PHYSIOLOGY AND MANAGEMENT

The Impact of Nutrient Loading Restrictions on Dairy Farm Profitability

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ABSTRACT

A linear programming model was utilized to determine the economically optimal dairy herd intensities, manure application rates, and crop mix for unrestricted and restricted scenarios of N loss on New York dairy farms. Two representative farms were developed for dairies with 60 or 250 cows that utilized manure handling systems: no storage and daily spreading versus 6 mo of storage and biannual spreading, respectively. Both farms were substantially affected by the imposition of restrictions on N loss, although profitability decreases were relatively smaller on the larger farm, partially because of better conservation and more efficient utilization of manure nutrients. Optimal cow numbers per hectare decreased by nearly 35% on the smaller farm as restrictions on N loss intensified. When initial hectares were retained, rates of return to equity capital decreased >150 and 100% on the farms with 60 and 250 cows, respectively, compared with 47 and 42% when hectare adjustments were optimal. Whether dairy farmers are able to make hectare adjustments under restrictions on N loss may well determine future sustainability and survival of the farming operations. If additional hectares are not available or feasible to acquire, herd reductions may be necessary to meet restrictions on N loss, dropping profitability even further. (**Key words**: profitability, herd intensity, manure nutrients, water quality)

Abbreviation key: **AU** = animal units, **CNY** = central New York, **GLEAMS** = Groundwater Loading Effects of Agricultural Management Systems, **LP** = linear programming, **NFI** = net farm income, **RORA** = rate of return on assets, **ROREC** = rate of return to equity capital.

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INTRODUCTION

In recent years, the potential for agricultural operations to have negative impacts on environmental quality has become increasingly apparent. Increases in dairy herd size or concentration of farms for a particular region or state can have implications for appropriate nutrient management practices and water quality. The inventory of milk cows in the US is becoming more concentrated on a smaller number of farms each year (9, 10). Over 61% of the US dairy cows were in herds of <50 cows in 1969; by 1987, only 26% were in herds of this size. Conversely, the percentage of US dairy cows on farms with >100 cows increased from <17 to >42% during the same period. Similar changes in US cropland hectares have not kept pace with the trend of herd expansion. Although the mean number of cropland hectares per farm has increased, that increase has not been as substantial as the increase in cow numbers (9, 10). The mean number of cows per farm has increased nearly 84% from 1969 to 1987; the mean number of cropland hectares per farm has increased only 37%, resulting in a decrease of 25% in the mean number of cropland hectares per cow on US dairy farms.

Evaluations of alternative ratios of cows to land as they affect farm production decisions, profitability, and nutrient losses can lead to a better understanding of optimal resource allocation and its effect on the environment. This study quantifies these relationships and answers the question of optimal ratios of cows to land for profitability of farming operations under unrestricted and restricted scenarios of N loss.

MATERIALS AND METHODS

The theoretical framework for this study involved the incorporation of enterprise budgeting and linear programming (**LP**) analysis. Enterprise budgeting and LP were used to define and describe the whole farm systems by their various components and magnitudes as herd intensities changed and as restrictions on N loss were imposed. The theoretical underpinnings for the use of LP to evaluate changes in resource availability and operation restrictions are its ability to simultaneously evaluate input and output relationships for all farm enterprises and to determine optimal enterprise levels based on the objective function. Optimal combinations for the enterprise are obtained by utilizing a LP model incorporating all decision processes that occur at the farm level. The solutions are subject to the resources available and to the technical relationships among resources, inputs, and products. A fundamental representation of a farm level LP model can be expressed as

$$\text{MAX } Z = \sum_{j=1}^{n} c_j X_j$$

subject to

$$\sum_{j=1}^{n} a_{ij} X_j \le b_i \text{ for } i = 1 \text{ to } m$$

$$X_j \ge 0 \text{ for } j = 1 \text{ to } n$$

where X_j refers to the level of the farm activity j (j = 1 to n) possible activities of a product or commodity produced, bought, sold, or transferred in a production process; parameter c_j refers to the estimated gross margin of a unit of the activity j, measured in terms of the price, return, or cost per unit of the activity j; a_{ij} refers to the quantity of the resource i (i = 1 to m) required to produce one unit of the activity j. Finally, b_i refers to the amount of the resource i endowment available to the decision maker. The constraint set included common LP relationships on the farm, such as cropland, labor, and livestock as well as crop growing, feeding, purchasing, and selling activities. In addition, the constraint set included balancing activities for manure production and spreading as well as limitations on the N and P lost for specific crop and fertilizer activities.

The LP models were solved to maximize returns over variable costs. Parametric adjustments were made in cropland hectares to evaluate alternative dairy herd intensities. Deductions from the maximized returns were made for fixed activities of livestock, crop, and land to determine net farm incomes (**NFI**) at the alternative hectares. A value of resident labor and management, which included unpaid family labor, was deducted from NFI to determine returns to equity capital. By relating these returns to farm owner equity, rates of return to equity capital (**ROREC**) were determined. As hectares were increased or decreased, adjustments were made for changes in rental or ownership holdings depending on mean costs for land rental and ownership of the representative farm to maximize the NFI. Mean fixed costs per hectare for crops and livestock were estimated from representative farm data (8). When hectares were adjusted, total fixed costs were affected, representing changes in the associated asset levels for the corresponding hectare base. When increases (or decreases) in fixed costs occurred, depicting increases (or decreases) in the associated asset values, resulting farm equity levels remained unchanged because purchase (or selling) prices and market values were assumed to be equal. Rate of return on assets (**RORA**) was also calculated to reflect the adjusted asset (investment) levels and reduce any bias associated with the ROREC calculation relative to differing levels of owner equity percentage between the two farms. These values were then compared with the ROREC calculations to determine whether the optimal hectare level would differ. The maximum ROREC over all hectares evaluated determined optimal cropland hectares for that particular representative farm. This procedure was completed for each farm under unrestricted and restricted scenarios of N loss.

