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Estimation of Relative Economic Value for Herd Life of Dairy Cattle from Profile Equations[1]

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ABSTRACT

Lifetime records of 122,679 cows from 7557 herds, obtained from Mid States Dairy Records Processing Center (Ames, IA), were used to determine net income and net income for the planning horizon. With a planning horizon of five lactations for each cow, the estimated profit from the replacements was credited to each cow not surviving until fifth calving. Net income was defined as lifetime income minus costs. Net income for the planning horizon was defined as net income plus profit from replacements within the planning horizon. Income was from the sale of milk, calves, and culled cows. Costs were included for heifer rearing, feed, labor, and breeding. Longer herd life yielded greater profit for net income and net income for the planning horizon. The rate of increase in profit for longer herd life was reduced for net income for the planning horizon, which accounts for profit from cows replacing a culled cow compared with profit from net income. The relative economic value (phenotypic standard deviation basis) of production to herd life was 0.18:1 for net income and 0.46:1 for net income for the planning horizon. The relative value for herd life was overestimated by about 2.5 times when profit from replacements was not considered. Values for production relative to herd life increased for high milk prices and low feed prices. Lower prices for culled cows in combination with high prices for milk and feed increased the relative economic value of production.

(**Key words**: relative economic value, herd life, production)

Abbreviation key: **NI** = net income, **NIPH** = NI for the planning horizon, **REV** = relative economic value.

INTRODUCTION

The economic importance of herd life has been well documented (2, 7, 11, 20, 25, 26). Two distinct effects of longer herd life on profitability are lower replacement costs and more cows producing at mature levels. The benefits of longer herd life could also result in reduced culling losses and reduced health costs.

Several researchers (3, 4, 6, 11, 19, 24, 25) have used field data to estimate the relative economic importance of herd life and production using profit equations. Different expressions of profit have been used: profit per day of herd life, profit per herd year, and lifetime profit. The profit equations have included incomes and costs over a chosen time period or over the lifetime of the cow. Relative net income was calculated for a large population by Norman et al. (19) using information available in DHI files of lifetime production. Using records with more detailed lifetime information, Tigges et al. (24) concluded that the relative net income that was calculated by Norman et al. (19) accounted for 95% of the variation in profit that was estimated from more detailed information.

The importance of accounting for opportunity costs of postponed replacement while estimating relative economic value (**REV**) for herd life was demonstrated by van Arendonk (25). This method accounts for the profit that is lost by keeping a cow that was already in the herd instead of obtaining an average replacement. An application of opportunity cost to net income (**NI**) has been examined further in other research (6, 8, 27, 28). The conclusions of those papers, that profit that was not adjusted for opportunity cost overestimates the impact of herd life on profit, were similar to the conclusions of van Arendonk (25). The studies account for the fact that another cow will take the place of a culled cow. Van Arendonk (25) used the same opportunity costs for all cows, but de Haan et al. (8) used specific opportunity costs for each herd-year of freshening. Genetic improvement in replacement heifers was not considered. All studies that considered opportunity costs assumed that the replacement cow would offer the

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same potential for profit as an average cow with the same herd life as the culled cow. However, the herd life of the replacement might not be the same as that of the culled cow.

In this study, NI and NI for the planning horizon (**NIPH**) (which accounts for income from replacements) were formulated using DHI variables for lifetime. The probabilities of the number of replacements required within the planning horizon were calculated using the mean probabilities of survival. Improvement in the genetic trend for milk production was included in the production from replacements. The main objective of this study was to estimate and compare REV for herd life and production variables using two profit functions.

