Alfalfa and Corn Silage Systems Compared on Michigan Dairy Farms

L. R. BORTON,[1] C. A. ROTZ,[2] J. R. BLACK,[1]
M. S. ALLEN,[3] and J. W. LLOYD[1,4]
Michigan State University, East Lansing 48824

ABSTRACT

Two primary roughages used for diets of dairy cows are corn silage (*Zea mays* L.) and alfalfa (*Medicago sativa* L.). A dairy forage system model was used to compare the relative merits of these two forages when varied amounts (none, one-third, two-thirds, and all on a dry matter basis) of the forage requirement were ammoniated corn silage and the remainder was alfalfa. Primary comparisons were the net return above feed and manure costs, but manure management issues and labor requirements were also considered. Economic comparisons were made for representative farms using a partial budget analysis synthesized from research reports and surveys. The highest net return was from alfalfa at 100% of the forage requirement, but differences in net returns across forage systems were small compared with the variation caused by weather among years. Changes in assumptions concerning farm size, soil type, crop yield, milk production, relative prices, and manure handling did not affect the conclusions of the analysis. In systems that used all alfalfa forage, much of the manure was applied to alfalfa crops, a practice that is normally discouraged because the manure reduces weed control, stand persistence, and yield. With alfalfa at 100% of the forage requirement, large amounts of excess manure nitrogen were produced on the farm. Application of nitrogen to alfalfa must be compensated by a reduced nitrogen fixation to avoid ground water contamination. Because of the lack of a strong economic advantage among the forage systems, the practice of having at least one-third of the forage requirement provided by each of the forage crops is favored to improve management of crops, manure disposal, and labor.

(**Key words**: corn silage, alfalfa, forage systems, economics)

Abbreviation key: **DAFOSYM** = dairy forage system model.

INTRODUCTION

Primary forages for Michigan dairy herds are corn silage (*Zea mays* L.) and alfalfa (*Medicago sativa* L.). Previous studies have shown that one forage is not always better than the other using economic criteria. A new look at this comparison is needed because of changes in the dairy industry, including larger farms, greater crop yields, higher herd production, and greater importance of manure nutrient management. Also, computer technology can provide a better analysis than was previously possible by using simulations that integrate weather risk and the many interactions among farm components.

The literature comparisons of corn silage and alfalfa include studies ranging from cow feeding trials to comparisons of whole farm budgets. Feeding trials generally demonstrate similar milk production from cows fed diets based on either corn or alfalfa silage when the rations are properly balanced. Broderick (5) found comparable milk production among cows fed diets based on either high quality alfalfa silage or corn silage balanced with corn grain, soybean meal, and other supplements. Colenbrander et al. (7) formulated dairy rations that were based on equivalent concentrations of NDF using three combinations of alfalfa and corn silages and found no differences in actual milk production, fat-corrected milk production, or milk composition. Dhiman and Satter (11) measured milk production of dairy cows over the entire lactation and concluded that the highest milk production came from cows fed a diet in which the forage was one-third corn silage and two-thirds alfalfa, but the differences among forage combinations were small. Those experiments have indicated that corn silage, alfalfa, or mixtures of the two can provide adequate nutrition for milk production when properly supplemented to meet the energy, protein, mineral, and vitamin needs of the dairy cow.

Because similar milk production can be attained using either corn or alfalfa forages, overall farm per-

Received February 26, 1996.
Accepted December 19, 1996.
[1]Department of Agricultural Economics.
[2]USDA, Agricultural Research Service.
[3]Department of Animal Science.
[4]Department of Large Animal Clinical Sciences.

formance and economics become the key issues for forage selection. Several studies (1, 17) completed 20 yr ago made comprehensive comparisons of dairy farms that produced alfalfa and corn silages; those studies concluded that the use of corn silage reduced costs on more productive cropland, but that alfalfa was better suited to less productive, rolling cropland. Labor and machinery resources, prices, and crop yields sometimes changed the recommendation for individual farms (1). If the price of alfalfa hay was less than three times the price of corn silage (as-fed wet weight basis), alfalfa was preferred (23). Either all alfalfa or all corn silage caused problems in crop rotation or a reduction in the number of cows allotted per unit of land (3). When available land was limited to less than 0.6 ha per cow, production of corn silage had a comparative advantage, but haycrop silage was preferred when available labor was limited (10).

In previous studies (1, 17, 19), total feed costs were similar across forage combinations, particularly in the range of 30 to 70% DM from corn silage. Knoblauch et al. (19) found that harvest, storage, and feeding costs for a 120-cow herd were highest for a system using equal amounts of haycrop silage and corn silage, but this combination was also most economical. The difference in farm profit between the best and worst combinations of alfalfa and corn silage considered was less than 10% of the maximum profit. Using prices following the 1973 oil embargo, Nott (20) found that management income was higher for corn silage that had been treated with ammonia than for alternatives that used alfalfa. In a more recent study, Nott et al. (21) showed that alfalfa with a yield of 8.6 tonne of DM/ha provided a more economical forage than corn silage at 10.7 tonne of DM/ha. The low yield of the corn silage was set to reflect that the lowest yielding corn is typically harvested as silage. Also, prices of soybean meal were unusually high relative to prices of corn grain, which further favored alfalfa.

As technology and regulatory policy change, the recommended mixture of corn silage and alfalfa may change. Mean milk production in Michigan has increased over 60% during the past 20 yr (3, 13). A problem that was associated with high corn silage diets 20 yr ago was fat cow syndrome, which was caused by too much dietary energy during late lactation. As milk production increased, this problem was reduced because more energy was needed much longer in the lactation cycle. New policies are now being enacted that require or encourage a better balance of farm nutrients to protect the environment. New understanding of nutrient requirements for both cows and crops enables a better evaluation of nutrient flows. Technologies, such as bunker silos, are also being adopted that change the procedure and costs of forage harvest and preservation.

Because of past and anticipated changes, a new analysis of forage options for the dairy farm is warranted. A comprehensive analysis of all aspects of feed production, milk production, and manure handling is required to incorporate variability in weather and related risks (21). The dairy forage system model, **DAFOSYM**, is well suited for this analysis. The model enables a multidisciplinary approach that maintains a fair comparison of the forages, including the complex interactions of crop growth, weather, machinery, labor, milk production, nutrient flows, and economics. Therefore, production costs, labor use, and nutrient management are evaluated with consideration of the entire farm operation.

The overall goal of this work was to use DAFOSYM to determine the best combinations of alfalfa and corn forage for representative Michigan dairy farms, considering machinery and labor utilization, nutrient loss to the environment, and overall farm profitability. Specific objectives were 1) to identify crop, machinery, facility, feed, and labor parameters that are representative of current Michigan dairy farms; 2) to evaluate the performance and economics of a representative Michigan dairy farm when corn silage supplied approximately none, one-third, two-thirds, or all of the forage DM requirement, and the remainder was provided by alfalfa; and 3) to determine the sensitivity of the results to farm size, relative crop yields, milk production, and important prices or costs assumed in the analysis.

MATERIALS AND METHODS

DAFOSYM simulates the growth, harvest, storage, and use of alfalfa and corn along with manure production, collection, storage, and application to cropland on representative dairy farms over many years of varying weather conditions (25, 27). DAFOSYM has been used to evaluate many alternatives in forage production and manure handling (4, 25, 26, 27, 28). To use the model, parameters are set to describe a representative farm at a given location. Simulation over many years provides a distribution of annual values of farm performance, costs, and economic returns as influenced by weather. This study required further development of DAFOSYM, the simulation of representative farms synthesized through expert opinion and surveys, and a sensitivity analysis to determine the impact of major assumptions.