Representative Farm Descriptions

Two representative dairy farms were developed that depicted herd sizes of 60 and 250 cows for dairy farms in central New York (**CNY**) using 1991 data from the dairy farm business summary (8). General characteristics for both representative farms are displayed in Table 1. Enterprise budgets, including receipts, variable expenses, and fixed expenses, were estimated for all possibilities of livestock and crops. In particular, separate livestock enterprise budgets were determined for dairy cows and heifer replacements for three forage-based TMR comprising predominantly alfalfa, corn silage, or orchardgrass.

Balanced TMR were determined for each of the forage bases; however, certain forage limitations were necessary. Alfalfa was allowed as the sole forage in the lactating cow TMR; however, dry cow and replacement TMR were limited to 50% alfalfa and 50% orchardgrass forages on a DM basis. Additionally, a complete corn silage forage TMR is not nutritionally suitable for dairy cows or replacements. A maximum of 75% corn silage (DM) was allowed in the lactating cow TMR, and alfalfa constituted the remaining forage. Corn silage TMR for dry and replacements cows were limited to 50% corn silage and 50% alfalfa (DM) forages. Finally, partially because of the lower protein and calcium content of orchardgrass, the orchardgrass forage TMR was also restricted. The orchardgrass TMR was limited to 75% orchardgrass and 25% alfalfa forages (DM). Actual on-farm TMR likely consist of combinations of these forage bases. The LP models were used to identify the appropriate

TABLE 1. General characteristics for two representative dairy farms.

Characteristic	60 Cows	250 Cows
Housing	Tie stall	Free stall
Milking system	Pipeline (2×)[1]	Parlor (3×)
Manure handling	Daily spreading	6-mo earthen pit
Livestock		
Cow, no.	60	250
Cow weight, kg	590	635
Replacement number	43	195
Replacement weight, kg	320	340
Milk production, kg/yr	7711	8505
Mean milk price,[2] $/45.4 kg	12.85	13
Manure production, tonnes/yr		
Cow	20.5	22
Replacement	7.8	8.4
Manure nutrients,[3] kg/tonne		
Total N	4.7	4.7
P_2O_5	2.6	2.6
K_2O	3.7	3.7
Resident labor,[4] h	4000	5000
Crop yields, DM tonnes/ha		
Corn silage	11.6	11.2
Corn grain	6.1	5.4
Alfalfa	5.6	4.9
Orchardgrass	4.5	4.5
Tillable cropland, ha		
Owned	51	186
Rented	24	87
Herd intensity,[5] AU/ha	1.43	1.82
Total assets,[6] $	478,136	1,628,299
Total liabilities	124,375	718,538
Net worth	375,761	909,761
Owner equity, %	74	56

[1]2× = Twice daily milking; 3× = three times daily milking.

[2]For the 1991 calendar year.

[3]As produced, farm averages.

[4]Includes operator and unpaid family labor.

[5]AU = Animal units or 454 kg of livestock weight.

[6]Equity statement information December 31, 1991.

proportions of each TMR to feed, based on farm characteristics and maximum profit. The LP framework allowed for simultaneous consideration of crop and livestock enterprises to maximize farm returns.

In addition, four different crops, corn grain, corn silage, alfalfa, and orchardgrass, were allowed in an 8-yr rotation. Corn crops, either as silage or grain, were limited to a maximum of 50% of total crop area based on common CNY crop rotations and soil conservation practices. If feasible, however, haycrop hectares were allowed to exceed the 50% minimum. In addition, corn silage was only allowed to be grown and fed to livestock; the remaining crops could be purchased, grown, fed, or sold. Crop activities were balanced such that total annual crop production was utilized through feeding or sales activities, depending on the crop. Therefore, excess grain and haycrop production above annual feeding requirements was assumed to have been sold.

Separate annual budgets were estimated for each crop and varied depending on the prior crop, yield, and fertilization requirement. Fertilizer requirements were based on average characteristics of silt loam for medium fertility soils and representative farm crop yields in CNY. Initial soil compositions of total N, P, and K were approximately 70, 11, and 100 kg/ha, respectively. Fertilizer requirements for N, P, and K were determined for each crop for each year in the rotation. Excess application of either manure or commercial fertilizer was allowed with no additional yield response. Therefore, excess applications of N, P, or K above fertilizer requirements could occur. Losses of N subject to those applications were restricted, not the applications themselves. Fertilizer requirements could be satisfied with manure or commercial fertilizer because nutrient contributions were calculated for both components. Application of manure was allowed to both haycrops. Application of manure to alfalfa provides an additional location for N disposal, even though alfalfa exhibits N fixation ability. Orchardgrass was a crop option providing a nonlegume haycrop with annual N requirements of nearly 80 kg/ha and an additional opportunity for manure application. Additional enterprise budget specifications can be found in a publication by Schmit (7).

Manure Handling Systems

The representative farms were specified to utilize different handling systems that affect nutrient losses and availability for plant uptake. Proper manure handling leads to more efficient utilization of manure nutrients for plant uptake and minimizes potential nutrient losses to ground and surface water supplies. The farm with 60 cows utilized daily spreading activities with solid manure handling. Lactating cows were housed in a stanchion barn, and manure was removed daily by a gutter cleaner. Dry cows and replacements were housed separately in a bedded pack barn that was cleaned quarterly. Bedding requirements were distinguished and reflected in the livestock budgets; the annual mean bedding requirement was 1.34 tonnes per animal unit (**AU**), where 1 AU was equal to 454 kg of livestock weight. Manure is surface-spread with a 5.66-m^3 solid manure spreader. Waste discharges from the milking center were not included with the solid manure handling system but handled separately. This type of manure system does not accommodate for milking center discharge and is handled separately for all farms in this classification (i.e., holding pond, drainfield, etc.). Existence of this type of system does not affect manure handling and is not included in this analysis; results should not be adversely affected.