MATERIALS AND METHODS

The data for this study consisted of the lifetime production data of 122,679 cows from 7557 herds. The cows were born between 1980 and 1988, and data were obtained from Mid States Dairy Records Processing Center (Ames, IA). Cows were excluded from the analysis if they were sold for dairy purposes. Cows were also excluded if they were >500 DIM, were >280 d dry, or were <590 d or >1090 d at first calving. No minimum length of lactation was required. Only records up to five lactations were considered to calculate NI. A planning horizon of five lactations was considered for each cow. The NI for a cow was based on lifetime income minus lifetime costs. Income was calculated based on 1994 prices (1) as follows: income from production = ($0.1363 × milk, kilograms) + ($1.2761 × fat, kilograms) + ($2.5302 × protein, kilograms). Income from the sale of calves = $87.14 for each live calf. Bull and heifer calves that were sold were assumed to have the same value. A value of 0 was assigned to calves that died at birth. Salvage value of cows = ($95 × BW, kilograms/100). Because BW information was not available, mean values for estimates of 490.9, 568.1, and 613.6 kg were assumed for lactations 1, 2, and 3, respectively. Total lifetime income = (production income) + (calf income) + (salvage income).

Feed costs for production were based on mean values for lactation milk production, parity, and DIM. Following the guidelines of NRC (17), feed costs for the dry period were based on the number of days dry and parity. A detailed explanation of the calculation of feed costs is in Appendix 1. Heifer rearing cost was adapted from the data of Karszes (15) and included the costs of the initial value of the heifer and the costs of feed, labor, and breeding until the day of first calving. Heifer rearing cost = $909.35 + (1.45 × age at first calving, d – 710). Labor cost was dependent on production (14) and was calculated as labor cost = ($6.31/h × 1.122 h × lifetime milk production, kg/100). Breeding cost was based on the number of services and was calculated as breeding cost = ($12.06) (lifetime number of services). Total lifetime costs = heifer rearing costs + feed costs + breeding costs + labor costs. The NI = total lifetime income – total lifetime costs. Fixed costs were not included in the calculation of NI because of the number of herds used and because, without knowledge of the herds, assigning fixed costs is difficult. As the emphasis is on cow characteristics and the cows were from several thousand herds, presumably, the omission of fixed costs would have a minimal effect on the parameter estimates.

A cow that was culled before reaching the fifth lactation was credited with profit from replacements until the end of the planning horizon for the profit function termed NIPH. We assumed that an average cow would take the place of the culled cow to utilize the same space and management resources. The number of replacements that were required for a cow culled after a particular lactation was based on the probability of survival for Holstein cows (18). The probabilities used to calculate the number of replacements required within the planning horizon for a culled cow are shown in Table 1. The number of calvings and not the length of lactation influenced the number of replacement lactations required within the planning horizon. If a cow is culled shortly after calving and does not survive for a major part of the lactation, the expenses of keeping her through the later part of the previous lactation and dry period are not recovered. One or more replacements may be required within the planning horizon, depending on the number of calvings survived by the cow. For example, the replacement for a cow that was culled after her second lactation needs to survive three lactations to complete the planning horizon of five lactations. The replacement may survive exactly three lactations, or more, or fewer. The different possibilities of survival of the replacements and the probabilities of each of those options are shown in Table 2. The number of possible replacements and probabilities were calculated in a similar way for cows that were culled after the first, third, and fourth calvings (see Appendix 2). The profit from replacements was calculated for each possibility and weighted by its probability to be added to NI to obtain NIPH. The NI and NIPH were the same for a cow surviving five or more calvings.

Several assumptions were made to calculate profit from replacements: 1) age at first calving was 833 d,

TABLE 1. Probabilities of survival that were used to calculate the number of replacements required.

Parity i	$P \geq$ Parity i	$P =$ Parity i
1	1.000	0.218
2	0.782	0.206
3	0.576	0.169
4	0.407	0.135
5	0.272	0.101

and number of services at each parity was 1.85, which were mean values from the data; 2) days dry of 61, 68, and 70 were assigned to lactations 2, 3, and 4, respectively, based on means calculated from the data; 3) the mean value from the data for milk production for each lactation was used as an estimate for production from replacements; and 4) the mean values calculated from the data for DIM for each parity were used as estimates for the replacements. For the last lactation of any replacement, an estimate of the mean production of cows that were culled after that particular lactation was used. For example, the mean production of first lactation cows that entered subsequent lactations was 6577 kg but was 4056 kg for cows that did not enter the second lactation. For replacement cows that were culled after first calving, an estimate of 4056 kg was assigned; a first lactation production of 6577 kg was assigned for replacements that survived more than one calving. An improvement in genetic trend of 97.26 kg/yr was incorporated into the first lactation production of replacements and was multiplied by a factor of 1.10 and 1.15 for lactations 2 and 3 or greater, respectively. These factors were based on the mean age of calving at each parity as calculated from the data.