Model Development

The animal submodel of DAFOSYM was modified to handle the range of forage mixtures, from all alfalfa to all corn silage, that was required for this study. Previous studies using DAFOSYM (26, 28) often used corn silage for about one-third of the forage requirement. To allow the animal to respond properly to all forage combinations, the intake constraints of the animal submodel were expanded from those previously used (27). Instead of predicting fill and roughage value directly from adjusted forage NDF, fill and roughage units were defined as functions of NDF. The revised intake constraints were

$$\sum_{i=1}^{k} X_{ij}\ FU_i \leq FIC_j\ BW_j \qquad [1]$$

and

$$\sum_{i=1}^{k} X_{ij}\ (RU_i - 0.75\ NDF_i) \geq 0 \qquad [2]$$

where

X_{ij} = amount of feed i in the diets of animals in animal group j (kilograms of DM per day),

FU_i = fill units of feed i,

FIC_j = fiber intake constraint for animal group j (kilograms of NDF per kilogram of BW per day),

BW_j = animal BW in animal group j (kilograms),

RU_i = roughage units of feed i, and

NDF_i = concentration of NDF in feed i.

The fill units and roughage units were defined as functions of fill factors or roughage factors, forage NDF, and particle size:

$$FU_i = FFE_i\ NDFE_i\ EP_i + FFS_i\ NDFS_i\ SP_i \qquad [3]$$

and

$$RU_i = RFE_i\ NDFE_i\ EP_i \qquad [4]$$

where

FFE_i = fill factor of effective particles in feed i,

$NDFE_i$ = NDF concentration of effective particles in feed i (fraction of DM),

EP_i = effective particles (alfalfa stem or corn stover) in feed i (fraction of DM),

FFS_i = fill factor of small particles in feed i,

$NDFS_i$ = NDF concentration of small particles in feed i (fraction of DM),

SP_i = small particles (alfalfa leaves or corn grain) in feed i (fraction of DM), and

RFE_i = roughage factor of effective particles in feed i.

Fill and roughage factors represented the resistance to particle size reduction in the rumen. These factors were set by considering the digestibility of the particle NDF as influenced by particle size. Values were assigned to fill and roughage factors that were the inverse of the estimated NDF digestibility of those particles; values were assigned to provide diets with at least 75% of the dietary NDF from forage and equivalent maximum milk production from diets based on alfalfa or corn silage. The values selected for feeds used in this study and the normal range for the portion of effective particles and effective particle NDF are listed in Table 1.

The portion of effective forage particles and the NDF concentrations of forage particles were predicted through the growth, harvest, and storage subroutines of DAFOSYM and thus varied with weather and management conditions. For alfalfa, stems were considered to be effective particles. Fill and roughage factors for stems were both assumed to be 1.25; thus, NDF from alfalfa stems contributed 25% more to the rumen fill of the cow and fulfilling roughage requirements than did the NDF of an average feed. The leaves were assumed to be small particles that degraded rapidly in the rumen and thus had only a small fill effect and no roughage value. For corn silage, stover was considered to be an effective particle size, and grain was considered to be a small particle size that was rapidly digestible. Fill and roughage factors for stover were set at 1.05. The model for the grain in silage was similar to that for alfalfa leaves having a small fill effect and no roughage value. Dry corn grain and high moisture corn without cobs were treated the same as corn silage grain. Soybean meal was assigned the same fill factor as alfalfa leaves (Table 1).

To enable higher milk production, fat was added as a feed option. Fat was considered to contribute to the energy requirements of the cows with no fill effect or roughage value. The maximum amount of fat allowed in the diets of high producing cows (first 60 d of lactation) was set at 1.0 kg/d; the limit in the diets of other cows was 0.5 kg/d. Fat was added to the ration up to this limit or until the energy density of the ration was sufficient to meet the production goal. With the milk production goals of this study, the maximum amount of fat was never fed to the highest producing group, and no fat was used for the other feeding groups.

TABLE 1. Characteristics of selected feeds that influence intake.

Feed	Effective particles[1]	NDF_i[2]	NDF Digestibility	Fill factor[3]	Roughage factor[4]
	— (% of DM) —		(%)		
Alfalfa stems	100	~60	40	1.25	1.25
Alfalfa leaves	0	~20	80	0.38	0
Corn stover	100	69	50	1.05	1.05
Corn grain	0	12	50	0.53	0
Soybean meal	0	14	80	0.38	0
Anhydrous ammonia or urea	0	0	. . .	0	0

[1]Feed particles large enough to stimulate rumination, i.e., alfalfa stems, corn stover, or corn cobs.

[2]NDF concentration in each feed component. Concentration of NDF in alfalfa stems and leaves varied with growth and harvest conditions.

[3]A factor that represented the relative influence that the NDF of a particular feed component had on fill relative to other feed components. Factors were set considering the digestibility of the particle NDF as influenced by particle size.

[4]A factor that represented the relative influence that the NDF of a particular feed component had on stimulating rumination relative to other feed components. Factors were set considering the digestibility of the particle NDF as influenced by particle size.

Description of Representative Farms

Representative farms were synthesized from data obtained by expert opinion and research surveys. A small survey of 13 farms located throughout southern Michigan was conducted to collect information on 1) relative yields of corn and alfalfa; 2) methods of forage production, harvest, and storage; and 3) forage combinations and feeding methods used to achieve maximum milk production (2). The 1987 Michigan Dairy Farm Survey (8) and 1992 Michigan Agricultural Statistics (13) were also used to identify typical farm areas and characteristics. The analysis was limited to three crops: corn for dry grain or high moisture corn, corn for silage, and alfalfa. A typical farm in Michigan might have other crop enterprises, but the addition of other crops would have only minor effects on the comparison of corn silage and alfalfa systems.

The primary farm studied included 120 lactating and dry cows, but farms with 60, 250, and 400 cows were also used to determine the effect of farm size. The number of primiparous heifers out of the total number of cows in the herd (or culling rate) was set at 26%. The number of older heifers (13 to 24 mo) was set at 30% of the cow numbers, and the number of younger heifers (3 to 12 mo) was set at 36% of the cow numbers. This proportion of heifers and primiparous cows reflected good management for a herd that was not expanding. Income from culled and excess animals was considered to be constant across all strategies and thus was not included. Milk production goals were selected to represent above average (8000 kg per lactation) and very high (10,500 kg per lactation) production. Although few herds currently reach the higher level, mean milk production has increased 2 to 3%/yr in recent decades (4). The assumption of high production should help this study maintain relevance in the future.

Representative farms were simulated using 26 yr of historical weather data (1953 to 1978) for East Lansing, Michigan. The primary mixtures of forage included all alfalfa, one-third corn silage and two-thirds alfalfa, two-thirds corn silage and one-third alfalfa, and all corn silage. The two soil types chosen were a Pewamo clay loam (water-holding capacity of 20.8 cm) and a Marlette sandy loam (water holding capacity of 17.1 cm). Most of the relevant variation from the soil groups was contained in the absolute and relative yields of corn grain, corn for silage, and alfalfa produced per unit of land area. These soil profiles were used in an application of the CERES-Maize model (18, 25) to generate data on corn yield based on planting period, harvest period, adequate nitrogen, no irrigation, and a hybrid with a relative maturity index of 108 d.

