Profitability of Dairy Cow Herd Life

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ABSTRACT

A dynamic model of a dairy herd was utilized to determine profitability of extending cow herd life. The model incorporated estimates of relationships between cow age, milk production, labor requirements, health costs, reproductive diseases, mastitis, and fertility. The basal situation simulated was a herd of approximately 80 cows producing their own replacements selected by pedigree index, culling cows on cost per unit of production, and breeding cows by artificial insemination with a time trend for sire genetic merit. Increasing cow herd life was simulated by lowering the culling criteria of cow profitability. Extending herd life resulted in more days open, lower annual milk yield per cow, decreased replacement cost and cull cow income, and increased cow health cost. Criterion of herd profitability was discounted income of cow or annual net income over 25 yr with future returns discounted 5% per year. Extending average herd life from 2.8 to 3.3 lactations increased average annual income by $29.92 per cow and increased discounted income by $314.52 (1977 to 1978 dollars). The profitability of a limited increase of average herd life was insensitive to increased feed price, poor management, decreased salvage value, trend of improving management, but high salvage value and low feed price significantly decreased profitability of extended herd life.

INTRODUCTION

There are numerous ways that the age at which a dairy cow joins and subsequently leaves the dairy herd could influence herd profitability. Maximum turnover of animals in the herd will reduce generation interval and can contribute to genetic trend, especially when most of the genetic improvement is from sire selection. However, milk production is determined by age of cow and other environmental factors as well as the cow's breeding value. Also, the investment in a replacement heifer before she freshens must be recovered during her productive lifetime, or herd life. Investment in replacement stock will influence returns on investment for a dairy herd.

Many cows are culled at the discretion of the dairy producer even when they are capable of continuing to function in the milking herd. Culling for general health and production was classified primarily as voluntary culling by (3). Percentage of cows culled for production varied from 8 to 24% depending on age of cow, and culling on general health accounted for 6 to 28% of total culling after 108 mo of age (3). Inferior type accounted for 16 to 19% of all removals after first calving (3). Low milk yield was the reason given by (5) for 24% of cows sold for beef. A recent survey of dairyproducers in the Northeast (21) reported 24.2, 15.3, and 2.4% of culls were removed for low production, age, and breed of cow.

Several studies indicated herd profitability increased if herd life was extended (2, 13, 14, 16, and 19). For different female selection criteria in combination with sire selection systems, (16) reported the cow selection system with the highest average cow age at calving (60.6 mo) and calvings per cow (4.8 calvings) was more profitable than cow and sire selection systems with lower average age (39.7 to 53.5 mo) and 2.6 calvings, except at low cost of calf rearing. Increased voluntary culling usually did not maximize economic returns in (2). Voluntary culling on milk yield increased economic returns only at low cost of replacement heifers. At high rearing cost, voluntary culling from 3 to 8% maximized economic returns (2). By a

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formula for computing culling rate that maximized yield, (13) reported culling rate had little effect on mean herd yield and concluded a minimum of culling would be most profitable. In (14), actual yearly culling rate over 8 yr for Dairy Herd Improvement Association herds in Oregon was compared with optimal culling as determined by a multistage stochastic replacement decision model. The actual herd average replacement rate of 23% was twice the rate indicated by the model for price relationships over the 8 yr. Another study (19) utilizing an economic model that compared marginal income of a cow and her potential replacement concluded earned income per year could be increased by 20% by increasing herd life from 3.3 to 5.3 lactations.

Objective was to use the model (7) that included estimates of effects of cow age on milk and cow health to study profitability of cow herd life. If a relationship between herd life and profitability is established, additional questions are: 1) Is the relationship between herd life and profitability linear or is an intermediate herd life optimum? 2) Does substitution of a different set of parameters of cow health change the predicted relationship? 3) Is the predicted relationship affected by varying management and economic variables?

MATERIALS AND METHODS

A dynamic model (7) simulated consequences of varying rate of cow culling and changing cow average herd life to determine effects on herd economic characteristics. The model included effect of age of cow on milk, and incidence of reproductive problems and mastitis. Milk yields were dependent on dam's breeding value, genetic trend from sire selection, and health problems including reproductive disorders and mastitis. Costs for labor, health, feed, and fixed cost were accumulated daily and were dependent on age of cow. Health costs were adjusted at the end of lactation for milk yield. All costs and prices were based on or interpolated to 1977 to 1978 averages. Driving variables were in (7, Table 4).

Because total milk and costs were accumulated for each lactation, cows were evaluated on cost per unit of production. Pregnant cows were candidates for culling at the end of lactation. Infertile cows were candidates for culling 305 days after freshening and subsequently every 31 days until dried off and culled. When evaluated, cows were retained or culled on cost per unit of production during present lactation including preceding dry period. First lactations were evaluated on costs since freshening. Shorter herd life was the result of retaining more profitable cows or cows with lower cost per unit of production. The criteria for profitability varied from cost of production equaling value of milk for least intensive culling and longest herd life to a cost per unit of production 45% below value of milk for intensive culling and shortest herd life. Profitability criteria for culling varied with cow age. Attrition rates are summarized in Table 1. With short herd life, heavy culling resulted in high attrition rates, particularly after first lactations. A more uniform intensity of culling was utilized across age classes for intermediate herd life (three to six lactations) while few immature cows were culled with long herd life (more than six lactations).

All runs simulated 30 yr and were initiated with 80 cows with an age distribution similar to (4, Table 5 and Figure 1). All cows were dry and scheduled to freshen uniformly over the first 13 mo of simulation. To evaluate differences of herd life, herds were simulated at nine rates of culling on cost per unit of production in combination with three sets of random number seeds at each culling rate. These combinations resulted in herds with different average herd life evaluated with the same initial herd. Because runs were initiated with dry cows and no replacements were available until calves from the first freshening reached breeding age, performance data on herds were not collected until after 5th yr of simulation.