For the final lactation of any replacement, the mean DIM of cows culled after that particular lactation, as calculated from the data, was used. An average of three calvings was assumed for a replacement surviving beyond the planning horizon of five lactations. This assumption was made so that either one-third or two-thirds of the costs of heifer rearing, calf value, and salvage value could be assigned to the profit from that replacement, depending on the number of lactations within the planning horizon. For example, in Table 2, the last of the three replacements may survive one or more lactations. However, only the income from the first lactation was included for NIPH and, therefore, only one-third of the costs for heifer rearing, calf value, and salvage value was considered. Using the assigned age at first calving, number of services, estimated production, DIM, and days dry, profit was calculated as income minus cost as described for NI for the different possibilities of number of replacements that were required and were weighted by their probabilities. The NIPH for each cow was calculated as the NI plus the profit from the replacements.

Multiple regression models were examined using NI and NIPH as dependent variables. Independent variables were lifetime milk, fat, and protein; age at first calving; and herd life (total days from first calving until the last day in the herd). Herd effects were included in the model and were absorbed. Production variables were expressed per day of lifetime DIM to avoid the confounding effect of time on both lifetime production variables and herd life. The regression coefficients for milk, fat, and protein were multiplied by their respective unadjusted phenotypic standard deviations, summed, and divided by the regression coefficient for herd life multiplied by its standard deviation to obtain the REV of production to herd life.

Sensitivity Analysis

Prices for 1994 were used in the analysis. The prices of milk, feed, cull cows, and calves are the major contributors to income and cost. Combinations of low and high prices were examined to study the impact of price fluctuations on profit and economic values. To pick a low and high value for feed prices, the fluctuation in the price index for feed was used. The price index for 1994 was 125 relative to a price index of 100 in 1977.

RESULTS AND DISCUSSION

The means for NI and NIPH for the number of lactations survived by a cow are presented in Table 3. The greater the number of lactations in a lifetime, the greater was the profit. However, when profit from

TABLE 2. Number of replacements, survival possibilities of the replacements, and probabilities that the replacement will be culled after the second calving.

Replacements possibly required	Survival possibilities of each replacement	P	
(no.)			
3	1, 1, ≥1	$(0.218)^2$ (1)	= 0.0475
2	1, ≥2	(0.218) (0.782)	= 0.170
2	2, ≥1	(0.206) (1)	= 0.206
1	≥3		0.576

replacements is credited to a culled cow, the increase in income for surviving an extra lactation is reduced. Cassell et al. (6) found similar results: an increase in herd life opportunity yielded a higher increase in NI adjusted for opportunity cost than did unadjusted NI. The NIPH is the true reflection of profit to the producer for that planning horizon because the replacement for a culled cow continues to generate income.

The phenotypic means and correlations of lifetime traits are in Table 4. The total lifetime production of milk, fat, and protein all had correlations >0.90 with herd life. The phenotypic correlations of herd life with the production variables per day of lifetime DIM was >0.30, which could be due to culling of low producing cows at younger ages. The correlations were reduced to 0.11 when the production per day of herd life was considered. Veerkamp et al. (26) found a phenotypic correlation of 0 between production variables and longevity adjusted for genetic differences in yield. Gill and Allaire (12) found a slightly higher correlation of 0.48 between daily milk production and herd life. Herd life had larger correlations with NI and NIPH (0.94 and 0.75) than did daily milk production of the lactation (0.48 to 0.60). These correlations indicate that characteristics other than production per day are more important in determining profitability. The correlations of age at first calving with production variables are slightly positive (0.05 and 0.06). The correlation was 0 when cows were excluded that survived only one or two lactations. Gill and Allaire (12) and Lin and Allaire (16) reported negative correlations (–0.10 to –0.32) between the age at first calving and lifetime production. However, correlations were positive (0.17 and 0.05) when only production from the first lactation was considered (12, 16).

