Title of the paper

An Integrated Precision Production and Environmental Management Analysis of a Kentucky Dairy Farm

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Summary
This study compares and contrasts the profitability of different dairy management practices through precision livestock farming. Feed analysis and crop yields were simulated. The proposed alternative feeding program demonstrated less manure and nutrient excretions. When mathematical programming model was employed, uniform rate application manifested the highest selected economic values.

Key words: Management practices, environmental pollution, nutrients, profitability, linear programming.

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Abstract

Dairy farms face the challenge of making decisions that are economically and environmentally sustainable. Manure and nutrient management under precision agriculture technologies offer the opportunity to improve the profitability and environmental risk management of dairy operations. A mathematical programming model developed incorporated biophysical simulation data from the Integrated Farm Management System (IFMS) in jointly addressing these concerns. The Cornell Net Carbohydrate and Protein System (CNCPS) version 5.0 was used for nutrient analysis, manure excretion estimation and to develop alternative model that used more own farm feeds and less purchased feeds. The results indicated that this alternative scenario provided less nitrogen (N) and phosphorus (P) loading and less manure excretion. Under three management practices examined, the uniform rate application of nutrients and irrigation performed the best followed by variable rate nutrients. The variable rate application of manure, nutrients and irrigation indicated to have the lowest economic values. The model results showed that optimizing the feeding strategy has the potential to decrease nutrient loading on farm, which demonstrates that environmental protection can be addressed simultaneously with profitability on an operating dairy farm. The optimization model is a useful tool in identifying environmentally and economically feasible solutions when designing a whole farm nutrient management plan.

Key words: Management practices, environmental pollution, nutrients, profitability, linear programming.

Introduction

While milk prices have remained stable or declined for many years, the costs of most production inputs have continued to increase (Rotz, Satter, Mertens and Muck). As a result of high-profile human health and environmental problems, there has been increasing emphasis placed on the role of dairy farms. Some regulatory initiatives and heightened public scrutiny come at a time when much of the dairy sector is losing money due to competition, reduced federal program support, unfavorable weather, and low milk prices. When dairy productivity is reduced, maintenance of a stable dairy farm economy is seriously threatened.

Due to its impact on water quality, phosphorus (P) has been identified as a major pollutant of concern in the US. Nitrogen (N) also can be a threat to air and water quality when large quantities per acre are applied than can be taken up by crops. Large amounts of N and P are normally imported to the farm as feed supplements and fertilizers. These nutrients, if directly discharged into surface water in runoff or deposited in water from aerial emissions, can cause significant water pollution. Some dairy farms, for example, depend heavily on the use of commercial fertilizer and the import of supplemental feeds in order to increase milk yield. While their use may have increased crop yields and milk production, and ultimately improved profitability of the dairy industry, there is a greater risk of buildup of nutrients in the soil and the loss of excess P and N to ground and surface water due to heavy imports of nutrients. To a dairy farmer, the risk of lost production with the perceived risk of underfeeding N and P has carried a greater weight than the less obvious environmental costs. Manure is an excellent fertilizer for grain and forage production and if applied at rates equivalent to crop needs, can minimize environmental impact. If manure is applied at higher rates, however, N can leach into ground water and P can build up in the soil and contaminate the surface water, harming the environment.

Given these potential adversaries in the face of a failing dairy economy, tools are needed to analyze and manage dairy farm resources to maintain profitability while protecting the environment and the health of humans and animals. Integrated precision production and environmental management practices may be used to analyze the alternative ways of reducing environmental pollution and provide a way to structure and incorporate information necessary for appropriate management decisions. More efficient use of own farm feeds and good crop planning can potentially reduce the environmental damage due to P and N. Dairy farms generally require large amounts of high quality and digestible forage to provide the effective nutrients such as fiber, energy, and protein for production, growth, and maintenance.

Efficient production of crops and forages strengthens the economic position of a farm and limits the potential negative impact on the environment. For long term profitability, consideration of crops to be grown, production costs, combination of feeds produced, and animal performance in the overall production systems is crucial. Management changes in crop production and feeding may help reduce the accumulation of excess P and N, while maintaining or improving farm profitability. Therefore, cattle feeding and crop programs may help dairy farmers manage their farms in a cost effective and environmentally acceptable manner that will comply with farming regulations. While some studies have been done to integrate crop and cattle production for optimum nutrient utilization, well documented comparisons of profitability of dairy farm with regard to different management practices are lacking.