Profitability Criteria

Discounted income after the 5th yr of simulation was calculated by:

$$\sum_{n=6}^{30} \left[\frac{R_n}{(1+i)^n} \right]$$

with net income per cow in the n^{th} yr of R_n for returns per cow in the n^{th} year and a discount rate of i. A discount rate of 5% was utilized, which is equivalent to an inflation

TABLE 1. Average attrition rates[a] with standard errors by age of cow for variable herd life in the basal situation.

Age at drying off[b]	Range of herd life (lactations)									
	2.6–2.99		3.0–3.99		4.0–4.99		5.0–5.99		6.0–6.61	
	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE
2 yr	.5457	.0133	.3620	.0239	.2084	.0077	.0764	.0211	.0050	.0028
3 yr	.1966	.0135	.1680	.0073	.1450	.0069	.1031	.0100	.0866	.0101
4 yr	.1512	.0112	.1725	.0094	.1436	.0124	.1186	.0096	.0878	.0096
5 yr	.2221	.0219	.2172	.0078	.1786	.0117	.1380	.0089	.1059	.0164
6 yr	.2015	.0240	.1835	.0126	.1632	.0140	.1240	.0097	.0984	.0073
7 yr	.2626	.0200	.2112	.0127	.1872	.0145	.1505	.0161	.0974	.0106
8 yr	.2902	.0383	.1959	.0197	.1675	.0151	.1736	.0168	.1278	.0228
8+ yr	.3730	.0245	.3335	.0078	.3141	.0130	.3036	.0124	.2722	.0094

[a]Attrition rates are the probability cows of a specified age at drying off will be culled plus cow mortality.

[b]Each age class includes all cows in the range including age and age + .999.

free discount rate of 3% (20) with an additional 2% allowed for risk. Discounted income also was calculated, which included salvage value of the herd after 30 yr. In calculating herd salvage value, cows older than 4.5 yr or with breeding values more than one SD below breed average were sold for slaughter. Cows sold for dairy purposes were worth 147% of value of cows sold for slaughter with a 25% premium for cows one SD above breed average for production. The same premium was paid for replacement heifers with superior pedigrees. Profitability of herd life was evaluated by comparing discounted income both with or without herd salvage value.

For herds with longer herd life, an increasing proportion of herd income could be generated by raising and selling replacement heifers. Because income from this source would be confounded with change of income generated from varying herd life, all herds raised only enough replacements to maintain herd size with income from excess heifers contributing less than 4.0% of herd net income.

Sensitivity Analysis of Model Parameters and Driving Variables

Conclusions concerning the relationship between cow herd life and profitability could be influenced by critical estimates in the model, economic environment of the herd, and herd management. To test the sensitivity of the relationship between cow herd life and profitability to variation of these factors, new parameters and driving variables were substituted into the model.

Many effects of age influencing production and costs of production are due to health problems of older cows (7, Figure 1 and Table 1). Different sets of age specific disease probabilities for cystic follicle, mastitis, metritis, and retained placenta were incorporated into the model (Table 2). Although the second set of disease probabilities did not estimate causal relationships between diseases, age specific rates were given for additional health disorders of foot problems, hypocalcemia, ketosis, ovarian hypofunction, and pneumonia, which were included in the model with veterinary costs for treatment. Original estimates for incidence and treatment costs for luteal cyst, dystocia, and twin calving were retained (7, Table 1).

Profitability of cow herd life may be influenced by economic environment of the dairy herd. Economic factors that fluctuate the most are feed prices relative to milk price and cull cow salvage value due to variation in meat prices. Variation in the ratio of milk to feed prices between 1966 and 1981 (15) ranged 18% from the midpoint. Consequences of an 18% decrease and 18% increase in feed prices (low and high feed costs in Table 2) were simulated. Because feed costs were 65% of the cost of raising replacements, lower feed costs would also decrease replacement heifer costs. Consequences of an 18% decrease of both cow and replacement heifer feed costs were simulated (low feed and replacement costs in Table 2).

From (1), the price ratio of milk to cow beef value between 1974 and 1979 deviated 30% from the midpoint. Consequences of a 30% decrease and 30% increase of price received for cull cows (low and high meat prices in Table 2) were simulated. Runs with variable economic characteristics simulated 30 yr. However, results of runs cannot be used to evaluate long

TABLE 2. Conditions evaluated in sensitivity analysis.

Condition	Variable	Value		Source of new estimate
		Original	New	
New disease probabilities	Cystic follicle, %	12.8[a]	8.1[b]	(6)
	Clinical mastitis, %	2,6,5,8 12.9[c]	6.5,10.6 16.2,29.6[d]	(6)
	Metritis, %	13.1[a]	7.9[b]	(6)
	Retained placenta, %	6.7[a]	5.9[b]	(6)
	Foot problems, %	....	5.6[b] ($7.93[e])	(6)
	Hypocalcemia, %	....	4.9[b] ($15.66[e])	(6)
	Ketosis, %	....	4.5[b] ($17.06[e])	(6)
	Ovarian hypofunction, %	....	5.1[b] ($25.77[e])	(6)
	Pneumonia, %	....	4.9[b] ($48.50[e])	(6)
Economic environments				
Low feed costs	Dollars/mcal feed	.061	.050	(15)
High feed costs	Dollars/mcal feed	.061	.072	(15)
Low feed and	Dollars/mcal feed	.061	.050	(15)
replacement costs	Dollars/calf per day	.688	.601	
Low meat	Dollars/kg cow<3 yr	.85	.595	(1)
price	Dollars/kg cow⩾3 yr	.68	.476	
High meat	Dollars/kg cow<3 yr	.85	1.105	(1)
price	Dollars/kg cow⩾3 yr	.68	.884	
Poor management	Reproductive disorders, %	See disease probabilities listed above[a]	+7.2,+7.0, +3.1,+3.3, +2.8[f]	(8)
	Clinical mastitis, %	2.6,5.8, 12.9[c]	5.2,11.6 25.8[c]	(17)
	Base daily health cost, $/day	.01,.024, .027,.0620[g]	same −.023	(9,12)
	Conception rate, %	62.0	46.4	(9)

[a]For age specific estimates see Table 1 in (7).

