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ECONOMIC AND ECOLOGIC ASSESSMENT OF GROUNDWATER NITROGEN POLLUTION FROM NORTH FLORIDA DAIRY FARM SYSTEMS: AN INTERDISCIPLINARY APPROACH

by

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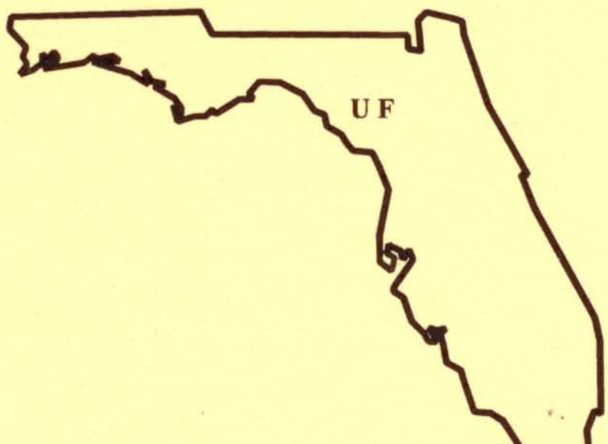

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"Economic and Ecologic Assessment of Groundwater Nitrogen Pollution from North Florida Dairy Farm Systems: an Interdisciplinary Approach"

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Abstract

The presence of nitrogen (N) in water is an environmental hazard because it affects human health and ecosystem welfare. The Suwannee River Basin in Florida has received much attention in recent years due to increased N levels in water bodies. Dairy waste is thought to be an important factor contributing to this water N pollution. Dairy farmers are now required to comply with stricter environmental regulations either under permit or under voluntary incentive-based programs. Dairy farmers are also aware that environmental issues in the near future will be the greatest challenges they will have to face. Evidence indicates that farms may reduce their total N loads by changing some management strategies. Using published and stakeholders' information, a dynamic, empirical, stochastic, interactive, and user-friendly model was created to simulate north Florida dairy farms and use it to test management strategies that may reduce nitrogen pollution and still maintain farm profitability. Testing different crop rotations, crude protein contents, time spent on concrete by milking cows, and time of liquid manure in the storage pond, it was found that intensive crop rotations have the greatest impact on reducing N loss and at the same time improve profitability. It was also found that reducing crude protein may reduce N release and increase profitability. Reduction in time spent on concrete reduces the amount of manure N handled by the system and consequently may reduce the amount of N lost to the environment. Increasing the time liquid manure spends in the storage pond may reduce the risk of N lost to groundwater but increases the amount of N lost to the air, which is not used by the crops and consequently decreasing profitability. A combination of decreasing crude protein content in the rations and efficient crop rotations may considerably increase profitability and decrease N loss to the minimum.

1. Introduction

Dairy farming is an important part of Florida's agricultural industry. The Florida Statistical Service has indicated that milk and cattle sales from dairies contributed $429 million directly into the Floridian economy in the year 2001. Florida is the leading dairy state in the Southeast; it ranks 13th nationally in cash receipts for milk, 15th in milk production and 15th in number of cows (*Bos taurus*). According to the USDA, there were about 152,000 cows on about 220 dairy farms at the end of 2002, and more than 30% of these dairy operations and cows are located in the Suwannee River Basin. These dairies face an increased government regulation due to social pressure because they attract the attention of neighbors and activists concerned with odors, flies and mostly with potential leaching of nutrients that might influence water quality (Giesy et al., 2002).

The presence of nitrogen (N) in surface water bodies and ground water aquifers is recognized as a significant water quality problem in many parts of the world (Fraisse et al., 1996). The Suwannee River Partnership states that over the last 15 years, nitrate levels in the middle Suwannee River basin have been on the increase and these elevated nitrate levels can cause health problems in humans as well as negative impacts on water resources. High nitrate levels in drinking water can cause methemoglobinemia or "blue baby" sickness in infants and other health problems in humans in the form of enlargement of the thyroid gland, increased sperm mortality, and even stomach cancer (Andrew, 1994). In addition to making water unsafe for humans and many other animals, high nitrate concentrations can lower water quality in rivers and springs and elevated concentrations of nitrate in rivers can cause eutrophication that results in algal blooms and depletion of oxygen that affects survival and diversity of aquatic organisms (Katz et al., 1999).

