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Production and Feeding Strategies for Phosphorus Management on Dairy Farms

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ABSTRACT

Long-term accumulation of soil phosphorus (P) is becoming a concern on some watersheds heavily populated with animal feeding facilities, including dairy farms. Management changes in crop production and feeding may help reduce the accumulation of excess P, but farm profitability must be maintained or improved to assure adoption of such changes. Whole-farm simulation was used to evaluate the long-term effects of changes in feeding, cropping, and other production strategies on P loading and the economics of 100-cow and 800-cow dairy farms in southeastern New York. Simulated farms maintained a long-term P balance if the following occurred: 1) animals were fed to meet recommended minimum amounts of dietary P, 2) the cropping strategy and land base supplied all of the forage needed, 3) all animals were fed a high forage diet, and 4) replacement heifers were produced on the farm to utilize more forage. The most easily implemented change was to reduce the supplemental mineral P fed to that required to meet current NRC recommended amounts, and this provided an annual increase in farm profit of about $22/cow. Intensifying the use of grassland and improving grazing practices increased profit along with a small reduction in excess P. Conversion from dairy production to heifer raising or expansion from 100 cows to a 250-cow "state-of-the-art" confinement facility (with a 70% increase in land area) were also profitable options. These options provided a long-term P balance for the farm as long as the production and use of forage was maximized and minimum dietary P amounts were those recommended by the NRC. Thus, management changes can be made to prevent the long-term accumulation of soil P on dairy farms while improving farm profitability.
(**Key words:** farm system, nutrient management, simulation, economics)

Abbreviation key: BMP = best management practices, **DAFOSYM** = Dairy Forage System Model, **NLEAP** = Nitrate Leaching and Economic Analysis Package.

INTRODUCTION

Phosphorus (P) loading from agricultural land to water is becoming a concern on many watersheds. Prime examples are watersheds in the Catskill region of eastern New York State. These watersheds, which are primarily covered with forests and dairy farms, supply 90% of the 5 billion liters of water required each day for New York City (NRC, 2000). This water is processed using chlorine disinfection without filtration, so natural purity is important. Regional and national health concerns associated with algal blooms resulting from high P levels in surface waters have caused state officials to address the need for water filtration. It is economically desirable for New York City to manage the watersheds for reduced pollutant loading instead of investing in a filtration facility and other potential treatments required to clean up the water.

Because cropland can provide a natural filter to supply clean water, agriculture is an acceptable land use for these watersheds (NRC, 2000). However, agriculture must do its part to maintain low pollutant loading. A Watershed Agricultural Program has been established to encourage the voluntary participation of farmers in developing whole-farm management plans that reduce pollutant loading. The Cannonsville Reservoir, part of the New York City water supply, has been designated as P restricted, thus management practices are being implemented or considered to reduce P loss from farms to the waterways in this area.

Many factors affect P loss from dairy farms. These include the amount of feed and fertilizer brought onto a farm, animal density, feeding strategies, manure application procedures, crops grown, and topography of the landscape. Over the last 20 years, intensification and expansion of dairy farms has increased the tendency for farm-scale surpluses of P, because inputs in feed and fertilizer are often greater than exports of P in product (Haygarth et al., 1998; Lander et al., 1998;

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Withers et al., 1999). These surpluses increase the potential for P enrichment of runoff (Sims et al., 1998; Kellogg and Lander, 1999; McFarland and Hauck, 1999).

Target implementation of best management practices (**BMP**) on critical areas for P loss can decrease watershed export of P (Sharpley and Rekolainen, 1997). In the LaPlatte River Basin of Vermont, implementation of BMP (control of barnyard runoff, milkhouse waste treatment, and use of waste storage facilities) decreased P export to Lake Champlain when more than 90% of the animals on the watershed were on farms where BMP were implemented (Meals, 1990). Studies have also demonstrated that changes in crop rotation (Sugiharto et al., 1994), manure-handling procedures (Van-Dyke et al., 1999), and feeding practices (Withers et al., 1999; Satter, 2001) can reduce surplus P on dairy farms.

Comprehensive analyses are needed to evaluate the environmental and economic impacts of various management practices that can be used to reduce P loading on dairy farms. Such long-term effects are best evaluated through computer simulation. By simulating farms over many weather years, the effects of management changes can be predicted quickly with little cost or risk to the producer. The Dairy Forage System Model (**DAFOSYM**) provides a tool for this type of assessment (Rotz et al., 1999b). This model has been widely used to evaluate forage conservation (Rotz et al., 1993), manure handling (Harrigan et al., 1996), cropping system (Rotz et al., 2001), grazing (Soder and Rotz, 2001), and feeding (Rotz et al., 1999b) options for various sizes and types of dairy farms in various locations.

The objective of this work was to determine effective management changes that dairy producers in the Catskill region of southeastern New York can make to reduce the potential loss of P to the watershed while maintaining or improving farm profit. Although these farms are in a specific climatic region, they generally represent dairy farms throughout the northeastern and mid Atlantic regions.

MATERIALS AND METHODS

Model Description

The whole-farm model, DAFOSYM, simulates crop production, feed use, and return of manure nutrients back to the land over many years of weather (Rotz et al., 1989; Harrigan et al., 1996; Rotz et al., 2001). Growth and development of alfalfa, grass, corn, soybean, and small grain crops are predicted on a daily time step based on soil and weather conditions. Tillage, planting, harvest, and storage operations are simulated to predict resource use, timeliness of operations, crop losses, and nutritive changes in feeds. Feed allocation and animal response are related to the nutritive value of available feeds and the nutrient requirements of six animal groups making up the dairy herd (Rotz et al., 1999a).

Table 1. Nutrient concentrations in feeds produced or purchased for the farms.