[b]For age specific estimates see Table 1 in (6).

[c]Incidence for first, second, and later lactations, respectively.

[d]Incidence for age groups 2<4, 4<7, 7<10, ⩾10.

[e]Veterinary costs for health disorders in dollars from (11).

[f]Increase in disease probabilities for cystic follicle, metritis, retained placenta, assisted delivery, and luteal cyst.

[g]Veterinary costs which are added to daily labor costs from Table 1 in (7) for lactations <3, 3, 4, >4, respectively.

range strategies because the economic environment would change in cycles. This analysis would show which economic variables influence profitability of herd life and show potential value of integrating econometric and animal models.

Poor management also could influence profitability of herd life because poor management would increase incidence of health disorders, which occur more frequently in older cows (7, Table 1). In poorly managed herds, cows may not be kept profitably in the herd as long as in herds with good management. Although management practices would influence many herd characteristics, the following aspects of poor management were simulated (Table 2). Teat dipping, dry cow treatment, and a herd health program were not utilized eliminating the cost of dry cow treatment of $7.56 (11) and decreasing prophylactic veterinary services by $.004/cow per day (9). As a result, incidence of mastitis doubled, incidence of all reproductive diseases increased by one SD, and conception rate decreased by 15.6% (Table 2). Specific information on reactions of cows of different ages to management practices would result in more accurate evaluation of the effect of management on profitability of increasing cow herd life.

The statistical model to evaluate the effect of poor management on annual incomes of cows of different ages was:

$$Y_{ijk} = \mu + M_i + A_j + MA_{ij} + e_{ijk}$$

where: Y_{ijk} is annual income per cow, μ is the population mean, M_i is management effect with M_i equal 0 for baseline, A_j is j^{th} cow age class effect for j equals 2 to 11 with A_j equal to 0 for cows greater than 11 yr, MA_{ij} is interaction of management by age, and e_{ijk} is an independent normally distributed residual.

The (7) model simulates trends of increased milk yield from sire and cow selection. Increased production decreases fertility by increasing services per conception and days open and raising health cost (7, Table 1). A trend of improving management (management trend) probably would result in constant cow health cost and fertility despite the trend in production. A constant cow health cost through time was simulated with a higher health cost and decreased fertility for high producing cows within years.

RESULTS

The criterion of cow longevity was herd life in lactations over the last 25 yr of the run. Table 3 contains information descriptive of herds with varying average herd life. Wide range of herd life resulted from different culling policies and random variation within culling policies with a corresponding range of 4.89 to 9.64 yr for average age at culling.

Figures 2 and 4 show changes of individual response variables through time for herds with varying herd life. Each line of a different herd life across time represents a separate run of 30 yr with the response variable plotted on the vertical axis for the last 25 yr of the run. Curvilinearity of time trends could be due to autocorrelated error terms as errors may not be independent from year to year with most cows remaining in the herd. Durbin-Watson statistic (18) was used to detect significant positive autocorrelations for 17 of the 25 runs (lines or herds in Figure 2) representing time trends for herd genetic merit. Because curvilinearity of time trends for herd merit was likely from autocorrelated errors, straight lines were fitted. However, significant autocorrelations were not detected for observations of cow annual income through time.

Because autocorrelations were not detected for time trends of cow income, runs with significant linear trends were tested for quadratic trends. Plots of runs with significant quadratic trends through time and plots of moving 5-yr averages did not reveal inflection points at consistent times across runs. Because no trends of curvilinearity for income across runs were observed, straight lines were fitted across time in Figure 4 to improve legibility.

The statistical model used to predict time trends for each run for both response variables was

$$Y_{ik} = B_{oi} + B_{1i}x + e_{ik}$$

where: Y_i is an observation of i^{th} response variable in the k^{th} yr, B_{oi} is the intercept, B_{1i} is the time trend for the i^{th} variable, x equals 6 to 30 for year of run, e_{ik} is the residual for the i^{th} variable, and i = 1, 2 for response variables

TABLE 3. Descriptive information[a] for herds with short herd life, long herd life, and least squares regression lines for the effect of herd life in lactations (x) on response variables (Y).