The farm with 250 cows conducted biannual spreading with a 6-mo earthen storage system. The farm utilized a milking parlor and free-stall building arrangement with additional housing for open and bred heifers. The milking herd, dry cows, and heifers >6 mo of age were housed in a free-stall building; manure entered the storage system daily as a liquid. With inclusion of milking center waste into the earthen storage system, estimated at 22.8 L/d per cow, and the assumption that rainwater accumulation equaled evaporation losses, the farm required a storage structure of approximately 5100 m^3. Manure was scraped by a skid steer loader to drop structures daily and entered the storage system by gravity. Manure was unloaded by agitation and pumping and surface-spread with a 11,355-L liquid spreader. Young calves <6 mo of age were housed in a bedded pack barn; manure was cleaned quarterly, handled as a solid, and surface-spread with a 5.66-m^3 spreader. Bedding requirements were lower for the liquid manure handling system and resulted in an annual mean bedding requirement of .58 tonne/AU. Differences in bedding requirements were reflected in the representative farm enterprise budgets, and the impact of the nutrient losses was accounted for in the model simulations of N loss. Different costs for manure application from solid versus liquid systems are also impacted by bedding requirements and are reflected in the LP models.

Nutrient content of manure can vary widely across farms based on feed selection, manure handling characteristics, and numerous other factors. Composition estimates were developed from available literature and represent a reasonable midrange estimate. Manure compositions from the various systems and resulting nutrient availability per tonne of manure applied were calculated for both representative farms (1, 4, 6). Nutrient composition of manure components excreted from the livestock was assumed to be the same for both farms in terms of kilograms of nutrients per tonne of manure produced (Table 1). However, manure production per cow and per replacement varied across farms because of differences in livestock weight and milk production. In addition, resulting nutrients available to the plants differed due to the aforementioned operating and storage characteristics of the manure handling systems. Although nutrient composition of manure would be expected to change, based upon production and TMR selection, they are not represented here. Instead, the emphasis is drawn to the difference in the nutrients that are available for plants across farms because of the type of manure systems utilized and the associated differences in manure handling practices. Manure analyses at the time of land application for the three manure systems (daily spread, bedded pack, and earthen pit) are shown in Table 2, along with the resulting plant-available nutrients per tonne of manure applied. Although the farm with 250 cows was a system predominantly based on liquid manure, available nutrients were converted to equivalent manure DM for applicable comparison. Based upon the proportion of livestock utilizing the various manure systems and the respective manure production, weighted mean plant-available manure composition was calculated because the ratio of cows to replacements affected the resulting composition and differed across farms. Finally, the nutrients that were available to the plants per tonne of manure applied and AU per year for each representative farm, based on system use and associated nutrient loss characteristics, are shown in Table 2. These levels were used to determine additional needs for commercial fertilizer application, if any, based on crop fertilizer requirements and manure application rates.

Approximately 40% of initial total N content was ammonium N, of which only 1% was assumed to be retained for plant uptake under daily spreading activities, 10% for bedded pack activities, and 50 and 0% for spring and fall earthen pit applications, respectively. Losses predominantly represent those that were due to volatization and denitrification. Organic N utilized a .35-.12-.05-.02 decay series (4), which indicates that 35% of the organic N is mineralized during the year in which it is applied, 12% of the initial organic N applied is mineralized the 2nd yr, 5% for the 3rd yr, and 2% for the ≥4th yr. Losses of P and K are more stable and were estimated at 30% of initial levels for daily spreading, 28.75% for the bedded pack, and 27.5% for the earthen pit (1, 6). Mean composition on the farms was calculated based on the aforementioned loss estimates and AU for the various manure activities.

As expected, the larger farm, utilizing a storage system and more timely application of manure, had higher estimated nutrient availability per tonne of manure applied. Because manure was spread daily on the farm with 60 cows, more nutrients existed per tonne of manure applied. However, daily application also exposed manure to larger losses from volatization, denitrification, runoff, and leaching. Storage on the larger farm conserved more nutrients than the daily application on the smaller farm. Therefore, the nutrient losses during storage on the farm with 250 cows are less than the field losses from daily spreading. On the farm with 250 cows, manure was spread twice annually for the earthen storage system: in the spring prior to tillage activities and in the fall after crop harvest. Daily spreading activities on the smaller farm occurred throughout the year. The spring spreading provided nutrients when the plants most needed them and a shorter time until incorporation, thus reducing potential volatization losses, surface runoff, and leaching of N.

The manure application rates available for corn grain and silage crops were 67.2, 44.8, 22.4, and 0 tonne/ha for both farms, representing the wide range of possible applications occurring on CNY dairy farms. Manure application on alfalfa was lower than on corn and limited to 22.4, 11.2, and 0 tonne/ha to minimize unwanted potential weed growth and to allow utilization of the N fixation properties of the legume crop. Manure application on orchardgrass was allowed at 33.6, 22.4, 11.2, and 0 tonne/ha, which is slightly more than on alfalfa because of the substantial N requirements of orchardgrass for maintained yield and nonlegume characteristics. Application of manure to haycrops was beneficial and resulted in additional opportunities for manure disposal with reduced nutrient losses (3). Allowance for manure application on all crop hectares and use of alternative manure application rates provided opportunities for efficient use of the valuable manure nutrient source with respect to economic and environmental considerations. Comparison of the aforementioned application rates with available nutrients in Table 2 provides the range of available nutrients applied per hectare. The farm LP models determine optimal application rates, and mean farm applications can then be determined.

