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

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Take Home Message

- Manure and nutrient management under precision agriculture technologies may offer opportunities to improve the profitability and environmental risk management of dairy operations.
- Developing strategies that will use more own farm feeds and less purchased feeds may provide less nitrogen and phosphorus loading and less manure excretion while improving farm profitability.
- An optimal whole farm nutrient management plan allows for changes in crop production and feeding that may help reduce the accumulation of excess P and N, while maintaining or improving farm profitability.
- Efficient production of crops and forages strengthens the economic position of a farm and limits the potential negative impact on the environment.

Introduction

While milk prices have remained stable or declined for many years, the costs of most production inputs have continued to increase (Rotz et al., 1999). 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.

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 larger 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 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. 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.

Given these problems, tools are needed to analyze and manage dairy farm resources to maintain profitability while protecting the environment and the health of humans as well as animals. While some studies have been done to integrate crop and cattle production for optimum nutrient utilization, well documented comparisons of profitability of dairy farms with regard to different management practices are lacking. This research examines 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. Specific objectives are to 1) develop a whole farm economic optimization model of an integrated production and management system using 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, yet many agricultural management practices are perceived to result in unnecessary risks to animal and human health and environmental pollution. Over the last two decades, the 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 et al., 1998). 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.

Decreasing N and P excreted by cattle can minimize environmental pollution while reducing fertilizer and feed imports, hence reducing costs. 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, 2001). 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 et al., 2004), 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. Klausner (1993) 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. About 70% of excess N escapes into the off-farm environment through volatilization and leaching into groundwater (Hutson et al., 1998). 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 et al., 1993). Westphal, et al. (1989) used linear programming to study the relationship of plant nutrient management strategies to optimal herd size and net farm return.

The amounts of nutrients, especially P and N, can be reduced without adverse effects on animals. Lower amounts of P 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. Crop choices, driven by soil types, have a great impact on cost of producing forage and increasing quality and yield. Whole farm analyses are needed to evaluate environmental and economic impacts of various management practices. 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 needs examination.

■ Data and Methodology

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

Table 1. Herd description

Group	Number of Head	Age (months)	Days Preg.	Days in milk	Milk (kgs /day$^{-)}$	Ave. weight (kgs)
Hutch calves*	14	1				54.9
Transition heifers*	21	4				90.7
Open heifers#	52	11				360.2
Bred heifers	34	22	172			455.0
Dry cows	33	45	253			640.0
Fresh cows	31	50	70	62	34.8	590.1
1st-calf heifer	30	36	150	182	32.5	570.2
High cows	70	60	123	183	37.7	679.9
Low cows	14	60	157	332	23.0	729.8

***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

Herd Feeding Scenarios

Two management feeding scenarios were analyzed and compared. First, 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. In the second or alternative 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 2). The feed types, crop yields, forage quality and total cropland acreages are the same as in the base line scenario but the crop mix can alter to meet feed requirements.

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

	Open heifers		Bred heifers		Dry cows		Fresh cows	
Ingredient	Base	Alt[1]	Base	Alt[1]	Base	Alt[1]	Base	Alt[1]
Corn silage			0.36	0.91	2.95	2.95	9.03	7.26
Alfalfa hay				0.45				1.81
Alfalfa silage			0.41	0.91			7.98	6.53
Maize meal					0.50	0.50	2.99	0.91
Gluten feed	1.81	1.81	1.23	1.23			2.99	0.91
Cotton seed							0.32	0.32
Protein mix					0.59	0.59	3.99	1.81
Canola meal			0.05	0.05	1.50	1.50	2.50	0.91
Minerals	0.14	0.14	0.14	0.14	0.14	0.14		
Total	1.95	1.95	2.18	3.67	5.67	5.67	29.80	20.46

Table 2 continued.

	1st calf heifers		High cows		Low cows	
Ingredient	Base	Alt[1]	Base	Alt[1]	Base	Alt[1]
Corn silage	9.07	6.35	9.25	7.26	6.21	6.80
Alfalfa hay		1.36	1.36	2.27		2.59
Alfalfa silage	8.48	6.49	8.48	7.80	6.99	7.26
Maize meal	3.49	1.36	2.99	0.91	1.81	1.81
Gluten feed	3.99	2.27	5.49	2.27	3.99	3.67
Cotton seed	1.00	0.45	1.50	0.45		
Protein mix	3.49	1.81	4.22	1.81	2.00	1.45
Canola meal	1.00	0.45				
Minerals	0.09	0.09			0.18	0.18
Total	30.62	20.64	33.29	22.77	21.18	23.77

Alt[1] = Alternative feeding scenario

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) into the next calendar year and all surplus feeds are sold.

Own Feed Crop Production

Corn silage crop was produced under two variable rate irrigation 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 (57 kg, 73 kg and 82 kg), P (18 kg, 27 kg and 36 kg) and K (14 kg, 26 kg and 29 kg). 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. In addition to these two alternatives a uniform rate strategy and a variable rate nutrient strategy with uniform irrigation is examined for both corn silage and alfalfa production.