Response variable (Y)	Y at minimum herd life (2.60 lactations)	Y at maximum herd life (6.61 lactations)	Y as a function of herd life (x)[b]	R^2[c]
Age at culling, yr	4.89	9.64	$1.87 + 1.17x$	.99
Culling for infertility, %	13.43	13.85	$17.26 - 2.41x + .31x^2$[d]	.44
			$(7.24 + .77x)$	(.24)
Days open	113.7	121.8	$104.19 + 4.62x - .32x^2$[d]	.92
			$(106.65 + 2.13x)$	(.91)
Days dry	49.2	61.26	$49.38 - 1.73x + .51x^2$[d]	.94
Days in milk	351.3	352.7	$330.53 + 11.33x - 1.21x^2$[d]	.59
Herd genetic trend/yr, kg	27.4	33.18	$20.30 + 1.68x$	.33
Milk/cow/yr, kg	7799	7197	$7778.05 + 95.97x - 27.74x^2$[d]	.70
			$(8102.82 - 126.00x)$	(.60)
Replacement cost/cow/yr	\$385.12	\$144.86	$784.74 - 199.62x + 15.74x^2$[d]	.99
			$(863.56 - 250.12x + 23.18x^2)$[d]	(.99)
Health cost/cow/yr	\$24.26	32.60	$19.65 + 2.06x$	.94
			$(17.68 + 2.36x)$	(.96)
Cull cow income/cow/yr	150.63	59.65	$301.06 - 74.33x + 5.81x^2$[d]	.98
			$(277.83 - 69.56x + 5.88x^2)$[d]	(.96)
Excess heifer income/cow/yr	0	19.05	$-49.74 + 24.87x - 2.22x^2$[d]	.95
			$(-74.04 + 39.99x - 4.41x^2)$[d]	(.89)
Income/cow/yr	409.41	459.45	$113.50 + 158.86x - 16.23x^2$[d]	.86
			$(-42.22 + 231.18x - 25.50x^2)$[d]	(.88)
Discounted income/cow[e]	4392.34	4901.43	$1281.26 + 1635.54x - 165.00x^2$[d]	.80
			$(584.37 + 1793.34x - 175.15x^2)$[d]	(.90)

[a]Collected for years 6 through 30 of the simulation.

[b]Least squares regression line for 27 herds simulated in the basal situation with variable herd life between the specified maximum and minimum and, in parentheses, herds simulated with the second set of disease probabilities. All regression equations significant at .05 probability with quadratic term included if type IV F test was significant ($P<.05$).

[c]Proportion of the variance in the response variable explained by the regression line for the base line situation and, in parentheses, the second set of disease probabilities.

[d]For the quadratic regression line $Y=b_0 + b_1 x + b_2 x^2$, the maximum or minimum occurs when the first derivative $(b_1 + 2b_2 x)$ equals zero or $x=-b_1/2b_2$.

[e]Annual cow income discounted 5% annually for years 6 through 30.

of herd genetic merit for milk and cow annual income.

Linear trends through time were significant in all runs for herd genetic merit and 25 of 27 runs for income. Fluctuations in Figures 2 and 4 for predicted response variables across herd life for any year are from random variation of slope of fitted lines. Proportion of variation around the mean of a run (R^2) explained by the trend regression lines averaged 92.2% for herd average genetic merit (Figure 2) and 51.9% for cow annual income (Figure 4).

In Table 3 and Figure 1, herds with older cows had more days open because of both direct effect of cow age on days open and indirect effect of age of cow on days open through incidence of reproductive disease (7, Tables 1, 2). Because one criterion for culling for infertility was maximum days open allowed, quadratic relationship (concave up) between herd life and percentage culled for infertility was positive (Table 3).

Herds with older cows had more days dry (Table 3 and Figure 1). Two criteria were used to dry off cows (7). Cows were dried off to allow recovery before freshening with younger higher-producing cows requiring a longer dry period. Alternately, cows were dried off when their production fell below a specified minimum. Because younger cows had fewer days dry, the production criterion was used more frequently for drying off because younger cows had higher persistency and shorter calving interval. Net effect of increasing days open and increasing days dry for older cows and declining production for cows older than 6 yr was that days in milk peaked for cows in herds with a herd life of 4.68 lactations [−11.33/2(−1.21) in Table 3 and Figure 1].

Herds with shorter herd life were of higher genetic merit because cows were daughters of more recent sires (Figure 2). This difference was apparent by the 6th yr of simulation and persisted through yr 30. Herd genetic trends ranged from 22.5 to 36.71 kg/yr. Average genetic trend across herd life was 27.81, which was less than annual trend of improvement of dairy sires (30 kg/yr). Herd genetic trend was less than trend of sires because genetic merit of cows in the original herd was independent of cow age. Genetic trend in the herd would occur only as original cows were replaced.

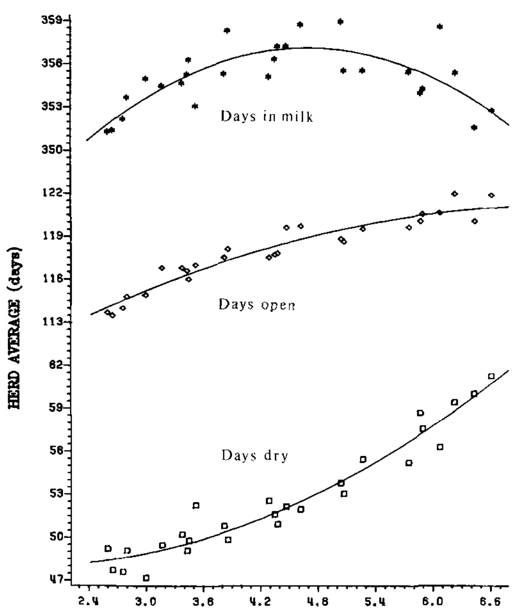

Figure 1. Effect of varying average cow herd life on herd averages for days in milk, days dry, and days open.

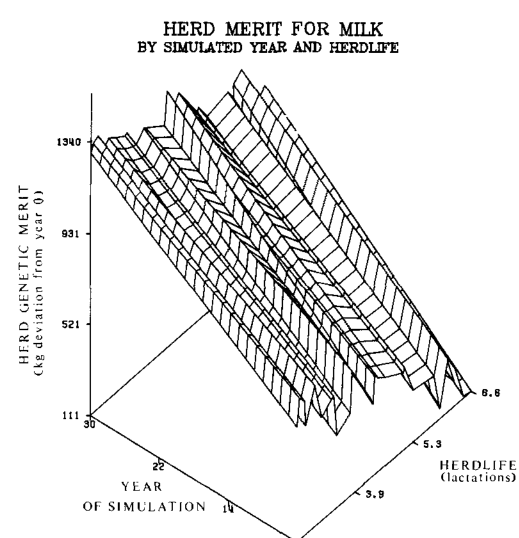

Figure 2. Baseline herd average genetic merit (relative to 0 for time 0) for herds with variable herd life for years 6 through 30 of the simulation.

