PROFITABILITY AND RISKS IN DAIRY FEEDING PROGRAMS: A MULTIPERIOD OPTIMIZATION

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INTRODUCTION

Considerable research has been conducted over the years to determine optimal rations for dairy cattle. Dean et al. extended earlier work through a comprehensive examination of milk production functions, isoquant shapes, and feed systems to maximize income over feed cost (IOFC) for a given point in time. Computerized formulations of dairy feeding rations are now commonplace and either minimize feed costs or maximize IOFC to meet nutrient requirements under assumed static conditions.

Computer models to formulate rations have not directly considered the role of body tissue catabolism (depletion to provide energy during periods of peak nutrient requirements) and anabolism (storage of energy when requirements are exceeded by appetite). Talpaz et al.'s optimal control model of the lactation curve appears to be the lone exception, but empirical solutions of real problems are complex and none have been reported. Further, the effect on expected costs or profits of alternative management and feeding practices has been considered without regard to the risk incurred by the producer.

Both of these neglected issues are addressed in the current study. We build upon the Dean et al. and Talpaz et al. studies by empirically examining interrelationships between milk yield, energy concentration of the ration, and storage and depletion of body tissue on the profitability and risks of managing the calving interval (production cycle). Expected IOFC and risks are measured for optimal feeding plans during the calving interval for mature Holstein cows in northeast Texas, the major dairy center of the state. Most herds in the area range from 60 to 120 cows, rely on Coastal bermudagrass for pasture, and buy all grain, by-products, and hay. Alternative milk yields, calving seasons, and calving intervals are examined.

Specific objectives are to: (1) examine the effects of milk yield on IOFC; (2) determine the cost of extending the calving interval; (3) determine optimal changes during the calving interval in the energy composition of total rations by scheduling compensating tissue depletion and repletion; and (4) compare the risks associated with alternative milk yields, calving seasons, and feeding systems.

METHOD OF ANALYSIS

Under the assumption that maximum IOFC is the dairyman's goal, a multiperiod linear programming (LP) model is constructed. Its objective is to determine the level of expected IOFC, weight loss-weight gain strategy (schedule), and ration composition for Holstein cows with two alternative calving intervals (13 and 15 months) and four yields of 3.5 percent milkfat milk (13,000, 15,000, 17,000, and 19,000 pounds in 300 days).[1] Multiperiod quadratic programming (QP) is used to determine the trade-off between profit and risk for cows with a 13-month calving interval. Profit is maximized, or risk minimized, over the entire lactation rather than for a single point (day) in the lactation. Thus, unlike conventional feed ration formulations, the optimization is recursively dynamic.

The models are constructed with six or seven two-month periods, except for the fifth period, which is of three months duration. Cows are in lactation in all but the last 60-day period. Therefore, actual lactations are 330 days (13-month calving interval) or 390 days (15-month) long. Interdependence among the stages occurs because of the cow's ability to mobilize body tissue in early lactation to help meet energy and protein requirements and to replete the tissue reserve in late lactation and the dry period.

DATA

Milk Production

Estimated daily milk yields across a 300-day lactation for mature cows follow McCraw and Butcher and depend on calving season. Averages by period are the means of predicted milk yields for days 1, 15, and 30 of each month in the

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[1] Results for alternative calving seasons are reported in Reyes et al. Additional modeling details are in Reyes.

period. For a 13-month calving interval, milk in month 11 (month 3 of period 5) is estimated at 5 percent of the 300-day total, which is similar to the estimate by Keown and Van Vleck. For a 15-month calving interval, 330-day milk yield is increased by 6 percent because of more days open (not pregnant), and yields for months 12 and 13 are 5 percent and 3 percent of cumulative 330- and 360-day totals (Schaeffer and Henderson).

Percent milkfat by period of lactation is calculated from estimated yields of fat and milk (McDaniel et al.). Milkfat percents by period for the cow yielding 19,000 pounds of 3.5 percent milk are 3.7, 3.4, 3.4, 3.4, and 3.5 percent. Percent milkfat in period 6 of the 15-month calving interval is 3.5.

Dry matter intake and net energy and crude protein requirements by period are from National Research Council estimates. Crude fiber content is restricted to the range 17–20 percent dry matter intake in each period. Minimum levels of calcium and phosphorus are based on the National Research Council minima. Maximum levels are also restricted (at twice the minima) to prevent excessive mineral concentrations.