The proportions of use for each system type influenced mean costs for manure application for each farm, which was reflected in the LP models. Costs for manure application on both farms were calculated based on machinery complement, proportion of use, and bedding requirements (2, 7, 11). Application costs reflected fuel, repairs, and maintenance requirements for the representative farms. Labor requirements were separated from those costs for accounting purposes and allocated to each enterprise. Fixed expenses for depreciation, insurance, taxes, and interest were calculated for both farms based on their required machinery and equipment complements and financial

TABLE 2. Manure nutrient composition, plant-available nutrients, and manure system costs.

	Daily spread	Bedded pack	Earthen pit
Manure system			
Manure analysis at time of land application (kg/tonne)[1]:			
Total N	5	4.5	6.5
Organic N	3	3	4
Ammonium N	2	1.5	2.5
P_2O_5	2.5	2.5	2.5
K_2O	4	4	4
Plant-available nutrients by system (kg/tonne):			
N	1.64	1.77	2.06
P_2O_5	1.74	1.78	1.82
K_2O	2.8	2.86	2.91
Representative farm	60 cows	250 cows	
Plant-available nutrients, kg/tonne			
Total N	1.67	2.04	
P_2O_5	1.75	1.81	
K_2O	2.81	2.89	
Plant-available nutrients, kg/AU[2] per year			
Total N	23.6	28.9	
P_2O_5	24.8	25.64	
K_2O	39.8	40.9	
Manure system expenses			
Variable costs, $/tonne	.53	.65	
Labor requirement, h/tonne	.15	.10	
Fixed costs, $/AU	42.54	27.19	

[1]Manure composition converted to equivalent DM for applicable comparison.

[2]AU = Animal units or 454 kg of livestock weight.

characteristics. Manure application costs for both representative farms are displayed in Table 2.

Estimation of Nutrient Loss

Technical coefficients representing N and P losses for the alternative manure application rates and crops in the rotation were specified and included in the LP models to determine aggregate farm level nutrient losses. The coefficients were derived using the Groundwater Loading Effects of Agricultural Management Systems (**GLEAMS**) simulation model (5), developed for field size areas. The GLEAMS model evaluates the effects of agricultural production activities on the movement of chemicals and nutrients within and through the plant root zone and estimates field losses of N and P in kilograms per hectare based on characteristics of soil and climate, selection of crop and tillage, and applications of manure and commercial fertilizer. Losses of N and P estimated included those that were due to nutrients contained in runoff, dissolved in sediment, and leached through the soil profile, representing losses after field application. Relative loss amounts from runoff, sediment, and leaching depended upon factors such as rainfall amounts and dates; temperature; and tillage, planting, and harvest times. Those losses represented losses to surface and groundwater supplies. The model also accounted for additional losses of N through mineralization, denitrification, and volatization.

Livestock waste management was modeled for the two representative farms based on manure nutrient composition and application rates in accordance with the aforementioned handling system procedures. Selected weather, soil, crop, and fertilizer components were entered into the simulation model to estimate mean kilogram per hectare losses of N and P per year. The individual loss estimates made using GLEAMS of N in runoff, attached to sediment, and leached through the soil profile were summed to determine total N lost. The same procedure was conducted for losses of P. Results from GLEAMS for corn grain following alfalfa on both representative farms are shown in Table 3; additional rotation results from GLEAMS were described by Schmit (7).

TABLE 3. Annual mean N and P losses for corn grain following alfalfa in the crop rotation.[1]

Manure application rate[2]	60 Cows		250 Cows	
	N Lost	P Lost	N Lost	P Lost
(tonne/ha)	(kg/ha)			
67.2	70.49	3.55	60.31	2.39
44.8	54.79	3.27	47.73	2.26
22.4	38.48	2.90	35.26	2.17
0	22.60	1.64	17.77	1.22

[1]Derived from Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) simulation model (6), representing sum of losses from runoff, attached to sediment, and leached through the plant root zone.

[2]Lower manure application required additional commercial fertilizer application to meet crop fertilizer requirements.

The GLEAMS simulations were conducted for all possibilities of crop rotation and application rates of manure.

The soil type modeled for both representative farms was an average silt loam developed from comparisons of commonly farmed soils in CNY. Some of the field parameters included effective saturated conductivity (.76 cm/h), mean field slope (5%), soil porosity (.43 cm^3/cm^3), and initial organic matter (4%). Crop parameters included varied leaf area indexes during the growing season, effective rooting depth (45 cm), tillage and harvest dates, crop compositions, and potential yields (Table 1). Additional nutrient parameters included nitrate, ammonia, and potentially mineralizable soil N, labile and mineralizable organic soil P, and manure and commercial fertilizer application levels, compositions, and numerous dates.

Initial soil N supplies and crop residues also contributed to the total available nutrients to the plants. Soil N contribution was estimated at 70 kg/ha. In addition, alfalfa sod contributions, assuming a 25 to 50% legume stand at the end of a 4-yr rotation, were 112, 56, and 28 kg/ha of available N for the 3 yr following the alfalfa crop, respectively. Contributions of orchardgrass sod were assumed at three-fourths of alfalfa contributions. These factors influenced commercial fertilizer application, if any, based on the associated manure application rate. Comparisons of initial manure compositions, available nutrients to the plants, manure application rates, and losses after field application depict before and after field application losses. For example, manure applied at 67.2 kg/ha represents 113 kg/ha of plant-available nutrients (67.2 × 1.67). The GLEAMS model estimated that N losses for corn grain following alfalfa were 70.49 kg/ha, with the assumption that the 113 kg/ha does not include any of the additional contributions just mentioned. Although this N loss might seem overly high, in light of the relatively high manure application rate following a legume crop and initial levels of soil N, losses of this size can occur.