Although herds with shorter herd life maintained their genetic superiority, trend of genetic merit of these herds between yr 6 and 30 was lower than of herds with longer herd life. The correlation between herd life and genetic trend was .597 ($P<.01$). Higher genetic trend of herds with older cows can be seen in Figure 2 as superiority of herds with shorter herd life is less at yr 30 than yr 6. Although herds with shorter herd life would have greater intensity of culling among cows, herds with longer herd life would have greater intensity of pedigree selection among replacement heifers. The net effect was intensity of cow culling had limited impact on herd genetic merit, which agrees with (23).

Higher average genetic merit in herds with shorter herd life contributed to higher milk production per cow in the milking herd per year in herds with short herd life. In Table 3 the relationship between milk per cow per year and herd life for the basal situation is negative for herd life greater than 1.73 lactations [−95.97/2(−27.74)]. Shorter herd life also would result in younger cows that have a lower incidence of mastitis and twin calving. Both disorders decrease milk yield, with mastitis decreasing production of older cows more than of younger cows (7, Tables 1, 2). Younger herds would have shorter calving intervals and fewer days dry (Figure 1). Counting heifers in the milking herd only after they freshen also would decrease time dry for herds with younger cows because first lactations do not have a preceding dry period. All these factors would affect annual milk per cow in the milking herd in addition to effects of age on daily milk production (Tables 1, 2, in 7), which estimate peak production for 5- and 6-yr-old cows.

From Table 3, extending herd life decreased replacement cost, decreased cull cow income, increased cow health cost, increased excess heifer income, and decreased milk production per cow per year. Replacement cost and cull cow income had negative slopes as herd life increased with decrease of replacement costs exceeding decrease of cull cow income (Figure 3). By substituting 2.8 and 3.3 for X in equations in Table 3 for replacement cost, health cost, cull cow income, and milk per cow, sources of income for herds with average herd life of 2.8 and 3.3 lactations were compared. The decrease of cow annual costs from lower

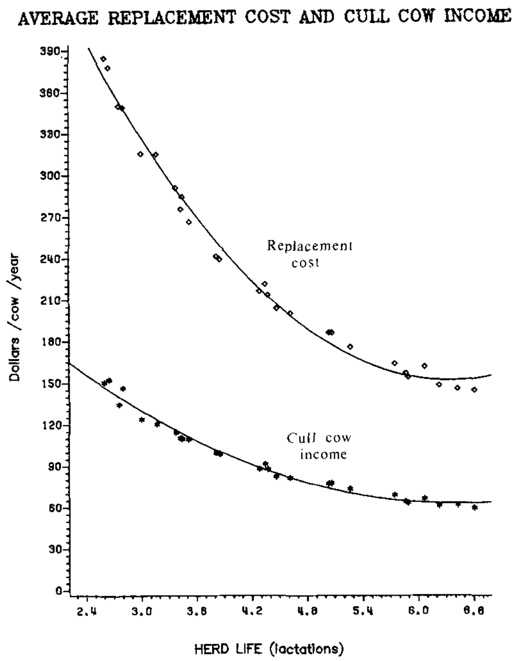

Figure 3. Basal annual replacement cost and cull cow income per cow in the milking herd for herds with varying cow average herd life.

replacement costs ($51.81), resulting from extending average herd life from 2.8 to 3.3 lactations, was greater than decrease of cow annual income from increased health cost (+ $1.03), decreased cull cow income (−$19.45), and decreased production (−36.62 kg or −$8.20). Net effect of changes in all response variables on cow income per year is in Figure 4. Increasing herd life from 2.6 to approximately 4 lactations resulted in a linear increase of income per cow in the milking herd. From 4 to 5.5 lactations, average income remained relatively constant with slight decrease of income for herds with herd life greater than 5.5 lactations. The same trend of discounted income is in upper plots of Figure 5, which is expected as differences in cow annual incomes were apparent by yr 6 and persisted until the end of the runs. The quadratic regression line fitted to discounted income predicted a maximum at 4.96 lactations [−1635.54/2(−165.0) in Table 3]. Including salvage value of the herd at the end of yr 30 did not affect the relationship between herd life and profitability.

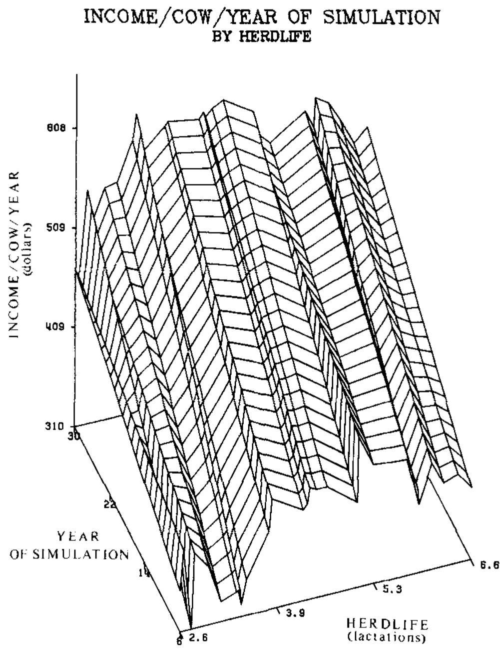

Figure 4. Basal annual net income (revenues from the sale of milk, calves, excess replacement heifers, and cull cows minus the costs of feed, replacement heifers, insemination, veterinary treatment, labor, and fixed cost) per cow in the milking herd per year for herds with varying cow average herd life.