Weight Loss and Gain

Maximum body weight loss (and corresponding repletion over the calving interval) is restricted to 330 pounds (25 percent of total body weight) in periods 1 and 2 combined. Similar weight changes are observed in mature producing dairy cows without adverse effects on health (Rakes and Davenport). Energy and protein data for catabolism (2.23 Mcal net energy, NE, and 145 grams crude protein, CP, per pound reduction in body weight) are from the National Research Council. Repletion values differ between lactation (2.32 Mcal NE and 227 grams CP per pound increase in body weight) and dry period (2.96 Mcal NE and 291 grams CP per pound increase in body weight). Programmed in this way, without explicit prices or costs, weight loss/gain strategies receive economic values indirectly by reducing nutrient concentration (and cost) in early lactation, with repletion using lower-cost feed (e.g., higher forage: concentrate ratio) in late lactation and the dry period. However, more energy and protein are required per pound repleted during the dry period than during lactation because the biological efficiency of repletion is lower then (National Research Council; Olds et al.).

Feeds and Nutrient Content

Only feeds commonly used in northeast Texas are considered. Ingredients are corn, sorghum grain, oats, wheat bran, cottonseed meal, soybean meal, sugarcane molasses, urea, defluorinated rock phosphate, Coastal bermudagrass hay, Coastal bermudagrass pasture, cottonseed hulls, and alfalfa hay. Nutritive values of feed other than pasture are supplied by the National Research Council. Since digestibility decreases as feed consumption increases, energy values for all feeds are adjusted by period, based on the proportion of expected energy intake required for maintenance in the period (Van Soest).[2] Protein values of feeds are also adjusted in proportion to the adjusted energy values.

Grazing is seasonal, and nutritive value and availability of pasture varies throughout the year. Yield and nutrient content of Coastal bermudagrass pasture are from local monthly experimental data for 1970–73 (McCartor and Rouquette). Available yields are decreased 30 percent to account for trampling and refusal. In this model, when land is used for pasture in any period, it can be used for no other purpose in the remaining periods. Although dairymen can in fact harvest excess pasture as hay, this option is not considered because of inadequate data about nutrient content of hay from pasture land, optimal fertilization of dual-purpose forage land, and the effect of haymaking on annual pasture yields. In addition, most dairymen purchase hay, and haymaking is largely a specialized activity in this region.

Prices and Costs

Feed costs in each period are calculated as the mean of prices on days 1 and 15 of each month for the years 1971–78. Feed prices are taken from records of a large local dealer and represent the cost of ingredients forming part of a feed mix already blended and delivered to a dairy in bulk, allowing for a 30-day payment with 2 percent discount. Annual production costs of pasture for the 8-year period are taken from Texas Agricultural Extension Service budgets for the area and range from \$.005 to \$.009 per pound dry matter. Milk prices are derived from monthly averages for the area during the same years. In the model, IOFC in each period is accumulated, transferred to the next period and culminated by transfer of the total to the objective function. The analysis covers only one lactation, thus IOFC is not discounted.[3]

Variability in milk and input prices is considered in examining the risks associated with alternative milk yields, calving seasons, and feeding systems. Variances and covariances of input costs and milk prices come from the 8-year (1971–78) monthly price series.

[2] This procedure is required to avoid serious errors of overestimating the nutrients available (i.e., the proportion of nutrients consumed) for the synthesis of milk.

[3] Because the distribution of net revenue over time varies with milk yield, calving interval, and weight fluctuation, a present value comparison of alternatives would differ somewhat from the undiscounted IOFC. Although not used here, the present value approach is preferred.

EMPIRICAL RESULTS

Income Over Feed Costs

The IOFC figures in Table 1 represent maximum average IOFC for each milk yield and calving interval alternative during the 8-year data period. IOFC increases with milk yield, thus intermediate yields in the range considered are not optimal. Successive increments of milk yield give positive but diminishing increments of IOFC, suggesting that an optimal yield may exist, but beyond the range of alternatives considered here. The slow rate at which marginal returns diminish may result in part from the multiperiod optimization of both the ration and body weight. Feeding programs that are structured to provide all required nutrients from the ration at every point in the lactation would likely encounter more rapidly diminishing returns, because they do not consider the greater economic value of catabolism and repletion of body tissue at higher yields.

Potential losses of milk and IOFC because of extended calving interval have been previously examined. Olds et al. estimated that IOFC decreased $1.18 per day in the range 40 to 140 days open when milk was priced at $9.50 per cwt. However, IOFC was calculated in retrospect based primarily on feed cost as a constant proportion (45 percent) of the price of milk. This procedure ignores variation in feed cost per unit of milk across the lactation, restricting covariation between IOFC and days open to the mutual association with milk yield. Thus, the responsiveness of profit to variation in ration cost is ignored.