	N	P	K
	(% DM)		
Pasture	3.2–4.2[1]	0.35	3.00
Alfalfa hay and silage	3.0–3.8	0.30	2.50
Grass hay or silage	1.3–2.1	0.30	2.50
Corn, oat or triticale silage	1.3–1.6	0.26	1.18
High moisture ear corn	1.4	0.34	0.31
Feed mix (average-sized farm)	3.2	0.60	1.21
Corn grain or corn meal	1.6	0.30	0.42
Soybean meal	8.8	0.70	2.41
Cotton seed	3.7	0.60	1.13
Distiller's grain	3.7	0.83	1.10

[1]Nitrogen concentrations in forage crops were related to growing and harvest conditions (Rotz et al., 1989).

Nutrient flows through the farm are modeled to predict potential nutrient accumulation in soil and loss to the environment (Rotz et al., 1999b). The quantity and nutrient content of the manure produced is a function of the quantity and nutrient content of the feeds consumed (Rotz et al., 1999a). Nitrogen (N) volatilization occurs in the barn, during storage, and between field application and incorporation into the soil (Borton et al., 1995). Denitrification and leaching losses from the soil are related to the rate of moisture movement and drainage from the soil profile as influenced by soil properties, rainfall, and the amount and timing of manure and fertilizer applications using functions from the Nitrate Leaching and Economic Analysis Package (**NLEAP**; Schaffer et al., 1991).

A whole-farm balance of N, P, and potassium (K) considers the import of nutrients in feed and fertilizer and the export in milk and animals (Rotz et al., 1999b). Supplemental P and K fed, if needed, is the difference between the requirement of the animal group and the sum of that contained in other feeds consumed. Concentrations of the three nutrients contained in milk and live body weight were set as 0.53% N, 0.09% P, and 0.15% K for milk and 2.75% N, 0.79% P, and 0.20% K for live weight (Morrison, 1956; NRC, 1989). Nutrient removals in each crop and that contained in feeds were determined using simulated crop yields and assigned or predicted nutrient concentrations (Table 1). Phosphorus and K losses from the farm were set at 5% of that applied in manure and fertilizer to represent normal losses through runoff (Sharpley and Rekolainen, 1997). Excess P and K accumulation in the soil was the difference between the total export and import of each mineral divided by the total farm area. This whole-farm balance assumed that, over the long term, these nutrients were uniformly distributed over all available land.

Simulated performance was used to predict production costs, income, and net return, or profit, of the farm for each weather year. A whole-farm budget was used where investments in equipment and structures were depreciated over their economic life, and the resulting annual cost was included with other annual expenditures and incomes determined for each year. Possible government subsidies and income tax implications were not considered. By modeling several alternatives, the effects of system changes were compared including resource use, production efficiency, environmental impact, and net return. The distribution of annual values obtained was used to assess the risk involved in alternative technologies or strategies as weather conditions varied.

Farm Descriptions

Two farms were modeled representing actual farms in southeastern New York. The first was an average-sized farm for the region, having about 100 cows, while the other modeled one of the larger farms with 800 cows. Farms were simulated for 25 weather years using historical weather data (1976 to 2000) from Cooperstown, New York. The typical soil in this region was a Lewbeach (shallow silt loam) with an available water holding capacity of about 10 cm. This soil and the rolling terrain of the region was better suited to grass production than deep-rooted annual crops such as corn.

The costs of production and net returns predicted for these farms were long-term annual values determined under the price and economic factors assumed. These values represented the costs and returns for these production systems, but they were not costs and profit of the actual farms.

Average farm. The average-sized farm consisted of 141 ha of owned land and 40 ha of rented land. Crops included 40 ha of alfalfa, 109 ha of grass, and 32 ha of corn. Alfalfa was seeded with an oat cover crop and maintained with a 4-yr stand life. Sixty-five percent of the manure was applied to the corn crop with the remainder applied to grassland. Additional fertilizer applied to the corn land included 105, 22, and 45 kg/ha of N, phosphate, and potash, respectively. Grass received 100 kg/ha of N and 135 kg/ha of potash. Alfalfa received 135 kg/ha of potash, but when established with an oat cover crop, the rates were 34, 17, and 100 kg/ha for N, phosphate, and potash fertilizers. Simulated crop yields are summarized in Table 2. Yields for rotationally grazed and less intensively managed pastures were adjusted to provide pasture consumption representative of that reported for this region (Fox et al., 1992).

Table 2. Mean and range in annual harvested crop and available pasture yields over 25 yr simulations for southeastern New York.

Crop	Mean	Low	High	CV
	— (tonne DM/ha) —			(%)
Alfalfa (3 cuttings)	6.7	5.1	8.2	14.3
Alfalfa (2 cuttings)	4.4	3.2	5.0	10.0
Corn silage	12.2	6.5	16.9	24.7
High-moisture ear corn[1]	6.8	4.7	9.0	20.5
Oat or triticale silage	5.1	3.1	6.5	15.0
Grass hay or silage	4.3	3.1	5.3	13.9
Pasture with rotational grazing	6.9	6.5	7.3	3.6
Other pasture	4.5	4.1	4.7	3.8

[1]For only a few weather years when high-moisture corn is produced.

Alfalfa was harvested using a three-cutting strategy where the first and third cuttings were harvested as wilted silage, and the second cutting was predominantly harvested as dry hay. About 50 ha of the grassland were grazed, with the remainder harvested as dry hay using a two-cutting strategy. Most of the corn was harvested as silage, but in high-yielding years, a portion was harvested and fed as high moisture ear corn. The oat cover crop was also harvested as silage. All operations were performed with equipment owned by the farmer (Table 3).

Storage facilities included a barn for hay storage, a bunker silo and three concrete stave tower silos (Table 3). Most of the corn and oat silages were stored in the bunker silo along with about half of the alfalfa silage. The largest tower silo was used for corn silage, the mid-sized tower was used for alfalfa silage, and the smallest was used for high moisture ear corn or corn silage.