Many estimates in the model were from information from commercial dairy herds. A commercial dairy herd would not be a random sample of cows of all ages because cows are subjected to selection during each lactation. Many estimates in the model, particularly for older cows, would be biased in their favor because they have been subjected to selection on past performance. Therefore, discounted income and cow annual income for herds with long herd life would be expected to show more decline than indicated. However, bias in favor of older cows would be less in simulating herd life close to the average of a commercial dairy herd. An increase of average herd life from 2.8 to 3.3 lactations would increase cow annual income by $29.92/yr (substituting 2.8 and 3.3 for *X* in Table 3) and increase discounted income by $314.52 over 25 yr (base line without herd salvage value in Figure 5 and calculated from Table 3). These percentages both represent 6.9% increase for different criteria of profitability resulting from a limited increase of cow herd life.

Model Sensitivity to Disease Probabilities

The second set of disease probabilities had lower base rates of cystic follicle, metritis, and retained placenta (Table 2). Utilizing different disease probabilities and adding age specific probabilities for foot problems, hypocalcemia, ketosis, ovarian hypofunction, and pneumonia (Table 2) had little effect on annual cow health cost. Regression lines (Table 3) for annual health cost were similar for both disease probability sets. Annual health costs for herds simulated with average herd life of 2.8 lactations (X=2.8 in Table 3) was $25.41 and $24.28/cow per year and for a herd life of 4.0 lactations (X=4.0) was $27.88 and $27.12/cow per year for the original and new sets. Because reproductive disorders and delayed conception from

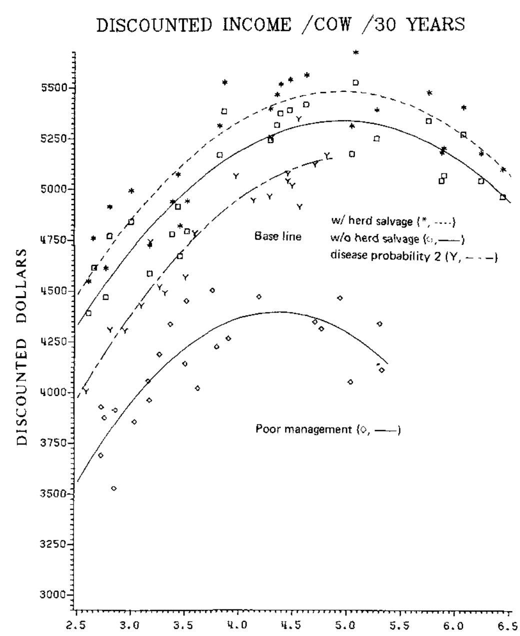

Figure 5. Upper plots: basal cow net income over 25 yr discounted at a 5% annual rate for herds with varying cow average herd life with salvage value of the herd included or excluded at the end of the run. Middle plot: discounted income over variable herd life obtained with a second set of disease probabilities in the model. Lower plot: discounted income over variable herd life with poor management.

reproductive disorders were more common in the original set, regression lines for days open in Table 3 predicted 2.04 and 2.45 more days open with the original set for cow average herd lives of 2.8 and 4.0 lactations.

Discounted income over 25 yr is plotted in Figure 5 for the basal situation for both sets. Lines for discounted income (Table 3, Figure 5) for both sets have maximums at the same approximate cow average herd life (4.96 lactations for the original and 5.12 lactations for the second set). Discounted income was lower for herds simulated with the second set producing \$334.52 less discounted income at a herd life of 2.8 lactations and \$227.93 less discounted income at 4.0 lactations. Decrease of income with the second set was from higher incidence of mastitis (Table 1). More frequent mastitis lowered production with regression lines for milk in Table 3 with X equal to 2.8 and 4.0 predicting the second set producing 79.26 kg less milk/cow per year at a herd life of 2.8 lactations and 119.27 less milk/cow per year at 4.0 lactations. However, the relationship between increasing cow herd life and discounted income remained relatively constant with an increase of herd life from 2.8 to 3.3 lactations resulting in \$314.52 more discounted income with the original set and \$362.46 with the second set (Table 3, Figure 5).

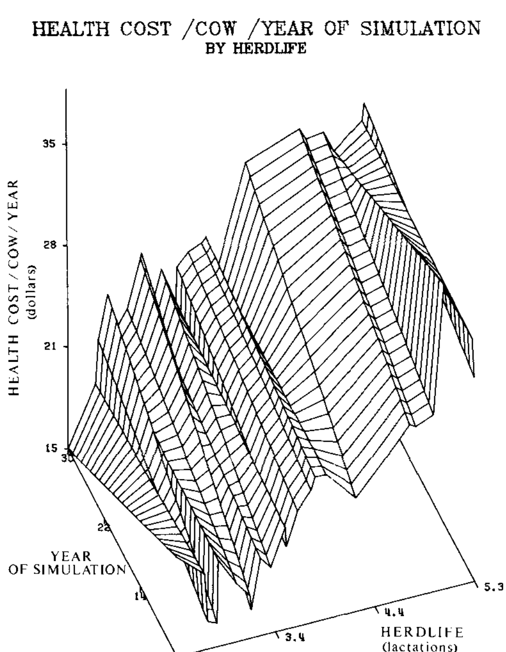

Figure 6. Annual health cost per cow in herds with poor management and variable herd life for simulated yr 6 through 30.

Model Sensitivity to Poor Management

To determine sensitivity of conclusions on profitability of herd life to changes of dairy herd management, driving variables that would be influenced by poor management were varied. Major effects in the model that were influenced by both management and cow age were incidence of reproductive diseases and mastitis.