Objectives

The primary purpose of this research is to examine the potential of variable rate application of manure, irrigation, and nutrients coupled with alternative feeding strategies to manage environmental risk of whole farm nutrient balance levels while considering profitability. This paper examines some of the environmental, economic, and management issues dairy farmers must address to utilize nutrients in manure and fertilizer efficiently to increase profitability, while reducing nutrient losses to the environment. Specific objectives are to 1) develop a whole farm economic optimization model of an integrated production and management system with the possibility of precision agriculture technology, 2) compare alternative practices (variable versus uniform rates of manure and major macronutrients) with respect to expected net returns and environmental loadings of major macronutrients, and 3) improved formulation to more closely match herd requirements with more homegrown feeds from the cropping enterprise, thereby reducing imported nutrients.

Background

The livestock industry accounts for half of all sales in U.S. agriculture (ERS), yet many agricultural management practices are perceived to result in unnecessary risks to animal and human health and environmental pollution. Nitrogen is a part of amino acids that forms proteins required by all animals. When proteins are consumed by animals, various forms of N are excreted. Phosphorus is a mineral nutrient required for bone growth and many other important functions. If these nutrients are directly discharged into surface water in runoff or N deposited in water from aerial emissions in large quantities, can cause significant water pollution. Decreasing N and P excreted by cattle can minimize environmental pollution while reducing fertilizer and feed imports, hence reducing costs.

Over the last two decades, livestock industry has experienced intensification and expansion of dairy farms that have increased surpluses of P and N due to heavy inputs in feed and fertilizer (Haygarth, Chapman, Jarvis and Smith). Precision feeding and whole-farm nutrient planning have not been adopted on a widespread basis because most dairy farms put emphasis on maximizing animal production and profits rather than on minimizing excretion of nutrients. Overfeeding of both N and P increases excretion and feed costs as well. For example, surveys conducted in the US indicate that producers typically formulate dairy diets to contain, dry basis, 0.45 to 0.50% P which is approximately 20 to 25% in excess of the National Research Council (NRC) suggested requirement (NRC). Phosphorus consumed in excess of cattle requirements is excreted in the feces, with only a small amount excreted in the urine. Livestock excretes 60 to 80% of P consumed (Knowlton, Radcliffe, Novak and Emmerson), an indication that a higher portion of P brought on to the farm in feed stays on the farm instead of being exported in meat or milk. A study by Klausner showed that on the typical dairy farm, N imported in feed, fertilizer, and N fixation in legumes is more than that exported in milk or meat by 62 to 79%, of which 62 to 87% of the excess N comes from imported feed. Approximately, 70% of the excess N escapes into the off-farm environment through volatilization and leaching into groundwater (Hutson et al.).

Studies have shown that implementing own farm feed plans that integrate nutrient management across herd, crop, soil, and manure components can decrease nutrient concentrations on dairy farms while increasing profitability (Rotz, Satter, Mertens and Muck; Wang et al.). Tylutki and Fox used CuNMPS model to integrate cattle and crop production on a dairy farm and found that profitability improved with environmental benefits of reducing erosion and P contamination of water bodies. There are other researchers who used linear programming (LP) model to find the best possible profitable combination of crops and herd type and size. Westphal, Lanyon and Partenheimer, and Henry et al. used an LP to study the relationship of plant nutrient management strategies to optimal herd size and net farm return. Nicholson, Lee, Boisvert and Black used an LP model to compare nutritional management strategies for dual-purpose herds in Latin America. Other studies have compared the economics of grazing-based dairy feeding systems to that of confined dairy operations. For example, Hanson et al. and Dartt et al. did surveys of dairy operations utilizing grazing as a forage source and Tucker, Rude and Wittayakun did a case study analyzing cows fed on pasture or in confinement. Each of these types of studies contributed meaningful information towards analyzing the production of forages, cattle, and profitability of farms.

The amounts of nutrients, especially P and N, can be reduced without adverse effects on animals. Lower amounts of P and N in many diets can be met by removing mineral P added to supplemental feed. The reduction of added mineral can reduce the annual feed cost and thus improve farm profit. Changes in cropping strategies may also affect P and N balance if the crop change greatly affects the import of supplemental feed or fertilizer. Better utilization of crops such as grass and forage may provide some reduction in the excess P on a farm.