The growth models for alfalfa and corn were phenological models; therefore, yields were related to the weather conditions for each season. The results generated by the CERES-Maize model had lower mean yields and greater variation across years for both soil types than was empirically reasonable. To obtain reasonable relative yields, predicted grain and silage yields were increased to levels that were consistent with expected yields for those soil management groups (6). The coefficients of variation for grain and silage yields across years was reduced by 50%, which provided values similar to those for actual data (24).

Silage CP contents (biomass nitrogen) predicted by CERES-Maize were also high and were scaled to a mean of 7.5% DM, which was typical for south central Michigan (12). The resulting final yields were similar to the typical yields obtained in the farm survey, and these yields maintained the proper relationship with weather; the lowest yields occurred in the driest years. Mean yields, as delivered to a storage structure, were 5.7 tonnes of DM/ha (6.7 tonnes/ha at 15% moisture) for corn grain and 13.6 tonnes of DM/ha (41 tonnes/ha at 67% moisture) for corn silage.

Alfalfa yields also were adjusted so that the range of predicted yields matched that of actual yields for the region. Yields predicted by the model were reduced 10% to provide mean long-term yields that were similar to those reported in the farm survey. The mean alfalfa yield (8.9 tonnes of DM/ha; 10.5 tonne/ha at 15% moisture) included both hay and silage and accounted for lower yields in the establishment year. A crop rotation effect was modeled based on values documented in previous studies (9, 14, 16, 29). When alfalfa was rotated to corn, the alfalfa crop supplied 112 kg/ha of nitrogen, and the corn yield during the 1st yr was increased 15%. Alfalfa was harvested in plots, and the quality of the harvested forage was influenced by the growing and harvest conditions (25). The NDF content of harvested alfalfa normally ranged from 36 to 45% of DM.

Storage facilities were assigned according to feed type. Normally, alfalfa silage was separated between two silos according to quality (concentration of NDF). If the NDF of a harvested plot was above 42% DM, silage was stored as lower quality silage, and all other silage was stored as high quality silage. First, third, and fourth cuttings were harvested for silage; the second cutting was harvested as baled hay. For the farms with 60 or 120 cows, alfalfa silage was stored in concrete stave silos, but, on larger farms, bunker silos were used for easier handling of large volumes of material. Corn silage was stored in concrete bunker silos on all farms, and high moisture corn was stored in concrete stave silos. All corn silage was treated with anhydrous ammonia at a rate of 15 kg/tonne of DM to add nonprotein nitrogen and to enhance preservation. Silo sizes were selected to balance initial costs and losses and thus provided a maximum net return for the farm. Hay was stored in a three-sided shed with a concrete floor.

As the amount of corn silage increased, the size of silos for alfalfa silage was reduced. With the two-thirds corn silage system, only one alfalfa silo was used, and no high moisture corn was used. High moisture corn was fed only when corn silage was less than half of the forage DM of the diet to avoid potential problems with ruminal acidosis and off-feed disorders. With the system using all corn silage, only one bunker silo was needed, and a small amount of purchased hay was stored outside under a plastic cover. The sizes and prices of storage structures used with the various forage systems on the farm with 120 cows are listed in Table 2.

Machinery requirements and sizes were selected to maximize net return to the farm. Machines were selected that provided adequate capacity and maintained or improved the net return. This procedure required trying several combinations of machinery for each strategy. As the forage mix changed from all alfalfa to all corn silage, the machinery requirement changed according to the capacity and capability needed (Table 2). To minimize differences across forage systems on the farm with 60 cows, chopped silage was used for all forage, and similar equipment was used for all forage combinations. With a herd size of 250 cows, two balers and forage harvesters were needed to meet the capacity required in the system using all alfalfa. Only one baler was needed for the systems using one-third or two-thirds corn silage.

The three possible systems used for manure handling, storing, and application were solid, spread slurry, and injected slurry. Slurry was chosen as the primary manure system because it made the best use of manure nutrients. With daily scraping, bottom loading of manure into storage, proper agitation, and injection, most nutrients were conserved. This procedure allowed the substitution of manure for purchased fertilizer, which was the optimal scenario. Injected manure was assumed for corn cropland, and surface spreading of manure was assumed for alfalfa cropland to avoid root and crown damage. Solid manure handling was used only in the sensitivity analysis as a low cost option in which manure nutrients were ignored. Manure with 16% solids was handled with a bucket and solid manure spreader. Storage was limited to a concrete pad with an end wall, which required daily hauling of the manure produced. Because incorporation of manure in the soil was delayed, most nonorganic nitrogen was lost to the air.

Long-term relative prices were used for feed and milk to mitigate the impact of fluctuating prices. Historical prices were used to establish the long-term price ratios of hay, soybean meal, and milk relative to corn. Over the previous 15 yr, the hay price (per kilogram of DM) has averaged about 75% of the corn price. Most recently, the ratio was closer to 1, which suggested a need to evaluate the effects of this ratio in the sensitivity analysis. The price ratio of soybean meal to corn averaged about 2.0, and the ratio of milk price (per kilogram) to corn price (per kilogram of

TABLE 2. Major machines and structures used in the four alfalfa and corn silage forage systems on a farm with 120 cows.

Machine or storage type	Size	Amount	Price	Size	Amount	Price
		(no.)	($)		(no.)	($)
	All alfalfa			One-third corn silage		
Tractors	100 kW	1	56,850	100 kW	1	56,850
	50 kW	1	27,150	50 kW	1	27,150
	35 kW, used	2	4000	35 kW, used	2	4000
Skid-steer loader	25 kW	1	15,050	25 kW	1	15,050
Mower-conditioner	3.7 m	1	15,200	3.7 m	1	15,200
Tandem hay rake	5.4 m	1	8500	5.4 m	1	8500
Round baler	12 tonne of DM/h	1	17,700	9 tonne of DM/h	1	15,200
Round bale wagon	4.9 tonne	1	4000	4.5 tonne	1	4000
Forage harvester and heads	18 tonne of DM/h	1	22,450	12 tonne of DM/h	1	26,550
Forage wagons	9 tonne	3	8650	9 tonne	3	8650
Forage blower	30 tonne/h	1	3800	30 tonne/h	1	3800
Corn planter	6 row	1	11,700	6 row	1	11,700
Mobile feed mixer	5 tonne of DM/h	1	17,100	5 tonne of DM/h	1	17,100
Slurry spreader/injector	9 tonne	1	9200	9 tonne	1	9200
Manure pump/agitator	450 tonne/h	1	9000	450 tonne/h	1	9000
Alfalfa silage silos and	400 tonne of DM	1	50,100	309 tonne of DM	1	41,600
unloaders	309 tonne of DM	1	41,600	180 tonne of DM	1	29,750
Corn silage bunker silo				300 tonne of DM	1	53,315
Hay storage barn	300 tonne of DM	1	16,700	200 tonne of DM	1	11,600
High moisture corn silo	164 tonne of DM	1	18,850	164 tonne of DM	1	18,850
	Two-thirds corn silage			All corn silage		
Tractors	100 kW	1	56,850	100 kW	1	56,850
	50 kW	1	27,150	65 kW	1	37,200
	35 kW, used	2	4000	35 kW, used	2	4000
Skid-steer loader	25 kW	1	15,050	25 kW	1	15,050
Mower-conditioner	2.7 m	1	10,500			
Forage harvester and heads	12 tonne of DM/h	1	20,100	18 tonne of DM/h	1	17,700
Forage wagons	9 tonne	3	8650	9 tonne	3	8650
Forage blower	30 tonne/h	1	3800			
Corn planter	8 row	1	14,000	8 row	1	14,000
Mobile feed mixer	5 tonne of DM/h	1	17,100	5 tonne of DM/h	1	17,100
Slurry spreader/injector	9 tonne	1	9200	9 tonne	1	9200
Manure pump/agitator	450 tonne/h	1	9000	450 tonne/h	1	9000
Alfalfa silage silo	258 tonne of DM	1	35,750			
Corn silage bunker silo	600 tonne of DM	1	78,800	910 tonne of DM	1	89,950
Hay storage barn	100 tonne of DM	1	6300			

DM) averaged 2.5. Other parameters were based on recent crop budgets or machinery cost estimates (13, 15, 22). The hourly labor price was set to include fringe benefits. Table 3 summarizes the prices and parameters used in the primary analysis.