The herd consisted of 105 large-framed Holstein cows, 60 heifers over one year old, and 45 younger heifers. Annual milk production was 9500 kg/cow with 30% of the milking herd replaced each year. Remaining heifers were sold as registered bred animals at an average price of $1700 each. Cows were housed, fed, and milked in a stanchion barn (Table 3). Heifers were on pasture during the growing season and housed in a barn during the remainder of the year. Cows were fed a high-forage diet supplemented with a grain mix. The mix primarily included corn meal, distiller's grain, rolled corn, wheat bran, whole cottonseed, and roasted soybeans along with minerals and vitamins.

Manure was handled in a solid form (20% DM) using gutter cleaners, a front-end loader, and box spreader. There was some short-term storage with associated volatile losses, but essentially the manure was spread on a daily basis. The manure remained on the field surface following spreading where any remaining N in an ammonia form was assumed to volatilize into the atmo-

Table 3. Machines and structures used to represent those of the two New York dairy farms.

	Average (100-cow) farm			Large (800-cow) farm		
Machine or facility	Size/type	No.	Initial cost ($)	Size/type	No.	Initial cost ($)
Tractors	35 kW, used	1	10,000	65 kW	2	34,800
	71 kW	1	34,800	74 kW	2	53,000
	112 kW	1	67,900	82 kW	2	58,000
Skid steer loader	25 kW	1	20,700	35 kW	2	31,500
Mower-conditioner	3.7 m, disk	1	23,900	4.0 m, disk	1	23,900
Hay rake	4.0 m	1	9,000	11.0 m	1	12,600
Baler	medium size	1	14,400	. . .	–	. . .
Bale wagons	4.5 t	5	3,100	. . .	–	. . .
Forage harvester	medium size	1	27,900	large self-propelled	2	197,400
Forage hauling	wagons, 6 t	3	11,900	dump trucks, used	5	30,000
Feed mixer wagon	. . .	–	. . .	medium, 8.5 tonne	2	18,900
Manure spreader	medium, 8 t	1	8,100	tank trucks, used	3	30,000
Moldboard plow	2.3 m	1	13,000	2.3 m	2	13,000
Tandem disk harrow	3.7 m	1	7,600	3.7 m	2	7,600
Seedbed conditioner	6.0 m	1	18,500	. . .	–	. . .
Corn planter	4 row	1	14,000	6 row	2	18,000
Grain drill	2.4 m	1	7,200	3.7 m	1	15,300
Hay shed	100 tonne	1	10,000	100 tonne	1	10,000
Silage bunker	9.8 × 32 × 2.4 m	1	27,700	30.5 × 46 × 9.1 m	1	60,000
Tower silo	6.1 × 18.3 m	1	19,400	. . .	–	. . .
Tower silo	4.9 × 15.2 m	1	12,800	. . .	–	. . .
Tower silo	4.3 × 10.7 m	1	9,200	. . .	–	. . .
Manure storage	. . .	–	. . .	lagoon, 88 × 3 m	–	115,000
Machinery shed	. . .	1	60,000	. . .	–	150,000
Milking center	pipeline	1	126,000	double eight parlor	–	512,000
Cow housing	stanchion barn	1	158,000	free stall barns	–	800,000
Heifer & calf housing	pens	1	68,000	freestall & hutch	–	375,000
Feed storage	bin	1	3,200	commodity shed	–	56,000
Pasture fence, etc.	. . .	–	11,000	. . .	–	27,000

sphere. The primary bedding material was old or weather-damaged hay that was not suitable for feed.

Large farm. The large farm consisted of 2025 ha of crop and grassland on the Lewbeach soil. Crops included 162 ha each of alfalfa and corn and 1700 ha of grassland. Alfalfa was established with a cover crop of triticale. The grassland included 373 ha of seeded grasses with 117 ha being Reed Canary grass. About 150 ha of the pasture grass was rotationally grazed with lactating cows, and the remainder was used less intensively by heifers and nonlactating cows.

All alfalfa and about 360 ha of grass were each harvested with a two-cutting strategy. First cutting alfalfa was predominantly harvested as dry hay and the second cutting of alfalfa and both cuttings of grass were predominantly harvested and stored as wilted silage. Following these harvests, this land was available for grazing. All corn and the triticale were harvested as silage. All silage was packed and stored on a large concrete pad where movable walls were used to separate silage types. Silage was packed with two large tractors to a depth of as much as 12 m. All hay was stored outdoors.

There were 800 cows and 600 heifers on the farm, with 30% of the cows replaced each year. Milking animals were assigned to three herds for housing and milking. Two of these herds were housed in free-stall barns and milked in double-eight herringbone parlors. The third group, which was primarily older animals, was milked in a tie stall barn with a pipeline milking system. The average annual milk production was 8170 kg/cow. Rations were mixed and fed using mobile mixing wagons. Forages produced on the farm were supplemented with purchased corn meal, soybean meal, whole cottonseed, distiller's grain, and minerals. Most of the manure was handled as slurry stored in lagoons. This manure was normally applied to cropland in the spring and fall where it was incorporated within a week of application. Sawdust bedding was imported onto the farm at a rate of about one tonne per day.

The economic analysis of the farm systems assumed new equipment and facilities depreciated over an appropriate amount of time (Tables 3 and 4). Prices on feeds, milk, and other farm inputs and outputs were set to reflect long-term average values in current dollars. Prices were held constant across simulated years so that economic differences among years were solely due to weather effects on farm performance. A real interest rate (approximately nominal rate minus inflation) of 6%/yr was assumed on investments. For the average farm, a labor cost was not included because the family management unit supplied all labor. On the large farm,

Table 4. Economic factors and prices assumed for various system inputs and outputs for the analysis of the New York dairy farms. Prices were set to represent long-term average prices in current value, which were not necessarily current prices.