Economic consequences of an increased incidence of management influenced diseases and decreased prophylactic health cost are in Figure 6. As in the basal simulation, differences in herd health cost characteristics existed by the 6th yr of simulation and persisted until the end of run. Lines fitted to annual observations of cow health cost within herd life are least squares lines. Only 7 of 23 lines had significant linear trends ($P<.05$) through time between yr 6 and 30, and all significant slopes were positive. Because little trend was observed for health cost through time, herd life was regressed on mean annual health cost. The increase of annual health cost per lactation increase of herd life was \$4.72 ($P<.01$). The increase of health cost was \$2.06 ($P<.01$) per lactation increase of herd life in the basal simulation. The primary reason health costs increased more rapidly as herd life was extended in poorly managed herds was mastitis occurred frequently in older cows in poorly managed herds.

Poor management changed the relationship between herd life and herd genetic trend. In the basal simulation, correlation between herd life and genetic trend was .597, but when poor management was simulated, these variables were not significantly related ($r=.086$, $P>.05$). With poor management, culling for infertility increased particularly in herds with long herd life. The increase of culling for fertility per lactation increase of herd life was 1.35% ($P<.01$) with poor management whereas culling for fertility increased in the basal simulation only for herd life greater than 3.89 lactations [2.41/2(.31)] or minimum for culling for infertility in Table 3). In addition, health costs with poor management increased particularly for older cows resulting in more older cows culled on profitability. Poor management increased culling for infertility and health cost, particularly for herds with more older cows instead of culling on contribution of production to profitability. This increased culling, on criteria unrelated to genetic merit for production, resulted in less genetic trend in herds with long herd life and poor management.

The relationship between cow average herd life and milk production was similar for the basal situation and poor management. Herds with younger cows produced more milk per cow in the milking herd per year with decreased genetic trend and increased mastitis in older cows in poorly managed herds enhancing this relationship.

Discounted income or Y with poor management and varying herd life is in the lower plot of Figure 5, which was generated by $Y=352.31 + 1836.68x - 209.68x^2$ where x is herd life in lactations. Similar increases of discounted income resulting from extending herd life from 2.8 to 3.3 lactations of \$278.82 and \$314.52 were obtained by substituting 2.8 and 3.3 in the above equation and for the basal situation in Table 3. The quadratic regression line fitted to discounted income with poor management predicted a maximum of 4.38 lactations [−1836.68/2(−209.68)) from preceding equation], which is less than the 4.96 lactation base line peak. Although herds with poor management could increase cow profitability by extending herd life beyond the 2.5 to 3 lactations common in commercial herds, cows should not be kept as long as in herds with better management.

The net effect of increasing health problems and costs and decreasing genetic and production trends in herds simulated with long herd life and poor management is profitability of extended cow herd life decreased. Table 4 shows effects of age of cow, poor management, and interactions of management by age on cow annual income. Age effect of first lactation heifers was tested separately from other age classes because their annual income was calculated without a dry period. For subsequent lactations, cows freshening at 5 or 6 yr of age were most profitable with 6-yr-old cows generating \$80.08 more income than 3-yr-old cows (\$84.92 − 4.84 in Table 4) and \$167.27 more income than 11-yr-old cows (\$84.92 − (−82.35) in Table 4). Poor management depressed annual income from 5-, 6-, 7-, and 8-yr-old cows the most. Interactions of age with management predicted poor management decreased income from 7-yr-olds by \$125.54 (management effect of −73.43 + management by age effect of −52.11) but had little effect on profitability of first lactations (+\$.48 = −73.43 + 73.91). The decreasing effect of poor management on profitability of cows freshening as 8-yr-olds or older was unexpected but may be due to lower precision of these estimates and pooled estimates in the model of age effects for cows 5 yr of age or older.

Model Sensitivity to Driving Variables Over a Limited Range of Herd Life

Because of potential bias favoring herds with extended herd life, sensitivity analysis of additional driving variables was restricted to a range of herd life from 2.4 to 4.2 lactations. For the basal situation, increasing herd life within this range resulted in a linear increase of discounted income of \$518.96 ± 115.15 per lactation increase of herd life. By restricting comparisons to this range, effects of increasing herd life from the commercial herd average of approximately three lactations were studied, but optimum herd life in different economic environments could not be determined.

In Figure 7, all regression coefficients for slope were significant ($P<.02$) except for low feed and replacement costs ($P=.30$) and high meat prices ($P=.41$) with significant regression lines explaining from 56.3 to 89.4% of the variance around the mean. The 95% confidence interval for the base line slope of 261.1 to 776.8 discounted dollars per lactation increase of herd life included slopes for low feed and replacement costs, trend of management, low meat prices, poor management, and high feed prices but did not include slopes for low feed (241.2 ± 80.3) and high meat prices (126.8 ± 143.1). Because slope for low feed and replacement costs (286.2 ± 252.0) was close to the slope for low feed prices and reduced replacement costs were expected to decrease profitability of extended herd life, low feed and replacement cost probably should be considered also as affecting profitability of herd life relative to the basal situation.

TABLE 4. Estimates of effects of age of cow at freshening, poor management, and age-management interactions on annual cow income.

Effect	df	MS X 10^6	Effects in dollars	
			Estimate	SE
Intercept	1		575.91	2.57
Management	1	344.865866**	−73.43	4.71
Age				
2	1	10.422221*	−50.11	4.89
3			4.84	4.29
4			15.65	5.32
5			92.42	6.39
6			84.92	7.24
7	9	50.985461**	60.98	7.62
8			28.21	8.34
9			−9.64	8.94
10			−39.48	10.22
11			−82.35	12.50
Interaction of management with age:				
2			73.91	7.53
3			7.03	6.98
4			−.06	8.69
5			−36.68	10.35
6	10	14.589659**	−43.58	11.50
7			−52.11	12.72
8			−31.82	15.37
9			−7.12	18.24
10			−7.00	20.46
11			40.06	22.93
Residual	531	.816941		

*$P<.005$.