The annual costs of seeds and pesticides were estimated to reflect clear seeding of alfalfa in the spring. The cropping program assumed that lime was spread on cropland every 8 yr at a rate of 6.8 tonnes/ha (22). Additional insecticide was included for corn following corn in a rotation to control rootworm. The annual pesticide cost for alfalfa reflected occasional insecticide use at a mean cost of $15/ha. The cost of fertilizer was based on recent fertilizer prices (22) and the units of nitrogen, phosphate, and potash needed to meet crop requirements.

For machinery operations other than tillage, all ownership and operating costs were considered. The economic life of machinery was assumed to be 10 yr, and the salvage value was assumed to be 10% of the original purchase price. Costs of all equipment, except the smallest tractors, were determined using new purchase prices (Table 2). Storage structures were assumed to have an economic life of 20 yr and no salvage value. A real interest rate of 6% was assumed on all long-term investments, which approximated the difference between an inflation rate of 4% and a loan rate of about 10% from an agricultural lending institution.

Tillage operations were modeled as a custom cost. Conventional tillage was used to enable the incorporation of manure. Corn tillage assumed plowing, disking, field cultivating, spraying, and spreading of fertilizer at a cost of $71/ha. Alfalfa costs included plowing, disking twice, spraying, spreading of fertilizer, and drilling seed at $103/ha. A land charge,

TABLE 3. Economic parameters and prices assumed in the forage system analyses.

Parameter	Value
Labor wage rate, $/h	9.35
Diesel fuel price, $/L	0.28
Electricity price, $/kWh	0.08
Corn drying cost, $/point per tonne	1.18
Milk price, $/L	0.284
Land charge or rental rate, $/ha	125
Seed and pesticide cost	
New alfalfa stand, $/ha	203
Established alfalfa, $/ha	15
All corn crops, $/ha	118
Corn after corn insecticide, $/ha	33
Cost of fertilizer	
Nitrogen, $/kg	0.31
Phosphate, $/kg	0.42
Potash, $/kg	0.24
Custom machinery costs	
Alfalfa tillage and planting, $/ha	103
Corn tillage, $/ha	71
Corn grain harvest, $/ha	65
Selling price of feed	
Corn grain, $/tonne of DM	113
Alfalfa hay, $/tonne of DM	90
Corn silage, $/tonne of DM	66
Buying price of feeds, bedding, and additives	
Soybean meal, $/tonne of DM	260
Corn grain, $/tonne of DM	118
Alfalfa hay, $/tonne of DM	100
Straw for bedding, $/tonne	67
Fat, $/tonne	440
Anhydrous ammonia, $/kg	0.26
Economic life and salvage value	
Life of machinery, yr	10
Machinery salvage value, %	10
Life of storage structures, yr	20
Structure salvage value, %	0
Real interest rate, %/yr	6.0

representing the cost of owning or renting land, was important to reflect the different land requirements for varying combinations of alfalfa and corn. An annual land charge of $125/ha was used.

A partial budgeting framework, rather than an analysis of the whole farm, was used to compare forage systems. Only factors that changed among systems were considered. Major factors included labor, machinery, supplies, and energy associated with growth, harvest, storage, and feeding of crops, as well as manure handling and application. Revenues included milk sales and excess crop sales. Costs for milking, cow facilities, and animal health care and revenues from animals sold were not included because they were not affected by the combination of corn silage and alfalfa.

Sensitivity Analysis

A strength of simulation studies is the ease in which an analysis can be rerun with a modified parameter to determine the sensitivity of the analysis to that parameter. Sensitivity information is useful in two ways. First, sensitivity indicates the error in return over feed and manure costs that occurred if an error was made when assuming the original parameters. Second, sensitivity indicates how the economic comparisons can be influenced by changing major assumptions of the design or management of the farm. If changing a parameter has a large impact on the results, that parameter may be selected as an important variable in the study.

A major variable tested in the sensitivity analysis was farm size. Any scaling effects were determined by varying herd size and the many parameters associated with an increase from 60 to 400 cows. As described previously, the land area of each farm was set to supply the major feed needed for most years, and machinery and structures were selected to maximize net return over feed and manure costs of the farm. For the farm with 60 cows, hay equipment was eliminated, and all alfalfa was harvested as silage to reduce machinery cost. Also, high moisture corn was not used because of the small amount of corn required.

For the farm with 120 cows, many other parameters were adjusted to measure effects. Corn yield was increased both 10 and 25% over that of the primary analysis. Milk production was decreased from 10,500 to 8000 kg per lactation. Cost or price changes included labor, land, tillage, and soybean meal. A more sandy soil type was used, which primarily decreased relative crop yields and increased susceptibility to drought. A constant land area was set across all forage systems, which increased crop sales as corn silage in the ration increased. A comparison was made using daily hauling of manure with no manure nutrient credits to determine how this change would affect the comparison of forage systems. Other changes included custom hiring of all field machinery operations, increasing machine life to 15 yr, and removing the rotation benefits when planting corn following alfalfa.

RESULTS

Primary Analysis

The primary analysis was done for a dairy farm with a clay loam (Pewamo) soil, 120 cows, and a milk production of 10,500 kg per lactation. Table 4 shows the 26-yr mean of the simulation results for each of the four forage systems. To grow the necessary amount of each forage, the land area that was needed for alfalfa was decreased as the use of corn silage increased (Table 4). About 30 ha less total land was required with the all corn silage system than with the all alfalfa system because the all corn silage system produced more feed DM per unit of land area.

Requirements for high moisture corn, corn grain, soybean meal, and fat varied with the amount of corn silage fed (Table 4). The total of high moisture and dry corn grain consumed decreased as the portion of corn silage increased because of the higher energy density of corn silage. Because of the lower protein content in corn silage, the use of soybean meal increased. The high energy content of soybean meal also reduced the corn grain requirement. Overall, as more corn silage was used, the amount of total DM fed decreased slightly, the amount of alfalfa sold decreased, and the amount of corn sold as grain increased. The amount of excess feed simply changed in proportion to the total amount of each crop produced because cropland was sized so that the forage and grain produced met the needs of the herd in 5 of 6 yr.

TABLE 4. Resource requirements, costs, and revenues[1] for the representative farm with a clay loam (Pewamo) soil, 120 cows, and a milk production of 10,500 kg per lactation for various ratios of corn silage and alfalfa.