Factor	Value	Factor	Value
Diesel fuel price	$0.29 /L	Selling price of feeds/animals	
Electricity price	$0.08 /kW-h	Grass hay	$66 / tonne DM
Mailbox milk price	$30 /hL	Grain crop silage	$75 / tonne DM
Total of livestock expenses	$238 /cow/yr	Calf	$20 /animal
Land rental charge	$25 /ha	Cull cow	$0.88 / kg
Property tax rate	5.0 %/yr	Heifer	$1700 / animal
Fertilizer prices		Buying price of feeds/bedding	
Nitrogen	$0.55 /kg	Alfalfa hay	$135 / tonne DM
Phosphorus	$0.66 /kg	Grain mix	$187 / tonne DM
Potassium	$0.29 /kg	Minerals/vitamins	$550 / tonne DM
Annual cost of seed and chemicals		Bedding	$66 / tonne DM
New alfalfa or grass	$200 /ha	Economic life	
Established alfalfa or grass	$15 /ha	Structures	20 yr
Corn following corn	$165 /ha	Machinery	10 yr
Corn following other crop	$135 /ha	Salvage value	
Oat or triticale	$56 /ha	Structures	0 %
Pasture	$0 /ha	Machinery	30 %
		Real interest rate	6.0 % / yr

the labor cost was fixed at the current actual cost of $600,000/yr.

Farm Level Verification

Evaluations were made to assure that the model adequately described the existing farms. The first step was a comparison of predicted yields to yields determined by the New York Agricultural Statistics Service (2000) for the county in which the farms were located. Predicted yields were set to long-term averages that were about 10% above the reported county yields for weather years 1990 to 2000. This yield level represented above-average management, which was consistent with the producers' reported production.

Next, total feed production and use on the farm was verified by comparing predicted feed sales to that reported by the producers. On the average-sized farm, small amounts of corn or hay were sold in only a few of the high-yielding weather years. On the larger farm, no feed was sold from the farm and no forage was purchased. Simulation results showed small amounts of hay or corn grain sold from the smaller farm in half of the weather years, and no forage purchased or sold from the larger farm.

The final step was to compare predicted and actual purchased feed requirements for an average or typical year. On both farms, all forage was produced on the farm, but most of the grain and all other concentrate feeds were purchased and imported to the farm. The predicted requirement of purchased concentrate was found to be within 10% of that reported for the farm. The supplemental P fed on each farm was set in the model to equal that determined from the amount of concentrate and minerals imported to the farm and the P concentration in those feeds.

Management Options

After the modeled farms were found to adequately portray the actual farms, alternative management strategies were evaluated to determine their potential impact on the environment and farm profit. These management alternatives were selected in consultation with the farm owners. Thus, strategies studied were those of interest to the farmer that would potentially alter the whole-farm P balance.

Average farm. Five alternative strategies were evaluated for the average-sized farm. The first was an adjustment of the P imported as fertilizer and supplemental minerals. On the current farm, small amounts of P were applied as starter fertilizer for the corn and oat crops (about 9 kg P/ha). Because there is excess P on the farm, this added P might be unnecessary. These applications were removed to determine their impact. Like most farms, the amount of P fed to the animals was somewhat higher than that recommended over the past decade (NRC, 1989), and this recommendation has now been reduced (NRC, 2001). The new requirement, based upon absorbable P, was implemented in the model for each animal group to determine the whole-farm impact of reducing this minimum P in diets that was primarily being met through purchased mineral P.

The next strategy evaluated greater use of pasture. Cows were fed during the growing season using intensively managed rotational grazing. This required a conversion of all land near the milking barn to grass, providing 72 ha of pasture. An additional investment of

$23,000 in fence and watering equipment was assumed for a total investment of $34,000. This included a high tensile wire fence around the perimeter of the pasture area and electric fence to maintain up to 30 paddocks. This change allowed better use of existing grassland and converted some existing corn and alfalfa land to grass. More intensive use of pasture increased the available yield by 50% (Table 2). Other changes made to represent a grazing farm (Conneman et al., 2000) included: 1) a 5% reduction in milk production, 2) a 15% reduction in the culling rate of cows with increased heifer sales, 3) a 30% reduction in veterinary expenses to reflect improved health, and 4) a 20% increase in the life of all field and feeding equipment due to reduced annual use.

The third strategy evaluated removal of corn and alfalfa from the farm. This included changes made for the second strategy, plus all remaining corn and alfalfa land was converted to grass harvested as silage. To better utilize high quality grass, a three-cutting strategy was used where first and third cuttings were harvested as silage and second was harvested as hay. Considering the lower energy and higher fiber contents of grass silage relative to alfalfa and corn silages, milk production was decreased an additional 5% (Broderick et al., 2002). This change in forage fed also affected the concentrate feeds required to meet animal energy and protein requirements (Rotz et al., 1999a).

The fourth strategy evaluated the conversion of the dairy farm to a heifer-raising enterprise. All mature animals were removed, and heifer numbers were increased to 180 head ≥ 12 mo of age and 180 < 12 mo of age for a total of 360. Animals were purchased as calves ($400/calf) and sold as bred heifers ($1700/heifer) near the time of calving. Feed production and land use were very similar to that of the current farm. Facility changes were made to accommodate the increased number of heifers and to remove milking equipment, but the overall investment required for animal facilities was the same as that of the current dairy. Livestock expenses, consisting of veterinary, breeding, utility, supply, and related costs, were set at $106/heifer produced (Penn State, 2000).

The fifth strategy evaluated expanding the farm business to include other family members using a modern confinement facility. Animal numbers were increased to 250 cows with 200 replacement heifers. A double-ten milking parlor and free-stall facility were used where all cows were housed and fed in confinement. A manure storage tank was added to provide 6 mo of storage. Manure was applied through a custom or contracted operation in the spring and fall where it was tilled into the soil soon after application. The land area was increased to 304 ha, which was enough land to provide all the forage needed for the herd. The added land was used to produce 80 ha of alfalfa (with 20 ha of oat cover crop) and 43 ha of corn. Two large bunker silos were used to store the annual requirement of silage from the corn, alfalfa, and oat crops. A large forage harvester was used, but all other equipment remained the same as that on the current farm. Animals were fed to meet the latest P requirements (NRC, 2001), and no starter fertilizer was used beyond that needed to maintain a long-term nutrient balance.