Initial examination of the estimated nutrient loss using GLEAMS demonstrated some clear trends. First, as manure application rates increased, losses of N and P increased. Higher manure applications contained more N and P than fertilizer requirements for the crops and increased potential losses to supplies of ground and surface water. Second, losses per hectare for the same rate of manure application were lower on the farm with 250 cows. The use of the manure storage structure conserves more nutrients during storage with application of manure only twice per year, most notably in the spring when plant uptake requirements utilize more manure N applied, lowering potential losses to water supplies. Nutrient provisions from more timely manure applications increased the proportion utilized by the plants such that fewer nutrients were lost. Estimated nutrient losses per hectare were equated with crop selection and manure application rates in the LP models to determine aggregate farm level losses of N and P. Relating aggregate losses with the tillable hectare level farmed determined average nutrient losses per hectare; those N losses will be restricted on a farm level basis to determine farm decision changes that are economically efficient.

Model Applications

To determine the impact on farm profitability of dairy herd intensities and constraints on N loss, the LP models for the representative farms were evaluated at alternative tillable hectares and restrictions of N loss. In addition to the initial 75 ha, the farm with 60 cows was evaluated at increased and decreased herd intensities based on the standardized cropland hectares of the farms sampled (8). Parametric adjustments in tillable hectares were conducted for 24, 32, 43, 107, 122, and 140 ha. The farm with 250 cows was evaluated at its initial level of 273 ha and for 111, 182, 223, 344, 385, 465, and 648 ha. Asset values and fixed costs corresponding to the crop production and land holding activities were adjusted as hectares changed and crop selection varied to calculate the resulting profitability. Hectares selected represent the range in cropland levels for CNY dairy farms of these herd sizes. Extreme hectares on both farms exhibit equivalent herd intensities in AU per hectare.

Representative farm model runs were conducted for all hectares mentioned with no restrictions on N loss and then with restrictions on N loss imposed. Mean N losses per hectare per farm, derived from the GLEAMS simulations, were restricted at three levels. Estimated losses of P were not considered excessive, ranging from 1.8 to 2.5 kg/ha, and therefore were not restricted in the LP model. Alternative farming practices, soil types, or geographic locations might need to consider losses of P further. The categories of constraints on N loss were imposed on the representative farms at 33.6, 28.0, and 22.4 kg/ha. Constraints represented mean losses for the entire farm, not any particular hectare loss. Some hectares could exceed the loss restriction level as long as the mean loss met the given constraint. This type of constraint is less restrictive than an individual hectare constraint but is more realistic in terms mandating farm N losses. Successive combination of more intensive restrictions on N loss with alternative hectares allowed determination of the economic impact of the restriction levels for various herd intensities. Optimal herd intensities and, hence, hectares could therefore be determined under the various restriction scenarios and allowed for comparison across the representative farms for equivalent constraints on N loss.

RESULTS AND DISCUSSION

Results for Unrestricted N Loss

The farm with 60 cows was evaluated at seven different hectare levels, representing a herd intensity range of .77 to 3.46 AU/ha. Unrestricted profitability was maximized at 75 ha; NFI and ROREC were $39,921 and 2.80%, respectively (Table 5). (The RORA were also calculated but not reported in Tables 5 and 6. The RORA represent higher percentage returns, yet the hectare levels where those returns were maximized remained the same for the unrestricted and restricted scenarios of N loss on both farms. Unrestricted RORA were maximized at 75 ha equal to 3.76% on the farm with 60 cows.) Comparison of animal numbers with optimal hectares resulted in a herd intensity coefficient of 1.43 AU/ha. Profitability was greatly reduced at 24 ha because cow numbers were reduced to meet the manure spreading constraints. These constraints refer to the assumption that all manure produced was spread within the farm boundaries. This constraint can be highly restrictive, especially at high AU densities (low hectare levels), but was retained because alternative methods for manure disposal were not a point of attention for this study. When herd intensities increased >4.5 AU/ha, maximum application rates would not allow for disposal of the entire amount of manure produced, resulting in herd level decreases to reduce total manure production. When herd size reductions were required, cows and replacements were reduced proportionately to maintain the original ratio of cow to replacement.

Relative profits were higher on the larger farm and occurred at greater herd intensities. Unrestricted profits were maximized at 223 ha; NFI and ROREC were $102,375 and 6.03%, respectively (Table 6). (Rate of return on assets for the farm with 250 cows and unrestricted scenario of N loss were maximized at 223 ha equal to 6.11%.) Comparison of herd size with optimal hectares resulted in a herd intensity coefficient of 2.22 AU/ha. The larger farm, however, also required herd size reductions at 4.5 AU/ha to meet the constraints on manure spreading. Higher initial results relative to the smaller farm accrued predominantly because of the more profitable livestock enterprises per AU. The higher milk production and milk price received for that production resulted in over a $250 increase in milk income per cow on the larger farm.

Comparison of initial hectares for the unrestricted scenarios across farms depicts changes in relative profitability from the associated differences in farm characteristics, including milk production and prices received. By definition of the methodology, representative farms were developed based upon the operating and financial characteristics in the CNY region. By that definition, different operating characteristics and financial conditions are specified. Our research concentrates its efforts and conclusions on the relative changes in profitability under the restrictions on N loss and variable AU densities.