Management changes can be made to reduce the P and N balances on dairy farms. Crop choices, driven by soil types, have a great impact on cost of producing forage and increasing quality and yield. 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 and N while maintaining or improving farm profit. Most importantly is to protect drinking water quality through the prevention of non-point source pollution. In all, nutrient accumulation and the potential for nutrients to enter the environment are influenced by the feeding program, herd productivity, and proportion of own farm feeds.

Comprehensive analyses are needed to evaluate the environment and economic impacts of various management practices that can be used for profit maximization of a dairy farm. These can be achieved through several ways, for example, decreasing nutrients brought on the farm by formulating rations based on farm specific animal requirements and feed contents, and improving the efficiency of nutrient utilization through improved feed and crop management strategies that aim to increase nutrient recycling within the farm boundary.

Data and Methodology

The decision-making environment of a hypothetical Kentucky dairy farm intended to be representative is modeled using a mathematical programming framework. The farm owns 300 head of Holstein cattle as described in table 1 and produces 3 feed crops for own farm use: alfalfa hay, alfalfa silage, and corn silage. The rest of the feeds are purchased.

Herd feeding scenarios

Two management feeding scenarios were analyzed and compared:

1) The feeding management practice (table 2) as the base line is used to calculate the base feed requirements and mass nutrient balance (N and P). The dry matter intake (DMI) was estimated for each animal in each group.
2) In this alternative scenario, the same feeds are used but DMI for each animal in each group is determined using feed requirements predicted by the CNCPS simulated in 1 above. Crop yields, forage quality, and crop acreages are the same as in the base line scenario. The intake of the purchased feeds for the herd is decreased and that of own produced farm feeds is increased to above 65% of the feed requirements (table 3).

Table 1. Herd description

Group	Number of head	Age (months)	Days preg.	Days in milk	Lact. number	Milk (lb day^{-1})	Fat %	Protein %	Ave. weight (lb)	Body condition score
Hutch calves*	14	1							121	
Transition heifers*	21	4							200	
Open heifers#	52	11							794	
Bred heifers	34	22	172						1003	
Dry cows	33	45	253		2				1411	
Fresh cows	31	50	70	62	2	76.7	4.5	3.0	1301	2.5
Ist-calf heifer	30	36	150	182	1	71.7	3.5	3.2	1257	3.0
High cows	70	60	123	183	3	83.1	3.5	3.0	1499	2.9
Low cows	14	60	157	332	2	50.7	4.2	3.3	1609	3.6
Average/ total	300	37				70.5	3.9	3.13		

*Hutch calves and transition heifers are less than 6 months old and are not include in the analysis because they are fed a complete purchased ration.
#Open heifers are older calves but have not yet conceived

Table 2. Rations fed as base feeding scenario (lbs/animal/day dry matter)

Ingredient	Open heifers	Bred heifers	Dry cows	Fresh cows	1st calf heifers	High cows	Low cows
Corn silage		0.8	6.5	19.9	20.0	20.4	13.7
Alfalfa hay						3.0	
Alfalfa silage		0.9		17.6	18.7	18.7	15.4
Maize meal			1.1	6.6	7.7	6.6	4.0
Gluten feed	4.0	2.7		6.6	8.8	12.1	8.8
Cotton seed				0.7	2.2	3.3	
Protein mix			1.3	8.8	7.7	9.3	4.4
Canola meal		0.1	3.3	5.5	2.2		
Minerals	0.3	0.3	0.3		0.2		0.4
Average/total	4.3	4.8	12.5	65.7	67.5	73.4	46.7

The Cornell Net Carbohydrate and Protein System (CNCPS) version 5.0 was used to predict nutrient requirements, nutrient balances, manure excretion, P and N excretion for the herd and to develop alternatives. The analysis did not include the hutch and transition heifers, since they are fed a complete calf feed. The following assumptions are made: (i) the herd is in a steady-state condition (neither expanding nor reducing herd numbers), (ii) the rations being fed are representative of the whole year, (iii) there will be no loss of silage and hay during storage, processing, and feeding, and (iv) the farm will carry no feed inventory (purchased and own farm feeds) on the next calendar year, and all surplus feeds are sold.