	Portion of corn silage in total forage			
	None	One-third	Two-thirds	All
Cropland, ha				
Alfalfa	118	78	40	0
Corn	44	71	104	132
Total	162	149	144	132
Feed quantities, tonne of DM				
Alfalfa	807	543	267	12
Corn silage	...	266	535	792
Corn grain	54	33	172	139
High moisture corn	148	148	...	...
Soybean meal	80	90	96	116
Total	1092	1083	1074	1063
Feed sales				
Alfalfa, tonne of DM	152	94	56	...
Corn grain, tonne of DM	62	97	153	199
Total crop sales, $	22,150	20,527	22,964	24,232
Manure quantities				
Produced, tonne of DM	407	399	391	381
Applied to corn silage, tonne of DM	...	81	212	351
Applied to corn grain, tonne of DM	94	174	180	30
Applied to alfalfa, tonne of DM	313	144	...	...
Nutrient fractions in manure DM, %				
Nitrogen	5.0	4.6	4.1	3.7
Phosphate	1.4	1.4	1.5	1.5
Potash	5.2	4.5	3.6	2.7
Manure and crop nutrients, tonne				
Nitrogen applied in manure	20.3	18.4	15.9	14.1
Nitrogen credit from alfalfa	3.3	2.2	1.1	...
Nitrogen removed by corn	5.6	10.5	16.1	21.3
Phosphate applied in manure	5.7	5.7	5.7	5.7
Phosphate removed by crops	8.8	8.4	8.3	7.9
Potash applied in manure	21.3	17.8	14.3	10.2
Potash removed by crops	30.8	24.9	19.4	13.2
Feed and manure costs, $				
Machinery	48,821	48,205	46,856	40,325
Fuel and electricity	6578	6177	5574	5134
Storage	21,352	23,946	23,163	20,350
Labor	17,285	17,166	16,121	15,571
Seed and chemicals	15,486	18,792	24,002	28,305
Grain drying	1496	1629	3832	3917
Land charge	20,250	18,625	18,000	16,500
Purchased feed and bedding	30,120	32,591	34,201	40,442
Total feed and crop costs	161,389	167,132	171,749	170,543
Net return over feed and manure costs, $				
$\overline{X}$	207,281	199,849	197,536	199,017
SD	11,944	12,389	14,673	15,520

[1]Numbers represent the mean of simulated results over 26 yr of historical weather data.

The quantity of manure produced decreased slightly as the proportion of corn that was grown for silage increased (Table 4) because of the higher digestibility of corn silage relative to alfalfa (4). Manure was applied to replace nutrients used by the crops without applying excess nitrogen to cropland that was used for corn (4). With this strategy, about 70% of the manure in the all alfalfa forage system was applied to alfalfa cropland on which manure nitrogen had a limited value. About 30% of the manure was applied to land used for corn grain; potassium was usually applied in excess. Excess potassium or phosphorus on corn cropland was credited to the requirements of alfalfa in future rotations.

With the all alfalfa forage system, over 30 tonnes/ha of manure was applied to alfalfa. Although reasonable for cropland, application of this much manure to an alfalfa stand could affect weed pressure and stand persistence. In our analysis, no adjustment of pesticide costs or stand persistence was made to reflect these effects. In the one-third corn silage system, about 21 tonnes/ha of manure were applied to alfalfa. The amount of manure that was applied to cropland used to produce corn for silage was limited by nitrogen because the credit from rotated alfalfa greatly reduced the nitrogen required. With the two-thirds corn silage system, most of the phosphorus and potassium requirements for corn silage were met through manure. Corn grain land usually had excess potassium applied, and no manure was spread on alfalfa land. In the all corn silage system, nearly all manure was applied to the land used for corn silage; phosphorus sometimes limited the amount applied.

The fractions of nitrogen, phosphate, and potash equivalents in manure were derived from a mass balance after handling losses were subtracted (Table 4). The nitrogen fraction was highest for the all alfalfa system because more protein was fed but was used less efficiently. Because the amount of phosphorus fed was based on mean requirements of the herd, total phosphorus in manure was the same for all forage systems. The phosphate fraction in manure DM increased somewhat as the proportion of corn silage in the diet increased because of the slight decrease in the quantity of manure produced. The use of more alfalfa caused higher fractions of potash equivalent in manure because the potassium content of alfalfa harvested in late bud stage was higher than that of corn silage.

Crops removed all phosphorus and potassium applied to cropland for all forage systems, but excess nitrogen occurred with large amounts of alfalfa (Figure 1). Phosphate removed by crops decreased slightly with less alfalfa because of lower requirements for corn than for alfalfa. Potash applied in manure and used by crops greatly increased as alfalfa increased because of the high removal of potash by alfalfa. A good balance of phosphorus and potassium was maintained with all forage systems because the amount leaving the farm in milk and excess crop sales was always greater than that imported in purchased feeds. The nitrogen balance, however, showed considerable excess for the all alfalfa and one-third corn silage systems. This excess is not a problem if the manure nitrogen applied to alfalfa displaces nitrogen fixed by the growing plants. A substantial loss of nitrogen to the environment should not occur in this case, but this assumption may not always be valid.

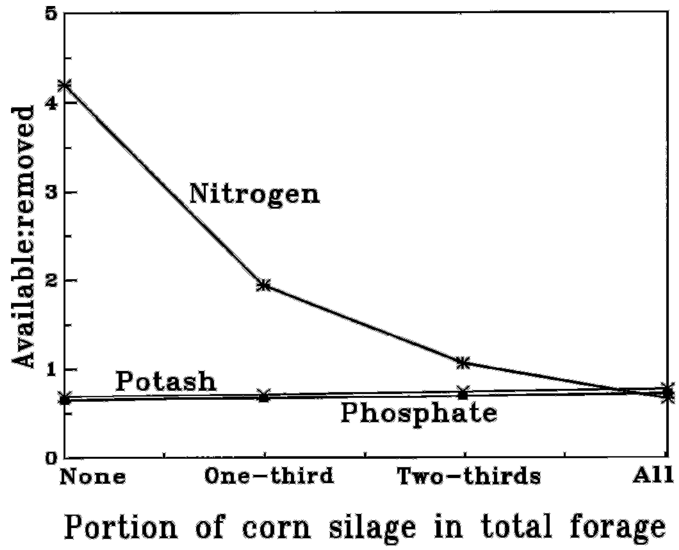

Figure 1. Ratio of nutrients available from manure and alfalfa credits to nutrients removed by crops for a 120-cow dairy farm using dietary systems in which the forage was none, one-third, two-thirds, or all corn silage and the remainder was alfalfa.

Machinery costs were highest for the all alfalfa system because of greater equipment requirements (Table 4). The costs for one-third corn silage were only slightly lower. Hay equipment was used less, but much of this savings was offset by the equipment required for the harvest of corn silage. For the system using two-thirds corn silage, a custom commercial baling operation was assumed, which, along with less overall use of machinery, reduced costs. Machinery costs were lowest for the system using all corn silage. Machinery investment and variable costs were lower for that system because no hay equipment was required, and less total cropland area was harvested. Labor costs were higher for high alfalfa systems because more equipment passes were required across fields for harvesting alfalfa.

TABLE 5. Sensitivity of differences in net return over the least profitable forage system to changes in the assumed values of major input parameters for the 120-cow farm.[1]

	Portion of corn silage in total forage			
	None	One-third	Two-thirds	All
	($)			
Primary analysis	9745	2313	0	1481
10% Greater corn yield	7307	1018	0	2710
25% Greater corn yield	4397	0	857	5367
8000 kg of Milk per lactation	10,859	3491	0	1711
Constant land area, 147 ha	6858	1489	0	2019
30% Lower labor cost	10,095	2627	0	1316
50% Higher land cost	8620	2000	0	2231
20% Higher soybean meal price	10,598	2625	0	446
20% Lower tillage costs	9290	2038	0	1675
No manure credits	9454	1765	0	1972
Sandy loam instead of clay loam	9369	2610	0	1428
Custom hire all field work	3856	0	843	2161
Increase machine life to 15 yr	10,524	3350	0	750
No rotation effect	7907	1524	0	2216
No rotation effect, no high moisture corn, no corn after corn insecticide, constant area	1746	0	438	4922

[1]Numbers represent differences among means averaged over 26 yr of historical weather data.