Results from the regression models (22) with NI and NIPH as dependent variables are presented in Table 5. The inclusion of the quadratic effects of herd life and age at first calving did not change the coefficient of variation. The linear effect was not significant when the quadratic effect of age at first calving was included. Herd life explained more variation in NI and NIPH than did the production variables expressed as yield per day. The regression coefficient for herd life did not change substantially with the different models. The increase of an additional day of herd life for NI was twice that of NIPH at $2.28 and $0.95, respectively. Removal of production variables from the model did not significantly change the regression coefficients of herd life for NI and NIPH, which were 2.37 and 1.04, respectively. The regression coefficients of production variables cannot be interpreted independently of each other because of the high correlation among production variables. This difference indicates that herd life has a higher impact on profit when income from replacements is not considered. Similar conclusions were reached by other researchers (6, 8, 25, 27). Ignoring profit from replacements leads to the assumption that the number of cows in the herd varies depending on herd life. When age at first calving was included in the model, neither the regression coefficients for other traits nor the coefficient of determination changed significantly.

For both Models [1] and [2], REV was about 0.18:1 for NI and 0.46:1 for NIPH. The difference indicates that NI overestimates the value of herd life by almost 2.5 times. The relative value for herd life is much larger than that reported in most other studies. The study by Van Arendonk (25) was the first to incorporate opportunity cost into a profit equation to estimate REV of herd life using field data. In the study by van Arendonk (25), the replacement was assumed to have the same herd life as that of the culled cow. After the opportunity costs of postponed replacement were accounted for, the estimated REV of milk production to herd life was 1.4:1 using production information from the first lactation. The REV for

TABLE 3. Phenotypic means and standard deviations for net income (NI) and NI for the planning horizon (NIPH) for different numbers of lactations survived by a cow.

Lactations survived by a cow	Cows	NI		NIPH	
	(no.)	$\overline{X}$	SD	$\overline{X}$	SD
1	40,773	–127.57	334.83	2140.43	334.83
2	29,136	805.69	482.40	2449.96	482.40
3	20,539	1718.64	639.15	2810.35	639.15
4	14,314	2600.80	808.18	3206.35	808.18
≥5	17,917	3643.20	907.69	3643.20	907.69

TABLE 4. Phenotypic means, standard deviations, and correlations for lifetime traits.[1]

Trait	$\bar{X}$	SD	Milk DIM	Fat DIM	Protein DIM	AFC	Herd life	NI	NIPH
Milk per lifetime DIM	21.78	5.36	1.00	0.85	0.91	0.05	0.32	0.48	0.58
Fat, kg per lifetime DIM	0.78	0.18		1.00	0.87	0.06	0.31	0.48	0.58
Protein, kg per lifetime DIM	0.69	0.18			1.00	0.05	0.35	0.51	0.60
AFC, d	832	96				1.00	0.05	–0.04	–0.11
Herd life, d	805	585					1.00	0.94	0.75
NI, $	1271	1456						1.00	0.91
NIPH, $	2670	798							1.00

[1]AFC = Age at first calving, NI = net income, and NIPH = NI for the planning horizon.

production to herd life or productive life has ranged from 0.25 to 8.00 (10, 21). Dekkers (10), using herd life or herd life adjusted for milk production, found REV ranging from 0.25 to 1. Strandberg (23) [quoted from Dekkers (10)] also found similar REV of 0.24 to 1 for production to productive life. Harris and Freeman (13) reported REV of production to herd life predicted from type traits to be 8:1.

The labor costs that were assigned in the present study were based on milk volume. The exclusion of labor costs from profit increased REV of production to herd life to 0.6:1 for NIPH, although REV remained the same (0.18:1) for NI because NIPH includes income and cost from replacements. Labor cost is one of the major expenses involved in heifer rearing.