Table 3. Rations fed as alternative feeding scenario (lbs/animal/day dry matter)

Ingredient	Open heifers	Bred heifers	Dry cows	Fresh cows	1st calf heifers	High cows	Low cows
Corn silage		2.0	6.5	16.0	14.0	16.0	15.0
Alfalfa hay		1.0		4.0	3.0	5.0	5.7
Alfalfa silage		2.0		14.4	14.3	17.2	16.0
Maize meal			1.1	2.0	3.0	2.0	4.0
Gluten feed	4.0	2.7		2.0	5.0	5.0	8.1
Cotton seed				0.7	1.0	1.0	
Protein mix			1.3	4.0	4.0	4.0	3.2
Canola meal		0.1	3.3	2.0	1.0		
Minerals	0.3	0.3	0.3		0.2		0.4
Average/total	4.3	8.1	12.5	45.1	45.5	50.2	52.4

Own feed crop production

Corn silage crop was under two management practices:

1) Variable rate irrigation (low, medium, and high) under two soil types (deep clay loam and shallow loam) in the simulation model was used. Variable rate N, P, and K was applied as follows: N (125 lbs, 160 lbs, and 180 lbs), P (40 lbs, 60 lbs, and 80 lbs), and K (30 lbs, 58 lbs, and 65 lbs).
2) Variable rate irrigation (medium and high) as well as no irrigation under two soil types (deep clay loam and shallow loam) was used. Variable rate manure, N, and

P was applied as follows: Manure (low, medium, and high), N (low, medium, and high), and P (low, medium, and high). Manure application rates are based on predicted available nitrogen in the manure excretion.

For alfalfa crop, irrigation was included for two levels (low and high) as well as for no irrigation. The simulation model used two soil types (deep clay loam and shallow loam) and variable rate potash (160 lbs, 200 lbs, 240 lbs, and 260 lbs). Relative Feed Quality (RFQ) of alfalfa was calculated from the neutral detergent fiber (NDF) and total digestible nutrients (TDN) both obtained from simulation results. Relative feed value (RFV) of alfalfa was obtained from the relationship equation of RFQ versus RFV estimated by Undersander and Moore. RFV has been widely used to ranking forage for sale, inventorying and allocating forage lots to animal groups according to their quality needs (Undersander and Moore. It is based on the concept of digestible dry matter (DM) intake relative to standard forage. Price adjustment in relation to RFV levels was calculated and the factor was plugged into the price regression equation developed.

The yield results for corn silage, alfalfa hay and silage were simulated from the Integrated Farm System Model (IFSM) using 25 years of weather data. While agronomic field trials are preferred, such information that allows a series of production strategies under several similar weather data was not available. Land for crop production was limited to 150 acres for each soil type. As IFSM is not equipped with weather data for Kentucky, the nearest state weather data at Roanoke weather location in Virginia State was used.

Data computed by the CNCPS and IFSM are coupled with other physical and economic data in developing the mathematical programming model for profit maximization above selected relevant costs. Decision variables included alfalfa hay, alfalfa silage, and corn silage production under two soil types and management practices (various irrigation and macronutrient application levels), dairy cow production, crop sales, and mean net returns. The labor requirements per month, input prices and input requirements per acre were taken from the University of Tennessee and the Southern Region SARE Training Project. Constraints included limited land, herd size, field labor, and relevant accounting equations. Three profit maximization scenarios were analyzed and compared:

1) Variable rate application of irrigation, fertilizer, and manure.
2) Uniform rate application of irrigation, fertilizer, and manure.
3) Variable rate nutrient application with uniform irrigation.

Results and discussion

The evaluation of the milk production, feeds and excretions are summarized in table 4. The milk production and yield remained the same in both scenarios, however, the CNCPS in the alternative feeding program predicted higher intake of own farm feed (70.4%) and less purchased feeds (29.6%) as against base scenario of 55.9% and 44.1% respectively. This change of feeding program imported less nutrients (N, P, and K) compared with base feeding program (table 5). The CNCPS also predicted less manure production in the alternative scenario than the base scenario (table 5). This model indicated that as more feed is imported by the farm to meet energy and protein requirements, the risk of importing nitrogen, phosphorus, and potassium is much higher. The situation may become worse if manure is not recycled back to the crops. The recycling of manure helps reduce the use of commercial fertilizer in crops, thus reducing costs and mass nutrient balance within the boundaries of the farm.