Fuel and electricity costs decreased as the use of corn silage increased. Again, alfalfa hay and silage harvests required more passes over the field and thus more fuel use. A little less manure was produced by cows fed greater amounts of corn silage, which reduced the fuel required for manure handling. The use of electricity for feeding decreased as less alfalfa and less high moisture corn were unloaded from tower silos. Storage costs were lowest for the single forage systems because fewer structures were required. Use of high moisture corn with the systems using mostly alfalfa greatly reduced costs for drying grain.

Seed and chemical costs, including fertilizer and pesticides, steadily increased as the amount of corn used for silage increased; the greater nitrogen and phosphorus needs of corn, especially corn silage, increased this cost. Anhydrous ammonia applied to corn silage further increased the chemical cost of high corn silage systems. These costs were partly offset by the high potassium requirement of alfalfa and the decreased land area needed when the amount of corn used for silage increased. Although manure nitrogen was better utilized by corn, less nitrogen was fixed by alfalfa because the amount of cropland needed for alfalfa was reduced.

The net return over feed and manure costs was highest for the systems using all alfalfa forage and lowest for the system using two-thirds corn silage, but these differences were not large (Table 4). The 26-yr mean annual net return with the system using all alfalfa was about $8000 greater than that of the system using one-third or all corn silage. This economic benefit was less than the yearly variation in net return caused by variable weather conditions.

In this type of forage system analysis, the cost of feed production is an important consideration. Production costs reflect the efficiency of producing each feed, and relative differences among feeds cause an economic advantage. In our analysis, production costs of all feeds were in proportion and normally less than their market value. Alfalfa production costs were about $70, $80, $92, and $0 per tonne of DM for the systems using none, one-third, two-thirds, and all corn silage, respectively. Costs to produce corn silage were about $0, $80, $75, and $75 per tonne of DM for the same forage systems. The similarity between the costs of producing alfalfa and corn silage indicated that all forage systems were similarly well designed for efficient production.

Sensitivity Analysis

An attempt was made to use reasonable and fair assumptions for the primary analysis. However, no individual farm was portrayed by the data used, so further analysis was warranted to determine how changes of farm parameters affected the results. Sensitivity of the net return of each forage system to selected assumptions and prices are summarized in Table 5. Differences in net returns were obtained by subtracting the lowest net return of the four forage systems from the net return of each. For example, the primary analysis yielded a difference of $9745 between the net returns of the system using all alfalfa and that using two-thirds corn silage. Because the system using two-thirds corn silage had the lowest net return, its difference was zero.

All changes in the sensitivity analysis were relative to the primary analysis using a 120-cow farm. An increase in corn yield relative to alfalfa yield was simulated by increasing corn yields (for both grain and silage) by 10% and then by 25%. Higher corn yields raised the net returns of all forage systems and shifted the net return differences across systems in favor of more corn silage (Table 5). Higher corn yields also reduced the differences among forage systems, particularly between the one-third and two-thirds corn silage systems.

As the herd mean milk production decreased to 8000 kg per lactation, the needed cropland was reduced by 18 ha for the all alfalfa system and by 28 ha for the all corn silage system. Less corn grain was required because of a lower feed energy requirement, but slightly more alfalfa was used. Total feed and manure costs decreased over $20,000 for each system, but the net returns over these costs were reduced at least $60,000 because of less revenue from milk sales. Manure production decreased 6%, reducing manure handling costs slightly. Overall, single forage systems had a slight economic advantage over mixed forage systems (Table 5).

Another possible assumption used for comparing the forage systems was to hold available land constant across systems and to sell any excess feeds produced. The land area was set at 147 ha, which was the mean area of the four systems in the primary analysis. Less land was used for the systems using all alfalfa and one-third corn silage, so their total costs for feed and crops decreased. More land was farmed for the systems using two-thirds and all corn silage, which increased costs. Differences in net returns across systems were less than those of the primary analysis, but the all alfalfa system still had the highest net return over feed and manure costs (Table 5).

Changing resource prices or costs affected overall net returns, and the change favored or penalized the system that used that particular resource most (Table 5). A decrease in labor costs of 30% slightly improved the economic benefit toward more alfalfa because alfalfa harvest used slightly more labor than did corn harvest for silage. An increased land charge of 50% reduced the economic benefit of using all alfalfa and slightly improved the relative benefit of using all corn silage. Increased soybean meal prices of 20% favored the higher alfalfa forage systems for which less purchased protein was required. A decrease in tillage costs of 20% shifted the differences very slightly toward more corn silage because tillage was used annually for corn but only every 4 yr for alfalfa.

When the fertilizer replacement credits of manure were ignored, total fertilizer costs increased by $8952, $9209, $8661, and $8170 for the systems using none, one-third, two-thirds, and all corn silage, respectively. Because the nitrogen spread on alfalfa cropland had no nutrient value and because rotating corn after alfalfa reduced nitrogen requirements, removal of the credits was expected to increase fertilizer costs more for the higher corn silage systems. The high potash requirement for alfalfa and the increased land area with more alfalfa balanced the decrease in fertilizer costs that resulted from less corn. Overall, the removal of the manure nutrient credits had little effect on the net return differences across forage systems (Table 5).

Using a sandy loam (Marlette) soil increased the amount of land required by 7 to 13% compared with the clay loam (Pewamo) soil because of lower mean yields. The alfalfa yield dropped more than did the corn yield. The yields at storage for the sandy soil were 5.5 tonnes of DM/ha (6.47 tonnes/ha at 15% moisture) for grain, 13.0 tonnes of DM/ha (39.4 tonnes/ha at 67% moisture) for corn silage, and 7.9 tonnes of DM/ha (9.3 tonnes/ha at 15% moisture) for an alfalfa hay equivalent. The increased land area increased most costs, including machinery, fuel, labor, seed, chemicals, and land. Crops sold under all four forage systems increased, which increased crop revenues 8 to 10%. Because of the increased costs, though, the net returns still decreased almost $3000 for each system, producing very little change in the differences across systems (Table 5). The standard deviations of net returns increased, reflecting greater variation in crop yields from weather effects on the sandy soil that was not irrigated.

When all field operations, including manure application, were custom hired, the differences across systems decreased greatly (Table 5). No adjustments were made for timeliness of operations. As the life of machinery was lengthened from 10 to 15 yr, a small change occurred across systems. Because more machinery was required for the high alfalfa systems, the net return of these systems was slightly improved over that of the high corn silage systems (Table 5).

Finally, several remaining factors that produced differences across forage systems were eliminated.

TABLE 6. Net returns per cow over feed and manure costs for four farm sizes and four portions of corn silage and alfalfa.[1]

Farm size	Portion of corn silage in total forage							
	None		One-third		Two-thirds		All	
	$\overline{X}$	CV[2]	$\overline{X}$	CV	$\overline{X}$	CV	$\overline{X}$	CV
	($)	(%)	($)	(%)	($)	(%)	($)	(%)
60 cows	1574	7.6	1544	7.6	1487	8.7	1519	8.6
120 cows	1727	5.8	1665	6.2	1646	7.4	1658	7.8
250 cows	1817	5.2	1783	5.4	1769	6.4	1755	7.2
400 cows	1846	5.1	1816	5.2	1794	6.3	1784	7.1

[1]Numbers represent means averaged over 26 yr of historical weather data.

[2]Coefficient of variation or 100 times the standard deviation divided by the mean.