Selection of the TMR for both farms was dominated by the TMR based on the corn silage forage. Corn silage proved to be a relatively inexpensive forage source relative to other TMR components and initially resulted in 71% of the forage base for dairy cows on both farms; the remainder was alfalfa (DM). These percentages are a weighted mean of the silage TMR (75% corn silage, 25% alfalfa) for lactating cows and of the corn silage TMR (50% corn silage, 50% alfalfa) for dry cows. As herd intensity increased, more alfalfa was included in the TMR and approached 40% corn silage, 55% alfalfa, and 5% orchardgrass (DM) for both farms. Replacements were always fed the corn silage TMR, consisting of 50% corn silage and 50% alfalfa forages (DM). Corn silage hectares were maximized at all cropland levels; at higher hectares, corn silage production was maximized in order to supply forage requirements; additional corn ground was planted to grain. However, when cropland approached the minimum hectares evaluated, maximum corn silage production could not fully supply TMR forage requirements. Therefore, even though corn silage hectares were maximized, alfalfa grown and purchased increased relatively more and increased the overall alfalfa forage in the TMR. At lower hectares, orchardgrass was grown to meet manure disposal constraints because orchardgrass allowed higher application rates of manure than alfalfa. Higher herd intensities resulted in more manure disposal per cropland hectare; therefore, application rates of manure were higher. Because alfalfa was relatively more profitable to feed than orchardgrass, orchardgrass was predominantly grown and sold; additional alfalfa was purchased and incorporated into the livestock TMR. With no restrictions on N loss, corn crops were maximized on both farms at all tillable hectares; corn grain increased as hectares increased, because corn silage production met feeding requirements. Overall, haycrop production was dominated by alfalfa on both farms; orchardgrass entered the crop mix at minimum hectares because of its higher allowable manure application rates. In addition, at maximum hectares, orchardgrass was slowly reintroduced into the rotation because of its lower labor requirements per hectare, representing approximately 9 and 4% of cropland hectares on the farms with 60 and 250 cows, respectively. Table 4 displays haycrop and corn crop percentages and weighted mean percentages for forage feeding for the unrestricted N loss scenario.

Manure application rates for the unrestricted scenario were similar for both farms and were maximized for lower hectares to meet the spreading constraints on both farms. As cropland increased, mean application rates on all hectares decreased from approximately 50.4 to 11.2 tonnes/ha. Initial means for manure application rates were 26.0 and 20.8 tonnes/ha on the farms with 60 and 250 cows, respectively. The higher initial application rate on the larger farm is justified by its higher initial herd intensity and manure production per AU. Unrestricted N losses over all hectares ranged from 50.0 to 25.3 kg/ha on the farm with 60 cows and from 44.0 to 23.2 kg/ha on the farm with 250 cows. Nitrogen losses on initial hectares were 31.6 and 32.4 kg/ha on the farms with 60 and 250 cows, respectively. Losses were greater for the larger farm because of the higher initial herd intensity. However, loss differed only slightly because of lower losses per hectare on the larger farm for equivalent rates of manure application. For equivalent herd intensities, the larger farm displayed lower N losses per hectare because of more efficient nutrient conservation with the 6-mo manure storage structure and more timely spreading with respect to plant nutrient uptake.

Results of Restricted N Loss

Reductions in profitability were substantial on both representative farms when restrictions on N loss were imposed. As restrictions intensified, optimal hectares increased as profitability declined. Changes from the unrestricted results were similar on both farms; however, relative impacts of decision changes on profitability and farm production were larger for the smaller farm. Tables 5 and 6 display results on profitability and N loss for all restriction scenarios on both representative

TABLE 4. Representative farm crop and feeding percentages for unrestricted N losses.

	Field crop selection[1]				Dairy cow TMR forages[2]		
Farm	Alfalfa	OG	CG	CS	CS	Alfalfa	OG
	(%)						
60 Cows							
24 ha	0	50	0	50	43	53	4
32 ha	20	30	0	50	47	50	3
43 ha	50	0	0	50	67	33	0
75 ha	50	0	20	30	71	29	0
107 ha	44	6	30	20	71	29	0
122 ha	42	8	32	18	71	29	0
140 ha	41	9	34	16	71	29	0
250 Cows							
111 ha	50	0	0	50	38	58	4
182 ha	50	0	0	50	56	42	2
223 ha	50	0	2	48	71	29	0
273 ha	50	0	11	39	71	29	0
344 ha	50	0	19	31	71	29	0
385 ha	50	0	22	28	71	29	0
465 ha	50	0	27	23	71	29	0
648 ha	46	4	33	17	71	29	0

[1]Crop percentages represent the percent of total crop hectares. OG = Orchardgrass, CG = corn grain, and CS = corn silage.

[2]Forage feeding proportions on a DM basis.

farms, including the marginal effects of reducing N losses with corresponding reductions in NFI.

At the restriction on N loss of 33.6 kg/ha, optimal hectares remained the same on both farms, 75 ha (1.43 AU/ha) on the farm with 60 cows and 223 ha (2.22 AU/ha) on the farm with 250 cows. Mean N losses per hectare were either near or below restriction levels for both farms, causing minimal adjustments to production and profitability. As more severe restrictions were imposed, optimal hectares increased on both farms, but significantly more on the smaller farm. Optimal hectares for the restriction on N loss of 28.0 kg/ha were 107 ha (1.01 AU/ha) and 273 ha (1.83 AU/ha) for the farms with 60 and 250 cows, respectively. When the restriction on N loss was 22.4 kg/ha, optimal hectares increased to 140 ha (.77 AU/ha) and 385 ha (1.29 AU/ha), respectively. However, returns were not maximized on the smaller farm over the tillable hectares evaluated. Returns (2.05% ROREC) were not maximized until 204 ha or .52 AU/ha. From unrestricted to the restricted N loss of 22.4 kg/ha, optimal AU/ha decreased over 64% on the smaller farm and 42% on the larger farm. Changes in relative size and incidence of AU

TABLE 5. Profitability results and marginal effects for alternative restrictions on N loss for a farm with 60 cows.