For the alfalfa crop, variable rate 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 (73 kg, 91 kg, 109 kg and 118 kg). 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 (2002). RFV has been widely used to ranking forage for sale, inventorying and allocating forage lots to animal groups according to their quality needs. 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 61 hectares 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 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 (2004) 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:

- Variable rate application of irrigation, fertilizer and manure.
- Uniform rate application of irrigation, fertilizer and manure.
- Variable rate nutrient application with uniform irrigation.

Results and Discussion

The evaluation of the feeds and excretions are summarized in Figure 1. 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 was associated with less manure production (Figure 2) and fewer imported nutrients (N, P and K) compared with base feeding program (Figure 3). 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.

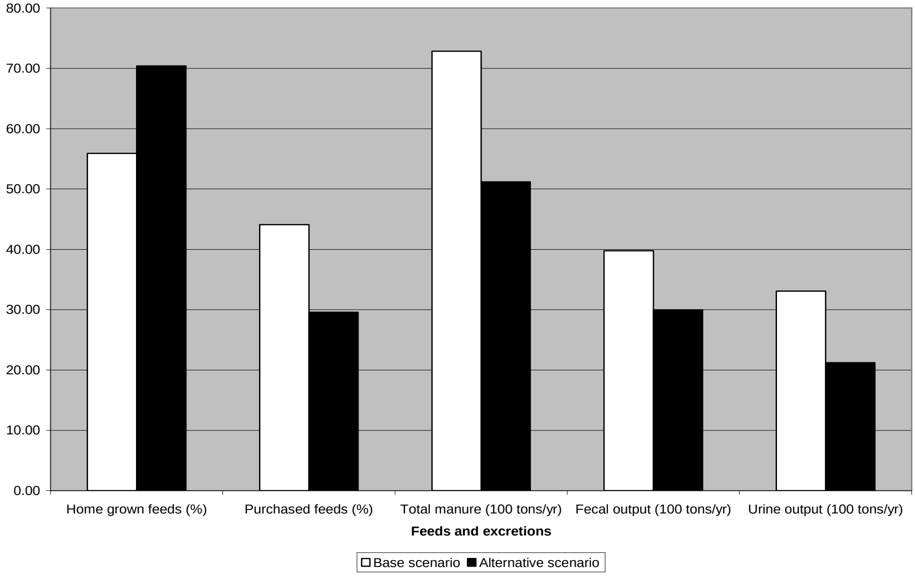

Figure 1. Evaluation of feeds and excretion

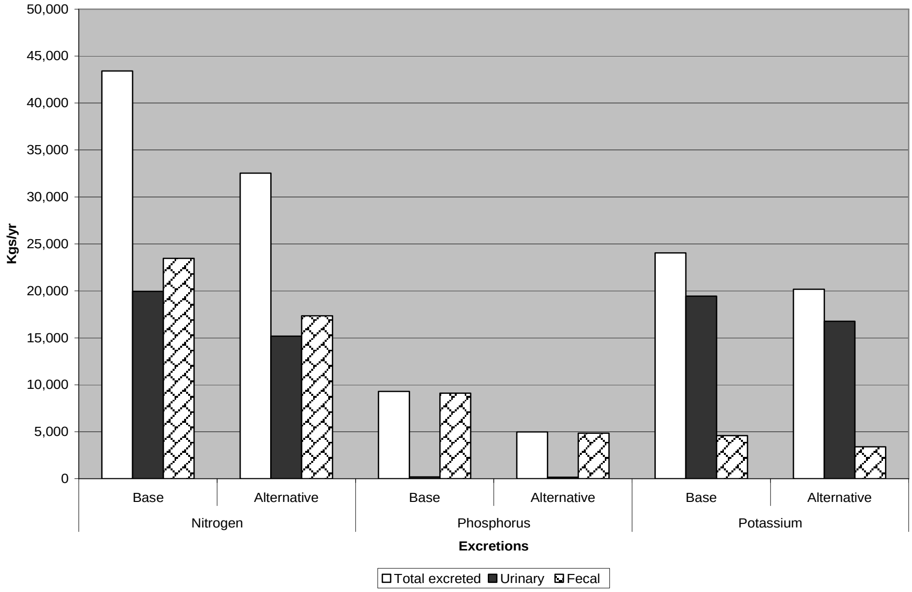

Figure 2. Predicted excretions

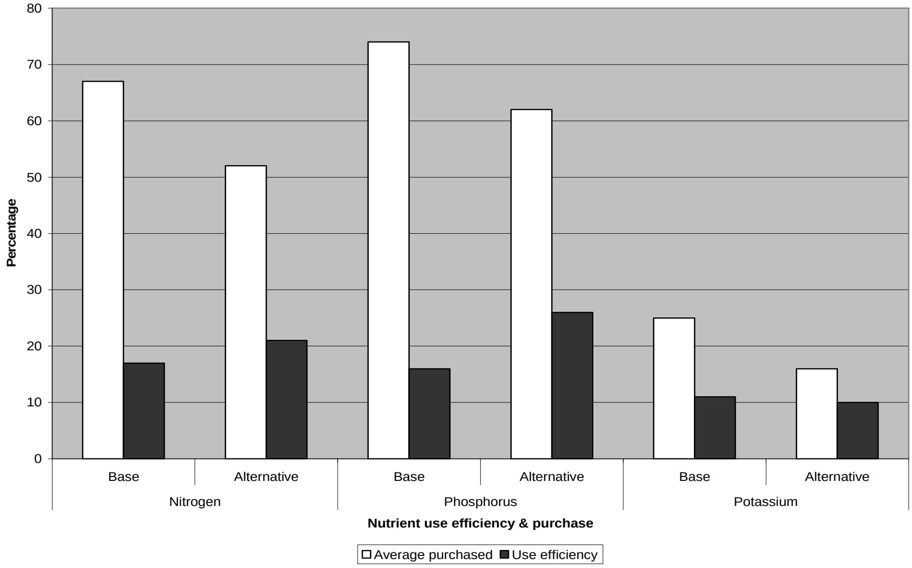

Figure 3. Nutrient use efficiency and purchases

The simulation yield results obtained from all crops were reasonable estimates compared with other studies. The results of the linear programming model for the selected management practices are presented in Figure 4. The uniform rate application of the alternative feeding strategy provided mean net returns above selected variable costs of US$272,161 and a coefficient of variation (CV) of 4.86% as compared to the baseline strategy with mean net returns of US$268,389 and a CV of 5.57%. This indicates that greater use of homegrown feeds was not only more beneficial environmentally but also enjoyed greater profitability and reduced economic risk. The use of variable rate irrigation and nutrient application resulted in mean net returns of US$270,717 and a CV of 5.07% under the alternative, high homegrown feed strategy while coupling variable rate nutrient application with uniform irrigation provided average net returns of US$271,490 and a CV of 4.87%. While uniform rate application was economically superior to others, economic results are quite similar. Consequently, there is a chance for any management practice to outperform others with implementation of the best management practice.