The Suwannee River basin has received much attention in recent years due to increased nitrogen levels in the groundwater-fed rivers of the basin that could seriously affect the welfare of the ecosystem (Albert, 2002). According to Katz (2000), nitrogen levels have increased from 0.1 to 5 mg l^{-1} in many springs in the Suwannee basin over the past 40 years. Pittman et al (1997) found that nitrate concentrations in the Suwannee River itself have increased at the rate of 0.02 mg l^{-1} year^{-1} over the past 20 years and that over a 33 mile river stretch between Dowling Park and Branford, the nitrate loads increased from 2,300 to 6,000 kg day^{-1} while 89% of this appeared to come from the lower two-thirds, where agriculture is the dominant land use.

Soils in this region are generally deep, well-drained sands, and nutrient management is a major concern (Van Horn et al., 1998). Over-applying manure nutrients to these soils is considered to be a major cause of nitrates, converted from manure ammonia sources while in the soil, leaching to groundwater and contributing to surface runoff. One of the most publicized concerns is N losses in the form of nitrate into the groundwater through the deep sandy soils of the Suwannee River basin (Van Horn et al., 1998).

Young stock includes recently born calves to heifers ready for first delivery (0 to 24 months, approximately). When a heifer has her new calf, that heifer enters the productive group as a fresh cow - first lactation, and her calf, depending if it is male or female, is sold or kept. All male calves are sold the day after they are born. Young livestock are usually managed in a different facility outside the main production facility. In the young stock facility, there are calves and heifer groups, according to physiological development. Calves and heifers are moved from group to group in time frames.

Heifers start their breeding program, which consists of heat detection and artificial insemination at approximately one year of age. When a heifer achieves pregnancy, nine months of gestation will follow until this heifer delivers and becomes a fresh - first lactation cow. During young and adult livestock periods, a number of animals will be culled from the herd because of their production performance, age, weight gained, general health, fertility, etc. Culling rates are characteristic of management and vary greatly across dairy farms.

The adult or productive herd develops in approximately yearly cycles. A fresh cow will produce milk for approximately ten or eleven months after delivery (300-330 days as a milking cow) after which she will be dried out for approximately two months (60 days as a dry cow). After the dry period, the cow delivers again and starts her next lactation. This intense productive cycle is possible because a cow that starts her lactation after a delivery is quickly inseminated again and can be pregnant after only a two month period (Voluntary Waiting Period (VWP)). Therefore, most of the milking cows are simultaneously, pregnant cows.

Cycles continue several times depending of the management decisions of the dairy farm. Some farms prefer to keep cows only for three lactations, while others may want to keep them for six, seven or more lactations. After the second and third lactations, milk production performance may decrease. Keeping cows for more lactations saves the cost of replacement, but at the same time has an opportunity cost of giving up higher expected rates of production with new cows entering the herd. During the 300-day milking period cows follow a typical milk productivity curve that increases rapidly at the beginning until reaching a peak. After that peak, production steadily decreases until the dry period.

In general, milking cows are confined (or at least, most of the time) while dry cows and young stock are kept in less intensive production facilities. The same happens with the diet: milking cows receive the highest nutrient-concentrated diet depending of their productivity. These diets are closely related to the nitrogen balance in and out of the farm. Different categories of milking cows are managed in the "intensive" facilities, which are the free stalls, walkways, and the milking parlor.
Florida dairies are required by official agencies to manage their on-farm waste. In north Florida, the most common practice of management of waste disposal is through a flushing – removal of solids – storage – and crop systems. Free stalls and milking parlor (and other adjacent intensive facilities) are implemented with open canals that allow

Rationality in the simulation models follows the logic of budgeting or accounting for the flows of N in the system, as developed by Van Horn (1997), Van Horn et al. (1998), and Van Horn et al. (2001). The simulation model accounts for N inputs (sources), within-system interactions, and outputs (sinks), according to a defined dairy farm system boundary.

Changes in alternative management strategies such as: 1) crude protein included in the diet, 2) time herd spends in confined areas, 3) time of liquid manure in waste storage pond, 4) crops planted, and 5) area planted will be tested in five-year time frames to compare economic and ecological outputs. Information was collected from published sources, personal observations, and stakeholders' communication, of which are documented in the modeling section.