Sensitivity Analysis

Profit was lowest when prices for milk and culled cows were low and when feed costs were high. High prices for milk and culled cows and low feed costs yielded highest profits. The REV for production was larger for profit functions for high milk prices and low feed costs and cull cow prices. The emphasis on production is higher when feed costs are low because feed is a major cost of milk production. Except for the extreme situation of high milk prices, low feed costs, and low cull cow prices, the REV for production to herd life was within a range of 0.37 to 0.5 for NIPH and 0.16 to 0.18 for NI.

CONCLUSIONS

Currently, about 57% of the cows survive beyond the second lactation. An increase in this percentage yields greater profit. However, when profit from replacements was accounted for, the rate of increase was reduced for NIPH as herd life increased. Herd life had a higher correlation with the profit functions than with production per day and also explained more variation in NI and NIPH than in production variables. The results indicate the economic importance of a longer herd life. Absolute and REV values for herd life were overestimated by about 2.5 times when profit from replacements was ignored. The REV for herd life found here were greater than those reported in most other studies and were greater than values currently used in the dairy industry. Our results indicate that the REV of herd life should receive greater emphasis in breeding.

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TABLE 5. Regression coefficients and coefficients of determination for the different models used with dollars of net income (NI) and dollars of NI for the planning horizon (NIPH) as dependent variables.

	Model 1		Model 2		Model 3		Model 4	
Trait	NI	NIPH	NI	NIPH	NI	NIPH	NI	NIPH
Milk, kg per lifetime DIM	5.92	11.86	5.08	11.02	36.03	23.59		
Fat, kg per lifetime DIM	655.93	721.31	609.06	674.36	744.76	729.46		
Protein, kg per lifetime DIM	476.73	301.24	485.99	310.51	3415.92	1500.11		
Herd life, d	2.23	0.90	2.24	0.91			2.37	1.04
AFC,[1] d	–1.27	–1.27						
R^2	0.95	0.79	0.95	0.78	0.38	0.47	0.93	0.73

[1]AFC = Age at first calving.