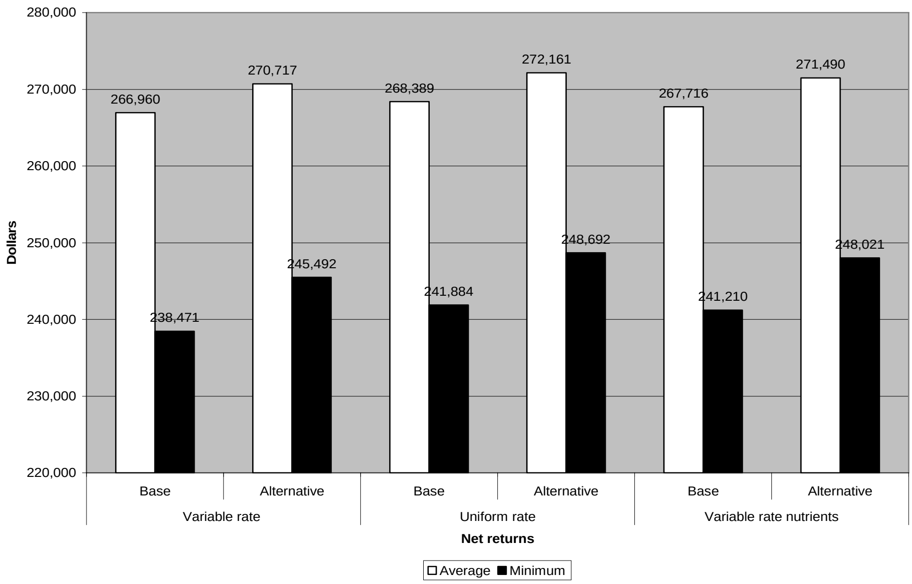

Figure 4. Net return results

According to this study's results, the corn silage crop with variable rate manure application was not produced. 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., 1995). Therefore, there was a great possibility that manure nitrogen was not enough to meet the crop's requirements, possibly explaining the lower yields under manure use versus no manure use. 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. This reduced farm production costs and hence improved 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. Increasing own farm feeds had an advantage of reducing imported feeds (Figure 1).

▪ Summary and Conclusion

Self produced farm feeds have the potential for reducing environmental pollution of N and P and improve profitability if attention is given to important best management factors. Furthermore, use of more own farm feeds has a greater probability of earning profits. However, dairy farmers need to consider which management practice to follow with 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. It also analyzed the environmental effect due to N and P on alternative feeding program. The CNCPS version 5 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, N and P are usually imported in quantities much higher.

The study also employs a whole farm economic model for profit maximization where the uniform rate application performed the best. In conclusion, it became apparent that herd feeding, crop production and nutrient management plans need to be integrated with each other to develop the most profitable farm plan. Dairy farmers need to consider important factors such as activity location, weather condition and soil types. Thus, soil testing before planting is crucial.

This study did not consider risk attitude of the producer directly. 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 reflected in 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 procedures 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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