Because the multiperiod model optimally manages the differential between milk income and feed cost (i.e., IOFC) over the entire calving interval, it may be the most appropriate method for evaluating costs of extended calving intervals. To make a relevant comparison, IOFC for 13- and 15-month lactations are adjusted to a common annualized basis in Table 1. Contrary to previous studies (e.g., Louca and Legates; Olds et al.), we find no short-run penalty resulting from lengthening the calving interval from 13 to 15 months. This conclusion assumes that the decision to delay conception (or actions to compensate for failure to achieve early conception) is made early in lactation so that an optimal weight loss/gain strategy is followed. Cows with a 15-month calving interval have at least the same annual IOFC as their correspondents with a 13-month interval.

TABLE 1. Income Over Feed Cost and Weight Loss/Gain at Four Milk Yields with 13- and 15-Month Calving Intervals[a]

Item	Calving Interval	300-Day Milk Yield (lb.)			
		13,000	15,000	17,000	19,000
	(mo.)	($)			
IOFC:					
Per Lactation	13	818	956	1,078	1,199
	15	955	1,112	1,254	1,383
Annual Basis	13	755	883	1,003	1,106
	15	764	890	1,003	1,106
		(lb.)			
Weight Loss and Offsetting Gain per Lactation	13	73	117	143	178
	15	117	125	156	220

[a]Initial calving is in the September-October season.

Not all benefits (e.g., lower reproductive costs because of fewer services per cow and less veterinary treatment) nor all costs (e.g., fewer calves for sale and slower genetic improvement) of extending the calving interval are considered in this analysis. Whether additional benefits and costs are offsetting remains to be examined. However, it is apparent that high-yielding cows are considerably more profitable than low-yielding cows. Although the former also tend to have longer calving intervals (Spalding et al.), appropriate multiperiod planning may alleviate possible adverse effects on herd profits.

Energy Concentration

For low-yielding cows, negative energy balance (loss of weight) can be avoided in all stages of lactation by altering the nutrient concentration of the ration. However, as noted in Table 1, weight fluctuation is economic at all yields considered. More energy and protein are required to replete body tissues than are gained from catabolism. However, the marginal cost of additional energy and protein concentrations in the ration increases rapidly enough to make body weight fluctuation profitable. This finding is in contrast to the recommendation of Black and Hlubik that the modeler should permit a change in body weight to enter the LP solution only when it is impossible to meet energy requirements from feedstuffs in early lactation.

Further, although more nutrients are required for weight repletion during the dry period than during lactation, much of the weight lost in early lactation is optimally restored when the cow is dry. Evidently the economic advantages of adding energy and protein to low-cost rations during the dry period and using correspondingly less-expensive rations in early lactations is sufficient to counteract the lower biological efficiency of repletion during the dry period.

Because this model permits high energy needs to be satisfied temporarily by some body weight loss, the energy densities of the optimal rations may differ in any period from rations if no weight change were permitted. In addition, the annual nutrient requirements for body maintenance and milk ultimately must come from feeds and tends to be greater than if body weight were stable.

Energy concentrations of optimal rations (with scheduled body weight change) and rations required for a constant weight are reported in Table 2 by period for a 13-month calving interval at all milk yields. The energy concentrations of optimal rations vary by period, but differences are less than for rations when no weight change is permitted. Thus, the optimal solution provides a more uniform distribution of energy density across all stages of the calving cycle.

The more uniform distribution of energy in the ration is consistent with results by Davenport and Rakes who compared feeding systems allocating 61 percent of annual energy in the first 180 days of lactation versus a uniform energy distribution. They found no difference between systems in the annual yield of fat-corrected milk or milk per pound of concentrate, and concluded that "agreement between annual nutrient intakes and annual nutrient requirements is more important than the scheme by which annual total feed allowance is distributed over the lactation cycle." Annual returns to inputs respond to a weight loss/gain strategy that permits more flexibility in formulating less expensive rations to meet nutrient requirements for the calving cycle. This means that it is economically prudent for dairy cows to lose some weight in the efficient production of milk solids.

Corn, cottonseed meal, urea, alfalfa hay, Coastal bermudagrass pasture, and defluorinated rock phosphate are included in most rations, particularly in the early periods of lactation. Sorghum grain, wheat bran, and Coastal bermudagrass hay are often used in latter stages of lactation and during the dry period. The LP shadow prices reveal considerable opportunity to modify ingredients in the ration with little adverse effect on IOFC.