Large farm. Five different strategies were evaluated for the 800-cow farm. The first was a reduction in the feeding of mineral P to not exceed currently recommended dietary amounts (NRC, 2001). The second strategy included the same adjustment in the P feeding requirement along with an increase in milk production. Production was increased by 11% to an annual level of 9080 kg/cow. This proposed increase may be achieved through changes in feed and animal management. Although this production is high for the grazing-based management system used on this farm, it provides an achievable goal.

The third strategy involved an intensification of grass use. The current farm has a large land base with 2.5 ha/cow in total land and 2.1 ha/cow in grassland. Much of the grassland is underutilized. Little to no fertilization or pest control is used, so grass yields are relatively low. To simulate greater utilization of the grass, grassland was reduced to 560 ha. This provided 884 ha of total farmed land, or a little over 1 ha per milking animal. Other management changes included application of N fertilizer at a rate of 75 kg/ha and an annual charge of $15/ha of grassland for weed control and perhaps overseeding of improved species. As a result, simulated annual grass yield was increased to 4.7 tonne DM/ha. Wilted silage harvests were taken from 145 ha of the grass in the spring and again in early summer. For the remainder of the year and for the remaining 415 ha of grassland, grass was efficiently utilized through rotational grazing. This strategy, including the existing corn, alfalfa and triticale crops, provided all the forage needed to maintain the herd. A fourth strategy combined the two previous options; grass production and use was intensified, milk production was increased, and dietary P requirement was decreased.

A fifth strategy included the changes assumed for the fourth plus an additional 390 ha of grassland was used to produce bred heifers. Six hundred heifers were added with 300 sold each year. This required an additional investment in heifer barns ($325,000), pasture fence ($30,000), and manure storage ($25,000). Calves were purchased for $400 and bred heifers were sold for $1700. Annual livestock expenses were increased by $106 per heifer produced and annual labor cost was increased by $40,000.

RESULTS

Simulation results include 25-yr average annual predictions of feed production and use, nutrient loss and accumulation, production costs, and the net return or profit of the farm. Important results to consider are the comparisons between the different strategies simulated, not the absolute values generated for a particular farm. Predicted values for a given farm, such as soil P accumulation and net return, vary greatly depending upon model assumptions, and thus should not be used to judge the viability of a specific farm. Relative differences between simulated systems though, provide meaningful evaluation of the effects of system changes.

Average Farm

Simulation results for the 100-cow farm with the current production strategy are listed in the first column of Table 5. Long-term predictions of feed use compared closely to those of the actual farm. A small amount of grass hay was occasionally sold from the farm, and the average purchase of concentrate feed mix was similar (334 tonne DM/yr). This verified that the model was adequately predicting crop production and feed use for the herd with an annual milk production of 9530 kg/cow. Based upon the simulated feed production, purchased fertilizer, purchased concentrate feeds, and export of milk, animals and hay sold, the farm had an annual excess of P. The annual accumulation of soil P averaged over the farm area was 5.1 kg/ha considering the loss to the watershed of 1.0 kg/ha. An economic analysis of this production system indicated an annual net return to labor and management of $988/cow.

Reduction of the P imported in fertilizer and feed are among the easiest management changes available to reduce excess P on this farm. Eliminating the use of P starter fertilizer on the corn and oat crops reduced the accumulation of soil P to 3.1 kg/ha (data not shown). Assuming that this could be done without adversely affecting crop production, this reduction in fertilizer use increased annual farm net return by $5.50/cow. Dropping the minimum amount of P in animal rations to current requirements further reduced the soil P accumulation, providing a long-term nutrient balance with a need for a small amount of fertilizer (1 kg P/ha). Decreasing the P fed without a change in the current fertilizing practice gave an excess of 1 kg P/ha with a loss of 0.8 kg P/ha. The savings in purchased minerals increased the annual farm net return by $22/cow.

Use of management-intensive rotational grazing reduced the concentrate feed purchased, reduced soil P accumulation, and increased farm profit (Table 5, column 2). Rotational grazing increased the productivity of grassland, which increased the amount of forage produced on the farm. Use of high-quality pasture, along with the assumed 5% reduction in milk production, reduced the purchase of concentrate feed by 16%. High protein contents in pasture forage led to excess N excretion, which increased N volatilization loss 6%. Reducing the amount of manure applied to fallow corn land in the fall though, reduced N leaching loss 22%. The reduction in the import of fertilizer and concentrate feed reduced the import of P to the farm by 3 kg/ha, which reduced the accumulation of excess P in the soil by about the same amount. A reduction in harvest, feeding, and manure handling operations, along with a reduction in purchased feed costs, increased farm profitability by $10,000 or $93/cow. Use of grazing also reduced the economic risk due to annual weather variations. This occurred because grass yields were more consistent than corn yields across weather years on this shallow soil. Also, there was excess pasture forage during most years, so drought years did not have as much effect on production costs.

Replacing the remaining corn and alfalfa with grassland had a small effect on forage use and concentrate feed requirements (Table 5, column 3). Excess P dropped to 1.8 kg/ha; including the newly recommended reduction in dietary P allowed a long-term P balance (data not shown). The major change was a large reduction in N leaching loss to groundwater. Compared to fall application of manure on fallow corn land, the model predicted that much more of the soil nitrate from manure would be captured and retained by the grass, thus reducing the potential for leaching loss in the spring. Production costs were slightly lower than those of the previous grazing strategy due to the reduction in annual costs of tillage, planting, seed, fertilizer, and chemicals for corn production. Due to the assumed decrease in milk production, farm income decreased providing an annual net return similar to that of the current farm. As in the previous strategy, the risk or variation in net return across weather years was reduced due to more consistent crop yields and an abundance of pasture forage during most weather years.