The rotation factor, which increased the yield of corn following alfalfa in a rotation, was removed. Because this factor had the greatest benefit for the all alfalfa system, the change shifted the economic advantage toward more corn silage. The system using all alfalfa still provided the greatest net return of the forage systems, but differences among the systems were less. Use of dry corn grain, constant land area for all four forage systems, removal of the rotation effect, and no use of insecticide on a corn crop that followed corn in a rotation caused a shift in the highest net return. The net return of the system using all corn silage was $4922 higher than the lowest net return of the one-third corn silage. Differences across all systems were about half of those in the primary analysis (Table 5).

Economies of size were considered; the herd size was varied, which altered corresponding requirements for land, machinery, and facilities. Prices were not changed between farm sizes, so the only technical economies of size involved were those resulting from spreading fixed costs over greater production. For the 60-cow farm, costs of machinery and labor were not found to be proportional to farm size, but energy, storage, seed, and costs of chemicals, land, and feed were all approximately half those costs for the 120-cow farm. On a per cow basis, net return differences across systems were a little greater for the smaller farm, but the ranking of the four forage systems did not change (Table 6).

With the 250-cow farm, economies of size were expected in categories such as machinery cost. Although the number of cows increased by 2.08 times over the 120-cow farm, the machinery costs increased by only 1.77, 1.74, 1.82, and 1.97 times for the none, one-third, two-thirds, and all corn silage systems, respectively. The lower increase for the high alfalfa systems reflects less efficient use of alfalfa equipment in the primary analysis. The net returns of milk and crop sales over costs were increased 2.19, 2.23, 2.24, and 2.20 times compared with the none, one-third, two-thirds, and all corn silage systems on the 120-cow farm. The 400-cow farm showed further economies of size in several cost categories. Machinery, energy, storage, and labor showed some reductions on a cost per cow basis. For the two larger farms, the lowest net returns shifted from the system using two-thirds corn silage to the system using all corn silage.

Overall farm size did not have much effect on the comparison of the four forage systems. Systems using two-thirds corn silage or all corn silage had the lowest net returns over costs for feed and manure (Table 6). The all alfalfa system remained the most economical, but differences across systems were small. As farm size increased, the differences across systems decreased. The standard deviation or variance in the net returns across years of weather also decreased as farm size increased. The lowest variance across years consistently was for the high alfalfa systems, which came from spreading the harvest over several cuttings each year. For each farm size, the difference between the highest and lowest net returns of the four forage combinations was less than one standard deviation of the variance in returns caused by weather.

DISCUSSION

The primary analysis indicated relatively small economic differences among the four forage systems ranging from all alfalfa to all corn silage. The difference in farm net return between the most economical (all alfalfa) and the least economical (two-thirds corn silage) systems was less than $10,000/yr. The sensitivity analysis indicated that this result was not likely to change much when reasonable changes were made in the description of the farm. The system using all alfalfa yielded the greatest net return under most scenarios, and the system using two-thirds corn silage normally yielded the least. Changes in farm size and other parameters sometimes greatly reduced the differences in net return across systems and never provided a substantial increase in these differences.

Although the all alfalfa system showed some economic advantage for most of the simulated scenarios, this advantage did not fully reflect the risk of maintaining an alfalfa stand. For this analysis, the decline in alfalfa stand was modeled to represent mean or typical overwintering conditions. In recent years, adverse winter weather in the northern states has occasionally caused a loss of most or all of the alfalfa on a farm. The added planting costs and loss of yield from this type of loss would offset the small economic advantage of the system using all alfalfa forage.

An important assumption in this analysis was that equal milk production could be attained with any combination of the two forages. Work by Dhiman and Satter (11) indicated that the combination of one-third corn silage and two-thirds alfalfa might provide a little more milk than the other forage ratios. A milk production change of 500 kg per lactation for any of the simulated systems caused a change of $5000/yr in the net return. Therefore, a difference in milk production could move the economic advantage more toward the system with the highest milk production. A $5000 improvement in the net return of any of the systems using corn silage relative to the other systems would not be enough to provide a substantial economic advantage.

Because large differences in economic benefit did not occur among the forage systems, some other factors should be considered in forage selection. Major considerations include herd management, manure management, and labor utilization. Use of a single forage source may require better herd management or at least different operating procedures to prevent adverse effects on cow health or milk production. With an all alfalfa forage system, manure management is a greater challenge. High manure application rates on alfalfa land are required to use manure nitrogen properly. Application of manure to alfalfa cropland may increase weeds and reduce yield and stand persistence.

Another important consideration is labor use. The use of more than one forage source distributes labor requirements more uniformly over the year (Figure 2). With the system using all alfalfa, spring planting, four alfalfa harvests, and corn harvest cause several short peak labor periods. The system using all corn silage requires spring planting, grain harvest, and a major peak labor requirement for corn silage harvest. A mixture of one-third corn silage and alfalfa reduces these peaks and spreads the labor requirement over more of the cropping season. In this analysis, labor scheduling was not a constraint, so there was no penalty for high labor periods.

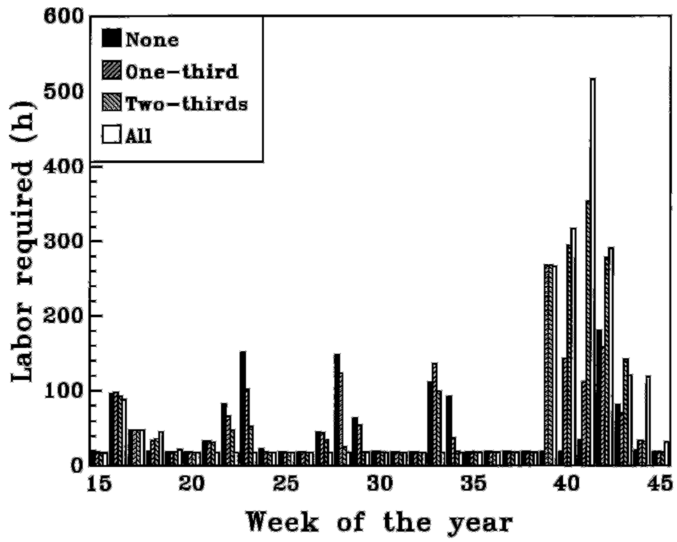

Figure 2. Distribution of labor requirements throughout the year for a 120-cow dairy farm using dietary systems in which the forage was none, one-third, two-thirds, or all corn silage and the remainder was alfalfa.

The potential impacts of herd management, manure management, and labor use may cause unacceptable tradeoffs for the small difference in net return determined among the forage systems compared. Considering all factors, the option that provided the lowest risk to the farmer and the environment was a forage system in which a substantial portion of the forage was obtained from both forage crops.

Use of other crops on the farm changes many aspects of the analysis, but the general conclusion should not change. Use of additional crops may affect the timing of field operations, provide bedding and the recycling of nutrients in that material, and increase nutrient removal and farm income through the export of feeds. These factors should interact only minimally with alfalfa and corn production and use and thus should not greatly affect their comparison. Work is underway to add grass, small grain, and soybean crops to DAFOSYM so that a comprehensive comparison of more cropping systems can be conducted.

CONCLUSIONS

A comprehensive comparison of forage systems that represented a range from all alfalfa to all corn silage tended to show slightly higher net return over feed and manure costs for the all alfalfa system. Differences in net returns among the ratios of corn silage and alfalfa were not large enough to encourage a sudden reallocation or reinvestment of resources.