REFERENCES

1 Agricultural Prices. 1994 Summary. USDA, Natl. Agric. Stat. Serv. Agri. Stat. Board, Washington, DC.
2 Allaire, F. R., and D. S. Keller. 1990. Specifying dairy merit for genetic improvement. Proc. 4th World Congr. Genet. Appl. Livest. Prod., Edinburgh, Scotland XIV:217–220.
3 Andrus, D. F., and L. D. McGilliard. 1975. Selection of dairy cattle for overall excellence. J. Dairy Sci. 58:1876–1879.
4 Balaine, D. S., R. E. Pearson, and R. H. Miller. 1981. Profit functions in dairy cattle and effect of measures of efficiency and prices. J. Dairy Sci. 64:87–95.
5 Beaudry, T. F., B. G. Cassell, H. D. Norman, and R. E. Pearson. 1988. Impact of prices on profit functions in dairy cattle. J. Dairy Sci. 71:485–491.
6 Cassell, B. G., B. B. Smith, and R. E. Pearson. 1993. Influence of herd-life opportunity and characteristics of cows and herds on different net income functions. J. Dairy Sci. 76:1182–1190.
7 Congleton, W. J., Jr., and L. W. King. 1984. Profitability of dairy cow herd life. J. Dairy Sci. 67:661–674.
8 de Haan, M.H.A., B. G. Cassell, R. E. Pearson, and B. B. Smith. 1992. Relationships between net income, days of productive life, production, and linear type traits in grade and registered Holstein cows. J. Dairy Sci. 75:3553–3561.
9 Dekkers, J.C.M. 1993. Theoretical basis for genetic parameters of herd life and effects on response to selection. J. Dairy Sci. 76: 1433–1443.
10 Feedstuffs. 1994. 66(1, 5, 9, and 13). Minnetonka, MN.
11 Gill, G. S., and F. R. Allaire. 1976. Relationship of age at first calving, days open, days dry, and herdlife to a profit function for dairy cattle. J. Dairy Sci. 59:1131–1139.
12 Gill, G. S., and F. R. Allaire. 1976. Genetic and phenotypic parameters for profit function and selection method for optimizing profit in dairy cattle. J. Dairy Sci. 59:1325–1333.
13 Harris, B. L., and A. E. Freeman. 1993. Economic weights for milk yield traits and herd life under various economic conditions and production quotas. J. Dairy Sci. 76:868–879.
14 Jose, H. D., and R. J. Grant. 1993. The dairy forage and enterprise records system demonstration herd project. Page 22 *in* Dairy Rep. Publ. EC 93-220-A. Nebraska Coop. Ext., Lincoln.
15 Karszes, J. 1994. Dairy replacement programs: costs and analysis. Anim. Sci. Mimeogr. Ser., Cornell Coop. Ext. No. 174, Cornell Univ., Ithaca, NY.
16 Lin, C. Y., and F. R. Allaire. 1978. Efficiency of selection on milk yield to a fixed age. J. Dairy Sci. 61:489–496.
17 National Research Council. 1989. Nutrient Requirements of Dairy Cattle. 6th rev. ed. Natl. Acad. Sci., Washington, DC.
18 Nieuwhof, G. J., H. D. Norman, and F. N. Dickinson. 1989. Phenotypic trends in herd life of dairy cows in the United States. J. Dairy Sci. 72:726–736.
19 Norman, H. D., B. G. Cassell, R. E. Pearson, and G. R. Wiggans. 1981. Relation of first lactation production and conformation to lifetime performance and profitability in Jerseys. J. Dairy Sci. 64:104–113.
20 Pearson, R. E., and R. H. Miller. 1981. Economic definition of total performance, breeding goals, and breeding values for dairy cattle. J. Dairy Sci. 64:857–869.
21 Rogers, G. W., and B. T. McDaniel. 1989. The usefulness of selection for yield and functional type traits. J. Dairy Sci. 72: 187–193.
22 SAS® User's Guide: Statistics, Version 6.08. SAS Inst., Inc., Cary, NC.
23 Strandberg, E. 1991. Breeding for lifetime performance in dairy cattle. Ph.D. Diss., Rep. 96, Dep. Anim. Breed. Genet., Swed. Univ. Agric. Sci., Uppsala, Sweden.
24 Tigges, R. J., R. E. Pearson, and W. E. Vinson. 1986. Prediction of lifetime net income from first lactation production and individual type traits in Holstein cows. J. Dairy Sci. 69:204–210.
25 van Arendonk, J.A.M. 1991. Use of profit equations to determine relative economic value of dairy cattle herd life and production from field data. J. Dairy Sci. 74:1101–1107.
26 Veerkamp, R. F., W. G. Hill, A. W. Stott, S. Brotherstone, and G. Simm. 1995. Selection for longevity and yield in dairy cows using transmitting abilities for type and yield. Anim. Sci. 61: 189–197.
27 Weigel, D. J., B. G. Cassell, I. Hoeschele, and R. E. Pearson. 1995. Multiple-trait prediction of transmitting abilities for herd life and estimation of economic weights using net income adjusted for opportunity cost. J. Dairy Sci. 78:639–647.
28 Weigel, D. J., B. G. Cassell, and R. E. Pearson. 1995. Adjustment of a net income function for opportunity cost of postponed replacement on a lactation basis. J. Dairy Sci. 78:648–654.

APPENDIX 1

Estimation of Feed Costs for Lactation Production and Dry Periods

Records for lactation production of 73,292 Holstein cows calving between 1993 and 1994 were obtained from the Mid States Dairy Records Processing Center. Lactations with <280 DIM or >500 DIM, dry period >180 d, and parities >5 were not included to estimate feed costs. The most common feed ingredients in the midwestern states—alfalfa silage, corn silage, corn meal, and soybean meal—were used to formulate a least cost ration. Mean feed costs during 1994 for the midwestern states, as obtained from *Feedstuffs* (10) and Dairy Research Unit (Mead, NE) were used in the ration formulation. Body weights for each parity were classified into groups with 22.68-kg intervals. Body weights that were <408.24 kg were set equal to 408.24 kg, and BW that were >725.76 kg were set equal to 725.76 kg. Lactation number >3 was assumed to be equal to 3 for the purpose of estimating feed costs. Feed costs, which were estimated separately for lactation and dry periods, were added to obtain total lactation feed cost.