Changing the dairy farm to a heifer raising enterprise may also provide a long-term P balance for the farm, but this is dependent upon the number of animals raised. A production level of 180 bred heifers per year was selected because this provided similar feed utilization as the current dairy strategy (Table 5, columns 1 and 4). Heifers used more forage, so a small amount of forage was purchased during some weather years. The need for concentrate feeds was reduced by over 50%, and the need for supplemental P in heifer diets was low

Table 5. A comparison of annual production and economic effects for various management changes simulated on the average-sized (100-cow) farm in New York.

Production or economic output	Current[1]	Intensive grazing[2]	All grass[3]	Heifer raising[4]	Expansion[5]
Hay and silage production, tonne DM	395	217	433	307	829
Corn silage production, tonne DM	303	264	0	303	707
High moisture corn production, tonne DM	41	10	0	41	118
Grazed forage consumed, tonne DM	146	481	478	387	223
Forage purchased (sold), tonne DM	(19)	(54)	(40)	77	33
Concentrate purchased, tonne DM	334	282	281	118	638
Milk production, kg/cow	9,530	9,080	8,620	0	9,530
Nitrogen imported, kg/ha	193.1	174.5	152.9	161.9	210.0
Nitrogen exported, kg/ha	49.9	49.4	47.4	20.1	58.1
Nitrogen volatilization loss, kg/ha	71.0	75.5	78.7	93.9	59.0
Nitrogen leaching loss, kg/ha	45.0	35.0	15.5	46.5	61.0
Phosphorus imported, kg/ha	14.5	11.7	10.5	4.8	10.4
Phosphorus exported, kg/ha	8.4	8.3	7.8	4.5	10.1
Phosphorus loss, kg/ha	1.0	1.0	1.0	0.9	0.9
Phosphorus accumulation, kg/ha	5.1	2.4	1.8	0.0	0.0
Machinery cost, $	48,538	47,134	43,163	48,346	73,459
Fuel and electric cost, $	4,046	3,343	3,129	4,218	10,487
Storage facilities cost, $	14,217	13,002	11,573	14,217	31,722
Seed, fertilizer, and chemical cost, $	26,633	27,366	25,441	26,632	30,733
Land rental and property tax, $	13,614	13,478	13,380	13,614	25,820
Purchased feed & bedding cost, $	72,700	60,965	60,318	33,950	144,799
Animal & milking facilities cost, $	42,746	42,746	42,746	22,173	81,666
Livestock expenses, $	38,108	34,958	34,958	94,050	61,150
Total production cost, $	260,602	242,992	234,708	257,200	459,836
Milk, feed, and animal income, $	364,333	356,537	340,799	302,955	785,845
Net return to labor and management, $	103,731	113,545	106,091	45,755	326,009
Standard deviation in net return, $	9,427	7,391	2,187	11,899	27,946

[1]105 cows and 105 heifers on 181 ha of land with 32 ha of corn, 40 ha of alfalfa and 109 ha of grassland.

[2]Pasture area was increased to 72 ha and cows and older heifers were rotationally grazed.

[3]All cropland was converted to grassland, pasture area was increased to 72 ha and cows and older heifers were rotationally grazed.

[4]Feed production was similar to current practice, but milking animals and facilities were removed and replaced by growing heifers and associated housing. Animals were fed to meet NRC (2001) P requirements.

[5]Farm was expanded to 250 cows and 200 replacement heifers on 304 ha (120 ha alfalfa seeded with oat cover crop, 75 ha corn, and 109 ha grassland). Animals were fed in confinement to meet NRC (2001) P requirements.

compared to that of lactating animals (NRC, 2001). Both the import and export of P were greatly reduced providing a long-term P balance.

The heifer raising strategy reduced the demand on family labor, but it was less profitable. Production costs were similar to those of the current dairy facility where the purchased calf cost was offset by the reduction in purchased feed and the elimination of milking facility costs. The net return to labor and management was half that of the current dairy farm, but the labor requirement was also less. With a labor requirement of 3800 h/yr for the current dairy and a requirement of 2000 h/yr for raising heifers, the net return per labor hour for raising heifers ($23/h) was just 15% less than that of the dairy ($27/h).

Expansion to 250 cows can also be done in a manner that leads to less accumulation of P on the farm. However, the stocking rate (animals per unit land) and the amount of supplemental P in animal rations are important considerations in planning this expansion. In this analysis, land areas in corn and alfalfa were increased (along with current grass area) to provide nearly all of the forage needed and some high-moisture corn during good corn growing years (similar to the current dairy enterprise). This required a 70% increase in land area with soil similar to that currently used for corn and alfalfa production. Phosphorus requirements in animal rations were reduced to current NRC recommended amounts.

Nutrient flows through the farm were generally improved in the expanded farm. With 6 mo of manure storage and more rapid incorporation of that manure, N volatilization loss was reduced 17% (Table 5, columns 1 and 5). However, with less volatile loss and greater N application per unit of land, N leaching loss increased 35% (16 kg/ha). A long-term P balance was maintained under the land area, animal numbers, and other farm characteristics assumed.

Table 6. A comparison of annual production and economic effects for various management changes simulated on the large (800-cow) farm in New York.