Changes in farm size, soil type, milk production, relative prices, and other major assumptions used in the analysis had small effects on the differences in net return across systems and the relative ranking of systems. These changes sometimes greatly reduced the differences in net return across systems and never provided a substantial increase in these differences.

Given the small economic differences among forage systems, the recommendation is to use a system in which at least one-third of the forage is provided by each forage crop. Use of more than one forage crop reduces the risk of crop loss, spreads labor requirements more uniformly throughout the cropping season, and maintains better use of on-farm nutrients.

ACKNOWLEDGMENTS

Acknowledgment is made to the USDA, Agricultural Research Service, the Michigan Agricultural Experiment Station, and the USDA National Research Initiative Competitive Grants Program award number 94-37502-0970 for the support of this work. All programs and services of the USDA are offered on a nondiscriminatory basis without regard to race, color, national origin, religion, sex, age, marital status, or handicap.

REFERENCES

1 Black, J. R., P. Wonderschneider, and S. Nott. 1974. Alfalfa and corn silage combinations to maximize Michigan dairy farm income. Staff Paper No. 74-10, Agric. Econ. Dep., Michigan State Univ., East Lansing.

2 Borton, L. R. 1997. A comparison of corn silage and alfalfa for forage on Michigan dairy farms. Ph.D. Diss., Michigan State Univ., East Lansing.

3 Borton, L. R., L. J. Connor, L. G. Hamm, B. F. Stanton, J. W. Hammond, M. Bennett, W. T. McSweeney, J. E. Kadlec, and R. M. Klemme. 1990. Summary of the 1988 northern U.S. dairy farm survey. Res. Rep. 509, Michigan Agric. Exp. Stn., East Lansing.

4 Borton, L. R., C. A. Rotz, H. L. Person, T. M. Harrigan, and W. G. Bickert. 1995. Simulation to evaluate dairy manure systems. Appl. Eng. Agric. 11:301.

5 Broderick, G. A. 1985. Alfalfa silage or hay versus corn silage as the sole forage for lactating dairy cows. J. Dairy Sci. 68:3262.

6 Christensen, D. R., D. D. Warncke, M. L. Vitosh, L. W. Jacobs, and J. G. Dahl. 1992. Fertilizer recommendations for field crops in Michigan. Bull. E-550A, Coop. Ext. Serv., Michigan State Univ., East Lansing.

7 Colenbrander, V. F., D. L. Hill, M. L. Eastridge, and D. R. Mertens. 1986. Formulating dairy rations with neutral detergent fiber. 1. Effect of silage source. J. Dairy Sci. 69:2718.

8 Connor, L., L. Hamm, S. Nott, D. Darling, W. Bickert, R. Mellenberger, H. Tucker, O. Hesterman, J. Partridge, and J. Kirk. 1989. Summary of the 1987 Michigan State University dairy farm survey. Res. Rep. No. 498, Michigan Agric. Exp. Stn., East Lansing.

9 Crookston, R. K., J. E. Kurle, P. J. Copeland, J. H. Ford, and W. E. Lueschen. 1991. Rotational cropping sequence affects yield of corn and soybean. Agron. J. 83:108.

10 Cuykendall, C. H., and G. L. Casler. 1973. Forage and grain programs for dairy farms with varying cow-land ratios. Bull. No. 27, New York's Food and Life Sciences Exp. Stn., Ithaca.

11 Dhiman, T. R., and L. D. Satter. 1994. Milk yield and rumen fermentation measurements in cows fed diets containing different proportions of alfalfa and corn silage. J. Dairy Sci. 77(Suppl. 1):222.(Abstr.)

12 Dysinger, K., D. D. Harpstead, J. Lempke, M. Allen, and D. Main. 1994. Corn hybrids compared in the 1994 season. Bull. E-431 (rev.), Coop. Ext. Serv., Michigan State Univ., East Lansing.

13 Fedewa, D. J., and S. J. Pscondna. 1992. Michigan Agricultural Statistics 1992. USDA Natl. Agric. Stat. Serv. Michigan Dep. Agric., Lansing.

14 Fox, R. H., and W. P. Piekielek. 1988. Fertilizer N equivalence of alfalfa, birdsfoot trefoil, and red clover for succeeding corn crops. J. Prod. Agric. 1:313.

15 Fuller, E., W. Lazarus, and D. Nordquist. 1990. Minnesota farm machinery economic cost estimates for 1990. Minnesota Coop. Ext. Serv., St. Paul.

16 Hesterman, O. B. 1988. Exploiting forage legumes for nitrogen contribution in cropping systems. Page 155 *in* Cropping Strategies for Efficient Use of Water and Nitrogen. Spec. Publ. No. 51. W. Hargrove, ed. Am. Soc. Agron., Madison, WI.

17 Hoglund, C. R., G. D. Schwab, and M. B. Tesar. 1972. Economics of growing and feeding alfalfa and corn silage to dairy cattle. Rep. No. 154, Michigan Agric. Exp. Stn., East Lansing.

18 Jones, C. A., and J. R. Kiniry, ed. 1986. CERES-Maize: A Simulation Model of Maize Growth and Development. Texas A&M Univ. Press, College Station.

19 Knoblauch, W. A., R. A. Milligan, D. G. Fox, and M. L. Woodell. 1979. Economic utilization of forages in the production of milk and beef in the northeast United States. Staff Paper No. 79-29, Agric. Econ. Dep., Cornell Univ., Ithaca, NY.

20 Nott, S. B. 1974. Corn silage versus alfalfa on average dairy farms. Rep. No. 265, Agric. Econ. Dep., Michigan State Univ., East Lansing.

21 Nott, S. B., J. Garsow, and D. Darling. 1990. Projected profitability on Michigan dairy farms in the 1990's. Rep. No. 530, Agric. Econ. Dep., Michigan State Univ., East Lansing.

22 Nott, S. B., G. D. Schwab, A. E. Shapley, M. P. Kelsey, J. H. Hilker, and L. O. Copeland. 1992. 1992 crops and livestock budget estimates for Michigan. Rep. No. 556, Agric. Econ. Dep., Michigan State Univ., East Lansing.

23 Owen, F. G., J. G. Kendrick, and C. F. Micke. 1973. Competitive relationship of alfalfa hay and corn silage in complete rations for lactating dairy cows. Rep. No. SB523, Nebraska Agric. Exp. Stn., Lincoln.

24 Parsch, L. D. 1982. DAFOSYM: a system simulation model for analyzing the economics of forages on commercial dairy farms. Ph.D. Diss., Michigan State Univ., East Lansing.

25 Rotz, C. A., J. R. Black, D. R. Mertens, and D. R. Buckmaster. 1989. DAFOSYM: a model of the dairy forage system. J. Prod. Agric. 2:83.

26 Rotz, C. A., D. R. Buckmaster, and L. R. Borton. 1992. Economic potential of preserving high-moisture hay. Appl. Eng. Agric. 8:315.

27 Rotz, C. A., D. R. Buckmaster, D. R. Mertens, and J. R. Black. 1989. DAFOSYM: a dairy forage system model for evaluating alternatives in forage conservation. J. Dairy Sci. 72:3050.

28 Rotz, C. A., and P. Savoie. 1992. Economics of swath manipulation during field curing of alfalfa. Appl. Eng. Agric. 7:316.

29 Russelle, M. D., O. B. Hesterman, C. C. Shaeffer, and G. H. Heichel. 1987. Estimating nitrogen and rotation effects in legume-corn rotations. Page 41 *in* The Role of Legumes in Conservation Tillage Systems. J. F. Power, ed. Soil Conservation Soc. Am., Ankeny, IA.