TABLE 2. Energy Concentration of Profit-Maximizing Rations and of Rations Requiring No Weight Change[a]

Period of Lactation[b]	300-Day Milk Yield (lb.) 13,000 Max Profit	13,000 No Weight Change	15,000 Max Profit	15,000 No Weight Change	17,000 Max Profit	17,000 No Weight Change	19,000 Max Profit	19,000 No Weight Change
	Mcal NE[c]/lb dry matter							
1	.65	.70	.68	.72	.67	.75	.68	.79
2	.68	.69	.68	.71	.68	.72	.71	.76
3	.68	.68	.72	.69	.71	.71	.74	.72
4	.70	.67	.73	.68	.73	.69	.71	.71
5	.67	.64	.70	.65	.71	.66	.74	.67
6	.62	.53	.62	.53	.67	.53	.69	.53

[a]For 13-month calving interval with initial calving in the September-October season.
[b]All periods have 2 months except the 5th which has 3 months.
[c]Adjusted following Van Soest.

Risks

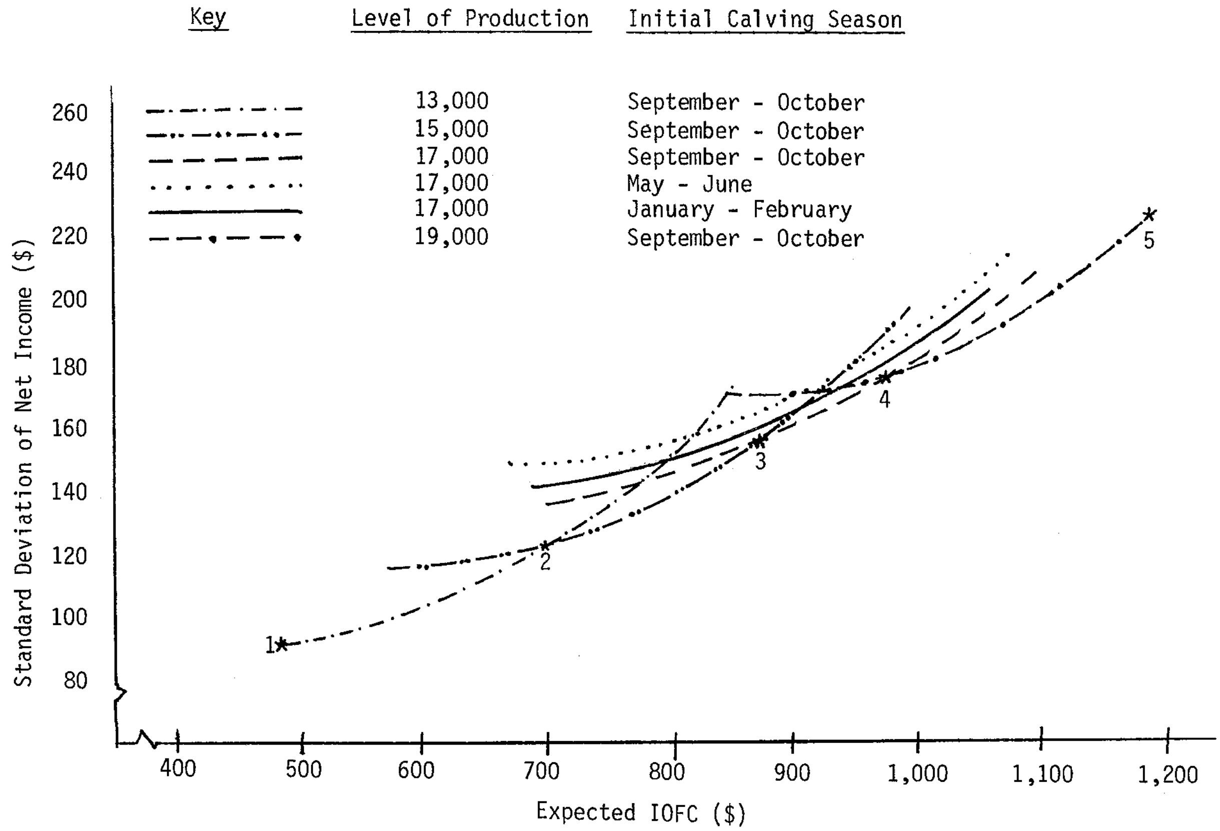
Attention has focused thus far on profit-maximizing feeding systems. It is possible that alternative feeding plans may yield expected IOFC levels close to the maximum and also provide greater flexibility for individual producers. Knowledge of the approximate increases (or decreases) in the variance of IOFC, as higher milk yields and higher expected IOFC levels are attained and alternative feeding plans are selected, may be as important for decision making as the IOFC expected. Results from the QP analyses provide additional information on feed substitution, sources of variation, and the risk of alternative feeding plans.