Ration Formulation for the Lactation Period

Mean values for milk production per day for each lactation were calculated as lactation production divided by DIM. For each parity and BW combination, mean daily milk production was classified into groups with 4.54-kg intervals. A least cost ration was formulated for each combination of parity, BW, and mean milk production. For example, for lactation 1 and BW 408.24 kg, seven least cost rations were formulated. There were similar combinations for lactations 2 and 3. A total of >340 least cost rations were formulated using the Spartan Dairy Ration Evaluator (Version 2.0, Michigan State Univ., East Lansing).

The cost of feed to produce an extra kilogram of milk was obtained by regression of feed costs for each BW and parity combination on mean milk production per day. Because BW information was not available for data used in the study, the feed cost to produce an extra kilogram of milk across all BW classes for each lactation was averaged and was about \$0.055. Mean daily milk production that was <6.35 kg was equal to 6.35 kg. Calculation of feed costs for each parity is given.

Parity 1. If mean daily milk production = 6.35 kg + n, kilograms, then feed costs = (\$1.0349 + (n, kilogram) (\$0.0251)) (DIM), where n = mean value for milk production minus 6.35, \$1.0349 = intercept or feed cost to produce 6.35 kg of milk, and \$0.0552 = cost of producing an extra kilogram of milk.

Parity 2. If average daily milk production = 6.35 + n, kilograms, then feed costs = (\$0.9645 + (n, kilograms) (\$0.0561)) (DIM), where n = mean milk production minus 6.35, \$0.9645 = intercept or feed cost to produce 6.35 kg of milk, and \$0.0561 = cost of producing an extra kilogram of milk.

Parity 3. If mean daily milk production = 6.35 + n, kilograms, then feed costs = [\$0.96 + (n, kilograms) (\$0.0557)] (DIM), where n = mean milk production minus 6.35, \$0.96 = intercept or feed cost for producing 6.35 kg of milk, and \$0.0557 = cost of producing an extra kilogram of milk.

Ration Formulation for the Dry Period

Number of days until freshening was assumed to be 30 for the Spartan Dairy Ration Evaluator in order to calculate feed costs for the dry period for each combination of parity and BW. The mean feed costs per day across all classes of BW were \$1.003 and \$0.950 for parities 2 and 3, respectively; these values were multiplied by number of days dry for each lactation to obtain feed costs for the dry period. The dry period was 0 for first lactation cows.

APPENDIX 2

TABLE A1. Number of replacements, survival possibilities of the replacements, and probabilities that the replacement will be culled after the first calving.

Replacements possibly required	Survival possibilities of each replacement	P	
(no.)			
4	1, 1, 1, ≥1	(0.218)	= 0.0103
3	1, 1, ≥2	(0.218)(0.782)	= 0.0371
3	1, 2, ≥1	(0.218)(0.206)(1)	= 0.0449
3	2, 1, ≥1	(0.206)(0.218)(1)	= 0.0449
2	1, ≥3	(0.218)(0.576)	= 0.1255
2	3, ≥1	(0.169)(1)	= 0.1690
2	2, ≥2	(0.782)(0.206)	= 0.1610
1	≥4		= 0.4070

TABLE A2. Number of replacements, survival possibilities of the replacements, and probabilities that the replacement will be culled after the third calving.

Replacements possibly required	Survival possibilities of each replacement	P	
(no.)			
	1, ≥1		
2	1, ≥1	(0.218) (1)	= 0.2180
1	≥2		= 0.7820

TABLE A3. Number of replacements, survival possibilities of the replacements, and probabilities that the replacement will be culled after the fourth calving.

Replacements possibly required	Survival possibilities of each replacement	P
1	≥1	1.0000