	Cows	NFI[1]	ROREC[2]	N Loss[3]	NFI Change[4]
Unrestricted	(no.)	($)	(%)	(kg/ha)	($)
24 ha	47	26,577	–.97	50.03	NA[5]
32 ha	60	34,682	1.32	48.19	NA
43 ha	60	38,079	2.28	40.85	NA
75 ha	60	39,921	2.80	31.58	NA
107 ha	60	39,588	2.71	27.56	NA
122 ha	60	39,368	2.65	26.41	NA
140 ha	60	39,086	2.57	25.29	NA
Restriction of 33.6 kg/ha				Change[4]	
24 ha	30	12,823	–4.86	–16.43	–13,754
32 ha	43	22,580	–2.10	–14.59	–12,102
43 ha	53	31,209	.34	–7.25	–6870
75 ha	60	39,921	2.80	NA	NA
107 ha	60	39,588	2.71	NA	NA
122 ha	60	39,368	2.65	NA	NA
140 ha	60	39,086	2.57	NA	NA
Restriction of 28.0 kg/ha					
24 ha	23	5975	–6.79	–22.03	–20,602
32 ha	30	13,453	–4.68	–20.19	–21,229
43 ha	39	22,798	–2.04	–12.85	–15,281
75 ha	60	38,635	2.44	–3.58	–1286
107 ha	60	39,588	2.71	NA	NA
122 ha	60	39,368	2.65	NA	NA
140 ha	60	39,086	2.57	NA	NA
Restriction of 22.4 kg/ha					
24 ha	15	–1330	–8.86	–27.63	–27,907
32 ha	20	3711	–7.43	–25.79	–30,971
43 ha	26	10,013	–5.65	–18.45	–28,066
75 ha	45	24,980	–1.42	–9.18	–14,941
107 ha	60	32,031	.57	–5.16	–7557
122 ha	60	33,468	.98	–4.01	–5900
140 ha	60	35,196	1.47	–2.89	–3890

[1]NFI = Net farm income.

[2]ROREC = Rate of return to equity capital.

[3]N Loss = Mean N loss per hectare.

[4]Changes from unrestricted results.

[5]Not applicable.

intensity increased adverse impacts on profitability.

As the restrictions on N loss intensified, the maximum NFI and ROREC decreased. Maximum ROREC on the smaller farm were 2.80, 2.71, and 1.47% for the 33.6, 28.0, and 22.4 kg/ha restrictions on N loss, respectively. Profitability did not decrease with the restriction of 33.6 kg/ha of N loss because unrestricted N losses were below the restriction applied. Similarly, maximum ROREC for the larger farm were 6.00, 5.13, and 3.22% over all restriction scenarios. Maximized RORA occurred at the same hectare levels as those for ROREC on both representative farms. Maximized RORA were 3.76, 3.63, and 2.82% for the three restriction scenarios on the farm with 60 cows, respectively, and were 6.09, 5.57, and 4.42% on the farm with 250 cows, respectively. Restrictions on N loss reduced income

TABLE 6. Profitability results and marginal effects for alternative restrictions on N loss for a farm with 250 cows.

Hectares	Cows	NFI[1]	ROREC[2]	N Loss[3]	NFI Change[4]
Unrestricted	(no.)	($)	(%)	(kg/ha)	($)
111 ha	197	68,040	2.86	44.04	NA[5]
182 ha	250	100,829	5.86	37.46	NA
223 ha	250	102,375	6.03	34.64	NA
273 ha	250	98,317	5.59	32.37	NA
344 ha	250	91,917	4.88	29.49	NA
385 ha	250	97,345	4.38	28.20	NA
465 ha	250	77,821	3.33	26.11	NA
648 ha	250	56,336	.97	23.25	NA
Restriction of 33.6 kg/ha				Change[4]	
111 ha	161	50,313	.31	−10.44	−17,727
182 ha	250	95,689	5.30	−3.86	−5140
223 ha	250	102,375	6.00	−1.04	−322
273 ha	250	98,317	5.59	NA	NA
344 ha	250	91,917	4.88	NA	NA
385 ha	250	97,345	4.38	NA	NA
465 ha	250	77,821	3.33	NA	NA
648 ha	250	56,336	.97	NA	NA
Restriction of 28.0 kg/ha					
111 ha	125	35,908	−1.27	−16.04	−32,132
182 ha	204	66,279	2.06	−9.46	−34,550
223 ha	249	90,498	4.73	−6.64	−11,877
273 ha	250	94,129	5.13	−4.37	−4188
344 ha	250	90,792	4.76	−1.49	−1125
385 ha	250	87,228	4.37	−.20	−117
465 ha	250	77,821	3.33	NA	NA
648 ha	250	56,336	.97	NA	NA
Restriction of 22.4 kg/ha					
111 ha	83	11,384	−3.97	−21.64	−56,656
182 ha	135	26,116	−2.35	−16.06	−74,713
223 ha	165	33,692	−1.52	−12.24	−68,683
273 ha	203	47,485	0	−9.97	−50,832
344 ha	250	70,952	2.58	−7.09	−20,965
385 ha	250	76,775	3.22	−5.80	−10,570
648 ha	250	55,083	.83	−.85	−1253
465 ha	250	72,141	2.71	−3.71	−5680

[1]NFI = Net farm income.

[2]ROREC = Rate of return to equity capital.

[3]N Loss = Mean N loss per hectare.

[4]Changes from unrestricted results.

[5]Not applicable.

even more for higher herd intensities. As restrictions on N loss intensified, magnitude and incidence of cow reductions increased. Under the restrictive scenarios, not only did the entire manure source need to be spread on the existing land base, but maximum N losses also needed to be limited to the restriction imposed. Tables 5 and 6 display cow numbers for all hectares and restrictions evaluated. The larger magnitude and earlier incidence of herd size reductions were reflected in further decreases in NFI.