Dynamic Modeling of North Florida Dairy Farm Systems

A dynamic, event-controlled, empirical, stochastic model was created to represent north Florida dairy farm systems and in it the flows of economic and environmental variables are accounted for.

The Dynamic North Florida Diary Model (DNFDM, Figure 1) was intended to be user friendly as an interactive spreadsheet in Excel® software that could be shown to dairy farmers and other stakeholders in a way easy for them to understand. Creation of the DNFDM was suggested by a stakeholder as a way to gain dairy farmers' interest. The DNFDM also intends to be a powerful analyses tool for representing real situations. It runs in monthly steps, using monthly budgets, as opposed to the yearly approach of Van Horn et al. (2001).

The DNFDM has the following modules: feedstock, cattle, milk production, waste management system, and crop system. All these components interact among themselves and have two common variables throughout: nitrogen and money. It runs on a monthly basis for a desired number of years.

The model considers 11 classes of milking cows, from one-month to eleven months of lactation; two classes of dry cows, one and two month dry cows; and 24 classes of young stock: calves and heifers. At every monthly update, cattle classes increase their age by one month. Then, cows of milking group # 1 will become cows of milking group # 2 and three month-old calves will become four month-old calves, etc.

Culling rates apply to any month and the total culling rate for a specific farm is divided among the cattle groups and applied at each update. At any point in time, different cow groups require different diets, produce different milk quantities, require specific dairy facilities, and recycle specific amounts of nitrogen.

adult and young stock that determine the proportion of cattle that leaves the herd (for any reason) in time frames. Culling rates of 42% for the productive herd and 16% for the young stock are acceptable for Florida dairies according to data from the DHI.

				Lbs/day/cow		
group	**Description**		**milk**	**DMI**	**feces**	**urine**
1	milking	open	50	39.38	76.97	48.54
2	milking	open	100	55.92	126.31	66.02
3	milking	open	90	52.61	116.44	62.53
4	milking	open	70	46.00	96.71	55.53
5	milking	pregnant	65	44.34	91.77	53.78
6	milking	pregnant	60	42.69	86.84	52.04
7	milking	pregnant	55	41.04	81.91	50.29
8	milking	pregnant	50	39.38	76.97	48.54
9	milking	pregnant	45	37.73	72.04	46.79
10	milking	pregnant	40	36.07	67.10	45.04
11	milking	pregnant	35	34.42	62.17	43.29
12	dry	pregnant		25.20		
13	dry	pregnant		25.20		
		TOTAL MILK	18,150 lbs per COW/YEAR			

Table 1 Milk production, dry matter intake and manure excreted by cattle groups

On north Florida dairy farms, the most common system used to handle manure is a liquid manure system that encompasses a flushing system, a solid screening system, a treatment lagoon, and a storage pond. The flushing system uses large amounts of water to wash the manure from point of concentration to the treatment lagoon. Before reaching the lagoon a system separates solids from the remaining liquid. Liquid manure passes through the treatment lagoon, where some sedimentation is expected, and reaches the larger waste storage pond, where it is kept for a variable time. Liquid manure from the storage pond is used as fertilizer in the farm crop fields, usually applied to fields through sprinklers in central pivot irrigation units. Solids separated from the liquid manure take only a little more than 15% of the total N and it is usually composted for use on-farm or sold.

Using the Van Horn et al. (2001) nutrient flow approach, the amount of nitrogen that *reaches the waste system* is the difference between the amounts of nitrogen input in the feed less the digested proportion of it plus the weight gained by cows plus the amount of nitrogen used for reproduction (new calves):

$$N(waste) = N(feeding) - [N(digested) + N(weight) + N(reproduction)]$$

Part of the nitrogen is lost to the air as gaseous forms during flushing, storage, and spraying. While losses during flushing and spraying are difficult to control, the loss of nitrogen during storage can vary greatly according to management. In the DNFDM, storage time determines the quantity of nitrogen available for applying to crops. Storage time is a user choice. The greater the time in storage, the lower the nitrogen quantity available for recycling. Estimations of nitrogen losses to the air were adapted from Van Horn et al. (1998) on a monthly basis.

data in those cells by overwriting them; results will be displayed in the same cells. Light blue cells (including scrolling boxes) indicate cells that allow the user to change parameters of the model before running; these cells will not change values during simulation. Yellow cells are output cells that display the internal model calculation results.