The simulation yield results obtained from all crops were reasonable estimates compared with the various yields estimated from other research studies. The results of the

Table 4. Evaluation of milk, feed, and excretion

Particular	Base scenario	Alternative scenario
Annual milk production (lbs/yr)	3,731,213	3,731,213
Avg. Milk per lactating cow (lbs/day)	70.5	70.5
% home grown feeds	55.9	70.4
% purchased feeds	44.1	29.6
Predicted total manure	7285	5117
Predicted fecal output	3975	2997
Predicted urine output	3310	2121

Table 5. Nutrient evaluation

	Nitrogen		Phosphorus		Potassium	
Particulars	Base	Alternative	Base	Alternative	Base	Alternative
Av. % purchased	67	52	74	62	25	16
Excreted (lbs/yr)	95,712	71,726	20,499	11,011	53,001	44,473
Urinary (lbs/yr)	44,006	33,489	403	318	42,892	36,955
Fecal (lbs/yr)	51,706	38,237	20,096	10,701	10,110	7,518
Nutrient use efficiency (%)	17	21	16	26	11	10

linear programming model for the selected management practices are presented in table 6. The farm management practice of uniform rate application provided a mean profit above selected variable costs of US$272,161 and a coefficient of variation (CV) of 4.86% compared to variable rate application that provided a mean profit of US$270,717 and a CV of 5.07%. The management practice with the variable rate nutrient application provided an average profit of US$271,490, CV of 4.87%, and the profit maximization level of 100.29. Clearly, the results indicated that the management practice with the uniform rate application was overall superior to others followed by variable rate nutrients. All selected economic indicators performed the best, while the variable rate application had the lowest values. However, the range in differences is small, meaning that there is a chance for any management practice to outperform others with implementation of the best management practice.

Table 6. Economic indicators

Indicators	Variable rate	Uniform rate	Variable rate nutrients
Average profit ($)	270,717	272,161	271,490
Minimum profit ($)	245,492	248,692	248,021
Maximum profit ($)	298,679	299,730	299,058
CV %	5.07	4.86	4.87
% optimum	100	100.53	100.29

According to the analysis in this model, the corn silage crop with variable rate manure application indicated to be non-optimal because no acreage was used. The possible explanation is that up to 50% of the N could be lost to the atmosphere during handling, storage, and land application (Borton et al.). Therefore, there was a great possibility that manure nitrogen was not enough to meet the crop's requirements, resulting possibly to the lower yield compared to other management practices. When recycled and evenly distributed, manure has an added advantage to the farm crops including grass. The recycling of manure back to the farm crops replaced part of the purchased fertilizers. Thus reducing the costs of farm production, and hence improve profitability. If properly recycled with good crop planning, manure is expected to have an environmental benefit of reducing the potential for P and N contamination of water bodies. Increasing own farm feeds had an advantage of reducing imported feeds.

Summary and conclusion

The Own farm feeds have the potential for reducing environmental pollution due to N and P and improve profitability if special attention is given to important best management factors. This means that use of more own farm feeds has a greater probability of earning more profits. However, dairy farmers need to consider which management practice to follow in respect to location, weather condition, and soil types. Soil types and management practices as well as variation in feeding strategy are some of the factors that can affect net farm returns. This study analyzed and compared profitability of dairy management practices under two soil types and variable rates of manure, fertilizer, and irrigation using linear programming model. It also analyzed the environmental effect due to N and P on alternative feeding program. The CNCPSv5 was used for nutrient analysis using the Kentucky hypothetical dairy farm. The yields of alfalfa hay/silage and corn silage were simulated from the IFSM using 25 years of weather data.

The alternative scenario of feeding program, where the own farm feed intake was increased and purchased feeds reduced, had the lower loading of N, P, and K. Also the manure excretion in this scenario was lower than the base program. This indicates that the risk of environmental pollution can be reduced with best changes in feeding program. As more feeds and fertilizers are imported by a farm to meet dairy farm requirements, phosphorus and nitrogen are usually imported in quantities much higher.

The study also employs a mathematical programming model for profit maximization where the uniform rate application performed the best than the other two management practices. In conclusion and in evaluating this study, it became apparent that the herd feeding and crop production plans need to be integrated with each other and to develop farm business records for the most feasible and profitable farm plan. Dairy farmers need to consider important factors such as activity location, weather condition, and soil types. In this regard soil testing before planting is very crucial. The study had some other limitations. While risk management has long been considered to be an important component of the agricultural producer's decision-making environment, this study did not accommodate risk analysis in management decisions. Some risk sources such as fluctuation of yields, price changes, and risks of days unsuitable for fieldwork as a result of weather need to be considered for future research. Soil mapping is another component that needs to be considered for future research. The manure needs to be tested for nutrient availability before application to the crops due to N loss through evaporation and leaching to the ground. The use of more formal risk assessment procedure in farm planning that incorporates all costs, risks, and benefits associated with ration formulation more precisely targeted to the needs of the herd should improve the implementation of the best management practice.

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