Production or economic output	Current production strategy[1]	Increased milk production[2]	Intensified grass use[3] Current production	Intensified grass use[3] Increased production[2]	Intensified grass use[3] Additional heifers[4]
Hay and silage production, tonne DM	1,661	1,663	961	961	1,739
Corn silage production, tonne DM	1,928	1,930	1,922	1,922	1,930
Grazed forage consumed, tonne DM	1,603	1,557	2,300	2,262	3,141
Concentrate purchased, tonne DM	1,973	2,272	1,985	2,284	2,396
Milk production, kg/cow	8,172	9,080	8,172	9,080	9,080
Nitrogen imported, kg/ha	119.1	122.8	86.1	89.5	108.8
Nitrogen exported, kg/ha	24.3	26.2	24.3	26.3	28.3
Nitrogen volatilization loss, kg/ha	32.1	32.3	32.7	32.8	46.0
Nitrogen leaching loss, kg/ha	31.0	31.3	27.7	28.1	35.5
Phosphorus imported, kg/ha	7.9	5.4	7.6	5.2	5.4
Phosphorus exported, kg/ha	4.3	4.6	4.3	4.6	5.1
Phosphorus loss, kg/ha	0.6	0.4	0.6	0.4	0.5
Phosphorus accumulation, kg/ha	3.0	0.4	2.7	0.2	0.0
Machinery cost, $	216,345	217,396	195,541	196,467	221,397
Fuel and electric cost, $	47,368	47,908	34,730	35,221	46,447
Storage facilities cost, $	43,807	43,815	42,610	42,611	46,075
Seed, fertilizer, and chemical cost, $	100,713	100,713	91,194	91,196	119,224
Land rental and property tax, $	100,304	100,304	100,304	100,304	103,534
Purchased feed & bedding cost, $	418,097	448,869	399,035	428,754	452,502
Labor, $	600,000	600,000	600,000	600,000	640,000
Animal & milking facilities cost, $	193,187	193,187	193,187	193,187	229,630
Livestock expenses, $	194,000	194,000	194,000	194,000	326,000
Total production cost, $	1,913,821	1,946,192	1,850,601	1,881,740	2,184,809
Milk, feed, and animal income, $	2,131,545	2,339,213	2,132,695	2,340,688	2,837,569
Net return to management, $	217,724	393,021	282,094	458,948	652,760
Standard deviation in net return, $	64,670	64,470	71,879	72,379	66,828

[1]800 cows and 600 replacement heifers on 2,025 ha of land with 162 ha of corn, 162 ha of alfalfa and 1700 ha of grassland.

[2]Milk production was increased 5% through changes in animal and feeding management. Animals were fed to meet current NRC (2001) P requirements.

[3]Grass area was reduced to 560 ha with 415 ha grazed in the spring and all grass grazed in summer and fall. Management changes included application of 75 kg/ha of N fertilizer on all grassland and an annual cost of $15/ha for pest control and overseeding.

[4]Same as previous except an additional 390 ha of grassland was used to produce 300 bred heifers per year requiring additional investments in heifer barns, pasture fence, and manure storage. Annual livestock expenses were increased by $106 per heifer produced and annual labor cost was increased.

The expanded dairy enterprise also provided a good economic return. Most production costs doubled with the increase in animal numbers and crop area, but the income also more than doubled. The difference between income and production costs (excluding labor), or the annual net return to labor and management, increased by more than three-fold to $326,000 or $1300/cow. Given that this net income must support three families, the net return per family was similar to that of the current farm that supports one family. Although the standard deviation in net return increased considerably, the coefficient of variation (8.6%) was similar to that of the current farm.

Large Farm

Production and economic results of the current production system on the 800-cow farm are listed in column 1 of Table 6. Grazed forage yields were reduced considerably to match simulated and actual feed production and utilization records. With this change, though, predicted forage production, grazed forage consumed, and concentrate feeds purchased were all similar to that experienced on the actual farm.

Based upon the simulated production levels, purchased feed and fertilizer, and the large land base, the nutrient balance and losses from the farm appear very reasonable when viewed on a per unit of land basis (Table 6, column 1). Nitrogen volatilization loss is quite low compared to that of the smaller farm (Table 5, column 1). This is partially due to more rapid incorporation of manure, but primarily this number is small because the total loss is spread over a large land base. When the loss is determined on an animal unit basis, N volatile loss is only 34% less on this farm compared to the smaller farm. Nitrogen leaching loss is also less when spread over the entire farm area, but the loss per animal unit is similar between farms. Excess P accumulation in the soil is less per unit of farmland, but considering the large land base, this accumulation represents a substantial build up of P on the watershed.

Again, an easy and economical method to reduce P import and accumulation on the farm was to reduce the purchased mineral P fed. Implementing the new NRC (2001) P requirements reduced the import of P by 6,300 kg/yr, which brought the farm to a long-term balance (data not shown). Thus, P imported in feed essentially equaled that exported in milk and animals sold. Reducing the mineral P added to feed decreased the annual feed cost, and thus improved farm net return, by $18,400 ($23/cow).

Increasing the milk production level of the herd increased feed consumption and purchased feed costs. This increased cost was more than offset by the increase in milk income, increasing net return by $160,000 per year. Using the current P feeding strategy, this change created a small increase in the accumulation of excess P on the farm (data not shown). By combining this increase in production with a reduction in the dietary P requirement, a P balance for the farm was approached and net return was increased further (Table 6, column 2).

Farming less grassland and farming it more intensively showed some economic benefit with mixed effects on nutrient balance and loss (Table 6, column 3). Grazed forage consumption was increased along with a reduction in harvested grass silage providing a reduction in machinery and fuel costs. Purchased feed cost also decreased. All together, these changes increased the annual net return by $64,400 or $80/cow. Nitrogen leaching loss decreased as N was recycled more efficiently in the higher yielding, higher quality forage. The P balance over the whole land base (2025 ha) was affected little by this change. Because the excess P would be confined to less land, the annual accumulation on the 884 ha farmed would increase to 6.2 kg/ha.

Combining more intensive use of grass with greater milk production and reduced feeding of mineral P improved nutrient use and increased profitability (Table 6, column 4). With the combined changes, a reduction in N leaching loss was obtained along with a long-term P balance. The predicted profitability of the farm more than doubled with the increased milk sales and reduced production costs.

Adding the additional annual production and marketing of 300 bred heifers, increased forage use with a small increase in purchased concentrate (Table 6, column 5). Nitrogen losses increased, but a long-term P balance was maintained. Increased production costs were more than offset by heifer sales providing an additional $194,000 in annual net return.

DISCUSSION

These farm simulations illustrate that management changes can be made to reduce the P loading on dairy farms in this region. These changes can be made while maintaining and likely improving the profitability of the farms.