Expected IOFC-variance of IOFC (E-V) efficient sets are developed for a 13-month calving interval with (a) all four milk yields for cows calving in September-October; and (b) a milk yield of 17,000 lb. in 300 days for cows calving in two other seasons (January-February and May-June). The last two E-V efficient sets are derived to detect calving season effects on risk.

Each of six E-V efficient sets consists of about 90 E-V points. Differences in E-V values, weight loss-weight gain strategies, ration composition, and land requirements exist amont most of the sets. The E-V efficient sets, depicted in Figure 1, are of the typical concave form and intersect for different milk yields. Thus, some expected net incomes and variances could be attained with different milk yields. For example, an expected net income of $964 and standard deviation of $175 (point 4 in Figure 1) can be obtained by cows producing either 17,000 or 19,000 pounds of milk in 300 days of lactation.

E-V efficient sets for cows with different calving seasons do not intersect. For any given variance, expected IOFC is always greater for September-October calvings than for the calving seasons. Expected IOFC differences between the calving seasons are small (less than $50) for the IOFC maximizing solutions, but increase (to $120) as variance is substantially reduced. Thus, there is more incentive for risk-averse than for risk-neutral producers to consider management techniques to control herd calving.

The solution with the highest expected net income and variance on the efficient set for a given level of milk production and calving season is the same as the IOFC-maximizing LP solution for that situation. Other solutions have lower expected net incomes and lower variances. Since milk yields, prices, and feed costs are assumed normally distributed, IOFC is also normally distributed. By relating mean IOFC and standard deviation values to normal distribution tables, probabilities of occurrence of a given minimum IOFC can be computed for each point of an E-V efficient set. The minimum IOFC that would occur with probabilities of 50, 75, 90, and 95 per-



Note: Numbers on figure correspond to points identified in Table 3.

FIGURE 1. E-V Efficient Sets for a 13-Month Calving Interval

cent are reported in Table 3 for the five points identified in Figure 1. They include the two extreme points and the three intersection points in the E-V efficient sets that identify the E-V frontier across production levels and calving seasons. This information may be useful in determining the probability of minimum-survival IOFC levels to assist producers select a more appropriate strategy than suggested by the IOFC-maximizing LP solution. However, because of the particular shape of this E-V frontier, points that give higher expected IOFC's also give higher probabilities of attaining any minimum-survival IOFC level.

CONCLUSIONS

Multiperiod LP and QP models have been constructed to examine the economics and risks of various dairy herd management options and genetic situations for Holstein cows in northeast Texas. Each analysis was conducted for an entire calving interval (cycle), and tissue reserves of cows were permitted to be a temporary source of nutrients as long as they were fully repleted prior to the next calving. Major findings included the following:

1. Maximum IOFC increases consistently with milk production over the range considered (i.e., 13,000–19,000 pounds per cow in 330 days).
2. To maximize IOFC generally requires that cows temporarily lose weight to help meet high energy requirements in early lactation and then replenish body fat and tissue in late lactation and during the dry period. Optimal weight change schedules increase with milk yield and length of the calving interval.
3. No short-run IOFC penalty is apparent

TABLE 3. Minimum IOFC Values that Would Occur with Alternative Probabilities[a]

Points[b]	Standard Deviation of IOFC	Minimum IOFC with Probability of Occurrence 50%	75%	90%	95%
		($)			
1	88	442	383	329	298
2	122	688	606	532	488
3	152	850	747	655	599
4	176	964	846	739	675
5	237	1,199	1,039	895	809

[a]For cows having a 13-month calving interval and calving initially in September and October.
[b]Points correspond to numbered points in Figure 1.

from deliberate management to extend calving interval from 13 months to 15 months.

4. Differences in IOFC between calving seasons are considerably greater for a producer desiring to minimize risks than for a producer seeking to maximize expected IOFC.
5. Risks increase with milk yield, but not enough to lower the minimum IOFC that would occur with 75, 90 or even 95 percent probability.

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