When initial hectares were maintained, NFI decreased by nearly $15,000 for the farm with 60 cows and >$50,000 for the farm with 250 cows from the unrestricted to the most restrictive constraint on N loss. The ROREC dropped >150% on the smaller farm and 100% on the larger farm for their respective decreases in N loss of 9.18 and 9.97 kg/ha. When hectares were lower, profitability decreased. When farms were allowed to increase hectares under N loss restrictions, profitability decreases were smaller but remained substantial. With hectare adjustments, ROREC decreased >47% on the smaller farm and 42% on the larger farm from the unrestricted to most restrictive constraint on N loss. For the unrestricted scenario, optimal AU per hectare were 55% higher on the farm with 250 cows than on the farm with 60 cows. As restrictions were intensified, the gap between those levels widened. At the restriction on N loss of 22.4 kg/ha optimal AU per hectare for the larger farm were nearly 150% above that for the farm with 60 cows. Because N losses per hectare for the same manure application rate were higher on the smaller farm, herd size was reduced at lower herd intensities and led to relatively larger decreases in profitability.

Cropping pattern adjustments occurred as restrictions on N loss were imposed on the representative farms. Adjustments were similar on both farms; however, relative adjustments were larger on the smaller farm because equivalent decisions about cropping and manure application resulted in larger N losses per hectare. For any given cropland level, hectares of corn decreased or remained the same, depending on the restriction on N loss. Because of its higher N losses per hectare than the haycrops, corn represented a lower proportion of total cropland as the restrictions were imposed. The predominant increase in haycrops was alfalfa. As restrictions on N loss intensified, larger proportions of total cropland were planted to haycrops and accounted for 78 and 68% of the total cropland as herd intensities increased on the farms with 60 and 250 cows, respectively.

Selection of TMR under restrictions on N loss showed little change on both representative farms. Replacements continued to be fed the corn silage TMR consisting of 50% corn silage and 50% alfalfa forages (DM). Dairy cows on the farm with 60 cows were consistently fed the corn silage TMR over all hectares, representing 71 and 29% corn silage and alfalfa forages (DM), respectively. Dairy cows on the farm with 250 cows were also fed the corn silage TMR over all hectares, except for the two lowest hectares, on which forage approached 53, 45, and 2% for corn silage, alfalfa, and orchardgrass forages (DM), respectively. Maximum corn silage percentages were inadequate for an entire corn silage TMR; as restrictions on N loss intensified, a shift away from corn silage was exhibited. Further reductions in corn grain plantings also occurred under the restrictive scenarios of N loss.

Overall, mean rates of manure application on the representative farms decreased as restrictions on N loss were imposed to match crop fertilization requirements more closely. However, the magnitudes of change were lower on the farm with 250 cows because higher manure application rates could still meet the constraints on N loss. At initial cropland levels, both farms decreased mean rates of manure application over 5.5 tonnes/ha, even though the larger farm operated at a higher herd intensity. Manure application to haycrops provided a beneficial location for disposal of manure when herd intensity increased. As herd intensity decreased or restrictions on N loss intensified, rates of manure application decreased to 11 tonnes/ha; however, decreases were more gradual on the larger farm.

CONCLUSIONS

Evaluation of whole farm systems, incorporating forage systems and nutrient management analysis, identified different optimal dairy herd intensities, in terms of AU per hectare, for the small and moderately sized dairy farms. Both farms were substantially affected by the imposition of restrictions on N loss, but herd intensity remained higher on the larger farm, and profitability was higher. As restrictions on N loss were imposed and intensified, both farms exhibited lower levels of optimal AU per hectare density, but the smaller farm decreased significantly more.

Higher milk production and lower fixed costs per AU on the larger farm resulted in higher returns per cow. These factors transferred further into higher initial levels of profitability and aided in maintaining profitability as restrictions on N loss were imposed. Although crop yield levels differed slightly, crop selection was quite similar between the two farms. Lower crop yields and higher herd intensity on the larger farm contributed to lower requirements per hectare for purchased fertilizer and helped to maintain higher net returns relative to the smaller farm. Furthermore, manure storage on the larger farm allowed for better conservation of manure nutrients. More appropriate spreading intervals provided more efficient utilization of manure nutrients by the crops, resulting in increased returns. For equivalent levels of manure applications, individual hectare losses were lower on the farm with 250 cows. The lower N losses per hectare with the higher realized net receipts per cow permitted the larger farm to achieve higher ROREC and to incur diminished adverse impacts on profitability when restrictions on N loss intensified. Incorporation of differences across two farm sizes in crop and livestock production activities, manure handling systems, and financial condition allow for a comparison of the relative profitability impacts under a representative farm framework for smaller and larger farms in the CNY region.

Although cropping distribution and selection of TMR were similar on both farms, adjustments relative to the unrestricted results were greater on the smaller farm. Incorporation of haycrops into the rotation was increased as herd intensities or restrictions on N loss increased. These changes in crop selection accordingly increased the proportion of alfalfa in the TMR for both representative farms. Overall, mean rates of manure application decreased as cropland increased or as restrictions on N loss intensified. The less efficient manure handling system on the smaller farm, in terms of nutrient conservation for plant uptake, was evidenced by larger reductions in the rate of manure application as restrictions on N loss were imposed. Manure storage on the farm with 250 cows increased available nutrients per tonne of manure, decreasing the need for purchased commercial fertilizers per hectare.

Restrictions on N loss reduced mean losses of N per hectare and had a substantial impact on production decisions and dairy farm profitability. As herd intensity increased (i.e., cropland hectares decreased), restrictions on N loss caused significantly reduced profitability. Based on the substantial reductions in NFI, the need for dairy farms to adjust cropland levels under the imposition of restrictions on N loss was evident. Whether dairy farmers are allowed, or are able, to make adjustments in cropland levels may well determine future sustainability and survival of the farming operations. If additional cropland is not available or acquisition is not feasible, reductions in herd size may be necessary to meet restrictions on N loss, dropping profitability even further. Policy makers need to consider these problems when developing preventive regulations on nutrient loading. Reductions in NFI not only affect farm survival, but also rural communities and agribusiness sectors. The crucial balance is between manageable environmental regulations affecting US dairy farm operations and the ability of those farmers to make the transitions and adjustments necessary to maintain profitability and to obtain a reasonable return on their investment.

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