One of the easiest ways to reduce P import and the resulting accumulation in soil may be to reduce the amount of P fed. The NRC (2001) P requirements for dairy animals are lower than past recommendations, and recent experimental work has shown that these reduced amounts can be maintained without adverse effects on animals (Wu et al., 2000; Satter, 2001). In many diets, this lower amount of P can be met by removing mineral P added to supplemental feed at a cost of about $3.00/kg of P. As found in these simulations, removing this added mineral can reduce the annual feed cost and thus improve farm profit by about $22/cow. When byproduct feeds high in P content are fed, these supplemental feeds may need to be replaced with feeds lower in P content to achieve the same reduction in imported P. If the substitute feeds can be purchased at a similar or lower cost, an improvement in net return may again be achieved.

Changes in cropping strategies may also affect P loading, but these effects are normally small. A cropping change of replacing corn and alfalfa with grass reduced the excess P on the farm by 0.6 kg/ha. In a previous study, added corn, barley, soybean, or pastureland all had similar effects on the P balance of a dairy farm (Rotz et al., 2000). Cropping changes will only affect the whole-farm P balance if the crop change greatly affects the import of supplemental feed or fertilizer or the export in sold feed. On dairy farms where manure provides most of the P requirement for crops and those crops are used on the farm, cropping changes have little effect on the import and export of P.

Better utilization of a crop such as grass may provide some reduction in the excess P on a farm. This was illustrated on the average-sized farm where the use of rotational grazing of the milking animals provided a substantial reduction in purchased feed. On the large farm where more intensive use of grass had little effect on purchased feed, there was also little difference in the accumulation of excess soil P.

Use of more grass on farms in this region may provide an added benefit by reducing P runoff into streams and ultimately the reservoirs. Topography in this region is very hilly, and the soils are erodable. A sod cover of perennial grass will reduce water movement and help hold the soil and nutrients on the landscape (Sharpley and Rekolainen, 1997). As differences in P runoff among crops were not modeled in this study, this should be considered as an added benefit for grass production. Ideally the accumulation of soil P should be prevented, but if high soil P concentrations occur, runoff loss should be less when a perennial ground cover is maintained.

Intensive use of grazing potentially reduces the whole farm accumulation of P, but this strategy may alter the distribution of P within the farm. When cows fed a high-concentrate diet are on pasture for a major portion of the day, there is a potential for more P to be applied through manure than is removed through grazing causing a long-term accumulation. Although this is a potential concern, this study illustrates that with proper grazing management (i.e., controlling the frequency, intensity and duration of grazing) a P balance can be maintained in pastures. For the farms studied, pastures grazed by lactating cows were near a long-term P balance as long as additional manure was not spread over these fields.

A synopsis of all simulation results indicates that dairy farms in this region can maintain a long-term P balance if: 1) animals are fed to meet NRC (2001) P requirements, 2) the cropping strategy and land base used supplies all of the forage needed, 3) all animals are fed a high forage diet, and 4) replacement heifers are produced on the farm. Here, high forage diets are defined as those designed to feed the maximum amount of forage to each animal group while meeting their energy and protein requirements with supplemental feeds (Rotz et al., 1999a). The current 100-cow farm, the expanded 250-cow farm, and the current 800-cow farm were all able to maintain a P balance when these conditions were met. Raising replacement heifers helps maintain a nutrient balance because these animals consume more homegrown forage and less purchased concentrate relative to lactating cows. Conversion of the 100-cow dairy farm to a heifer-raising facility also provided a long-term balance when these conditions were met. Maintaining a higher milk production through greater import of purchased concentrates increases the amount of excess P, but as illustrated on the 800-cow farm, excess P is minimal when these conditions on dietary P and forage production and use are followed.

The goal for P management on dairy farms should be to maintain a long-term balance by reducing P inputs from feed and fertilizer and maximizing the use of farm-grown forage. When combined with conservation practices that minimize runoff and erosion, P loss to the watershed will be reduced through better recycling of nutrients on the farm. When excess nutrients occur, it is essential that this excess P in manure be applied to parts of the farm that are least vulnerable to loss by runoff and erosion (Gburek et al., 2000). Thus, with consideration of site topography and hydrology, as well as P needs of the crops, carefully managed application of excess P can reduce losses. This may provide short-term help, but it does not offer a long-term solution. A sustainable farm requires a long-term balance. Whole farm simulation provides an effective tool that can assist in the evaluation and selection of sustainable production systems that reduce or eliminate excess P while maintaining or improving farm profit.

CONCLUSIONS

Management changes can be made to reduce or eliminate the long-term accumulation of soil P on dairy farms. Reducing the dietary P to current NRC recommended amounts reduced the annual accumulation of soil P on two New York farms by about 7 kg/cow allowing a long-term balance with an annual savings in feed cost of about $22/cow. Intensifying the use of grass by using more grassland and/or rotational grazing reduced excess P by up to 5 kg/cow with an improvement in farm profit of up to $93/cow. A 5% increase in herd milk production created a small increase in excess P, but when combined with a reduction in dietary P, annual excess P was reduced by 6.6 kg/cow with an increase in profit of $220/cow per year. The conversion of a dairy facility to a heifer raising facility and an expansion from 100 cows to a 250-cow “state-of-the-art” confinement facility were both found to be profitable options. A long-term P balance was maintained for these farm options when the production and use of forage was maximized and the minimum dietary P did not exceed current NRC recommended amounts.

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APPENDIX

For those interested in further analysis and comparison of dairy production systems, a Windows® version of DAFOSYM is available from the home page of the Pasture Systems and Watershed Management Research Unit (http://pswmru.arsup.psu.edu). The program operates on computers that use any Microsoft Windows® operating system. To obtain a copy of the program including an integrated help system and reference manual, the home page can be accessed through the Internet at the address given. Instructions for downloading and setting up the program are provided.