**$P<.001$.

Therefore, decreasing cow feed cost by 18%, decreasing feed prices for cows and replacements by 18%, and increasing salvage value of culls by 30% reduced profitability of extended herd life. Low feed costs would decrease cost of growth gains of immature cows. With high meat prices, increased value of cull cows comes closer to covering initial investment in a replacement. If comparisons of profitability were based on percentage change of discounted income per cow instead of discounted dollars, effects of low feed costs, low feed and replacement costs, and high meat prices on profitability of herd life would be more pronounced as they result in less increase of income at a higher average cow income. Poor management, decreasing cow salvage value by 30%, increasing feed cost by 18%, and a trend in improving management did not affect significantly the profitability of increased herd life within the range of 2.4 to 4.2 lactations.

Although economic environment specified by driving variables would not be expected to remain constant over 25 yr, these results do show that cows should be culled earlier when feed costs are low and cow salvage value is high. Because feed and beef prices go through long cycles and culling and replacement decisions in the dairy herd influence herd characteristics for years, it might be worthwhile to integrate economic and biological simulation models. Culling decisions then could be based on predicted change of economic environment. However, a more complex model would require more computer time per run. Additional random variation in the model would mean more runs would be required to detect effects from changes of driving variables. One hundred

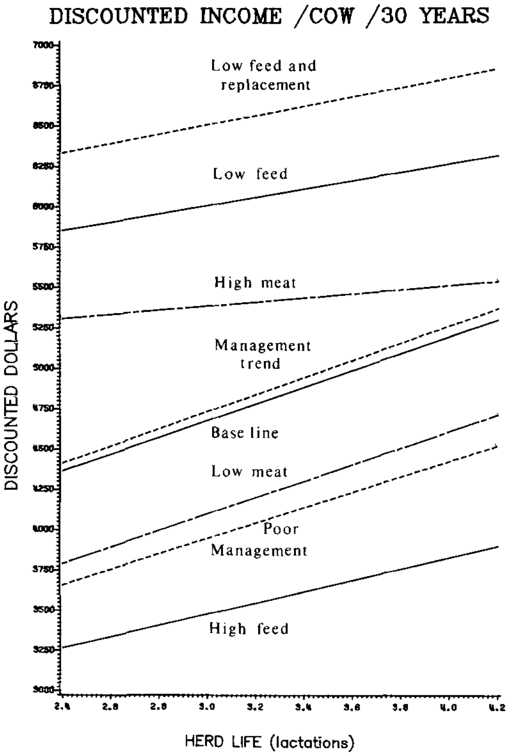

Figure 7. Discounted income for variable herd life with driving variables for: low feed and replacement cost; low feed cost; high cow salvage value; trend in improving management; basal simulation; low cow salvage value; poor management; and high feed cost.

and twenty runs were required to generate information in Figures 5 and 7 with each run using 20 min of computer time on an IBM 4341. The increase of computing requirements should be considered before increasing model complexity.

DISCUSSION

Conclusions on profitability of herd life agree with (2, 14, 16, 19). Positive net profit of an additional lactation for average and high producing cows in their 2nd through 10th lactation were calculated in (19) both with and without a genetic trend of milk production. Earned income increased by 20% for a herd with average production when herd life increased from 3.3 to 5.3 lactations. In Figure 5, the same change of herd life for the base line increased discounted income by 8.9%. This lower estimate for profitability of extended herd life is probably from including in the model effects of age of cow on health problems and fertility.

The culling rate which maximized profitability in (2) depended on replacement heifer cost and involuntary culling rate. Although maximum voluntary culling was suggested when replacement heifer prices were near or below beef value, voluntary culling 3 to 8% above the involuntary culling rate decreased economic returns when value of replacement heifers exceeded 150% of beef value. Lower replacement heifer cost also decreased profitability of extended herd life in Figure 7.

A coefficient of determination of 62.8% of the variance of observations of profit per day of herd life was explained by length of herd life for 933 Holstein cows (10). The relationship between herd life and profit per day of life for individual cows was curvilinear and increased most rapidly for short herd life. Profit per day was predicted still to be increasing slightly at a herd life of 2658 days or 7.3 yr [Figure 3 in (10)]. However, this relationship was obtained from observations of individual cows subjected to selection rather than from entire herds with variable herd life.

A dynamic programming model (22) investigated variation in some of the driving variables previously evaluated. As in Figure 7, decreased feed price allowed more intense culling of lighter cows. However, the model (22) was insensitive to changes of beef prices whereas high meat prices in Figure 7 decreased profitability of herd life.

In conclusion, results agree with studies on cow herd life. The recommendation for dairy herds with an average cow herd life of approximately three lactations is cows should be retained longer to increase annual net income. More specifically, extending herd life by one-half lactation would add to annual income if health and labor cost increased less than $30.00/cow per year. This is a conservative estimate because the additional $29.92 in annual income resulting from extending herd life from 2.8 to 3.3 lactations already included additional health and labor cost for older cows. Also, one of the criteria in selecting estimates for the model was that any bias would favor younger cows. These same general conclusions resulted from substituting in the model a different set of age dependent probabilities of health disorders. Although low feed cost and high meat prices decreased the profitability of extending herd life, there was no indication that lengthening herd life in either of these economic environments would result in an actual decrease of annual income per cow (Figure 7).

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