.14
				Year 3				
Net Cash Income	246084	250238	255934	257481	2947	0.03	-0.66	-0.67
Net Farm Income	233325	241108	242484	240614	3228	0.11	-0.14	0.83
				All Years				
Net Cash Income	251241	256327	260575	261496	1742	0.01	-0.24	-0.75
Net Farm Income	240966	245661	251282	254101	1741	0.01	-0.59	-0.63

[1]L = Linear, Q = Quadratic, LF = Lack of Fi

Vita

Mary Elizabeth Lissow was born June 18, 1975, in Rochester, New York to parents Michael and Jean Lissow. Her parents and younger sister later moved to San Jose, California where she graduated from Presentation High School in 1993. She then graduated from Washington State University with a Bachelor in Animal Science in 1997. Mary then went on to Virginia Polytechnic Institute and State University to acquire a Masters Degree in Dairy Management. During her masters program she assisted in several undergraduate classes, including Microcomputers in Agriculture, Dairy Enterprise I, and Dairy Enterprise II.