MONTH	MIN	MAX	AVG	RANGE OF VARIATION
JAN	12.00	17.99	15.86	5.99
FEB	11.80	15.95	14.75	4.15
MAR	11.90	16.65	14.84	4.75
APR	11.90	17.44	14.35	5.54
MAY	12.10	18.21	14.59	6.11
JUN	12.30	18.99	14.88	6.69
JUL	12.60	19.34	15.12	6.74
AUG	12.50	19.40	15.35	6.90
SEP	13.00	19.56	15.51	6.56
OCT	12.60	19.93	15.30	7.33
NOV	12.30	19.76	14.82	7.46
DEC	13.10	15.98	14.51	2.88

Table 2 US$ price per cwt (100 lbs) of liquid milk in Florida

The DNFDM can run in different modes. It can run showing "number" results which appear in cells. The "number" simulation is intended to show the friendliness of the model to stakeholders, especially to dairy farmers to gain their interest; additionally four boxes indicate graphically the monthly and accumulated values of N (red) and money (green). The DNFDM can also be run in a "graph" mode which shows the big picture of the main variables (profit, N leached (temporal and total), and cattle flow) during the time frame of simulation. "Graph" outputs are intended for analysis purposes, after several simulations. In either mode, "number" or "graph," there is the option to run a "stepwise" simulation, which stops the running every month to provide time to analyze the evolution of the variables. Simulations of main variables are also stored in an independent spreadsheet as an organized table for analysis purposes. Additionally, a "run 10 times" button is conveniently located to allow the user to run the model 10 times with chosen parameters and save results in an independent table. Experiments analyzed in this study were accomplished using this useful function.

5. Limitations of the DNFDM

Some current limitations of the model need to be recognized in order to improve it for further versions. These are:

- Cows get pregnant at the same time; monthly groups are assumed to be exactly the same age
- Costs and incomes only include variable costs related to the parameters in the study. For example initial cost of waste management facilities were ignored
- Production of milk is not seasonally corrected, it is only cow stage dependent

milking cows spend 80% of the time in confined areas, liquid manure is applied after seven days in the waste storage pond, and there are 93.90 acres of sprayfields to apply manure.

Experiments one to four tested the output changes with respect to changes in crude protein content in the diet of milking cows. Experiments five and six tested different lengths of storage of liquid manure in the storage pond. Experiments seven and eight tested the possible decrease of time spent in confined areas by milking cows. Experiment nine changed the crop of the largest field of 47.5 acres to a rotation (crop rotation # 2) of corn silage, forage sorghum, and rye silage. The last experiment, number ten, was similar to number nine for crop rotations, but crude protein in the diet was reduced to 15%. For each experiment, five years of simulation time was run, from January 2004 to December 2008, and two main variables were monitored: profit and nitrogen leaching. Every experiment was run ten times to observe the distribution of results for the profit that has stochastic price functions. Results are summarized in Figure 4. The baseline, or control treatment has the following outputs: 90% chance of getting at least $2.02 million of profit, 50% chance of getting at least $2.12 million of profit and 100% of chance of getting less than $2.18 million. There is an estimated N loss of 62K lbs of N during this five-year period.

Experiment	Crude Protein	Time Concrete	Days in Lagoon	Crop Rotation
CONTROL	17.50	80%	7	1
1	17.00	80%	7	1
2	16.50	80%	7	1
3	16.00	80%	7	1
4	15.00	80%	7	1
5	17.50	80%	14	1
6	17.50	80%	28	1
7	17.50	60%	7	1
8	17.50	50%	7	1
9	17.50	80%	7	2
10	15.00	80%	7	2

Table 3 Control and "experiments" with DNFDM for a 5-year period

Van Horn et al. (1998) indicate that some diet control over N excretion is possible. Decreasing crude protein may decrease the amount of N in the manure still maintaining optimum animal performance and milk production. These authors tested two different diet formulations proposed by the National Research Council (NRC): high and low. The high diet requires more crude protein to *assure* requirements are met and the low diet minimizes dietary N. These levels, high and low, were estimated to be 17.5 and 15.0 % of crude protein on diet by local dairy farmers. These ranges along with numbers provided by Van Horn et al. were used as functions in the DNFDM.

Total nitrogen lost during the five-year period varies considerably with different protein diets as seen in Figure 3. If crude protein is 17.5%, 62,000 lbs of N is expected to be

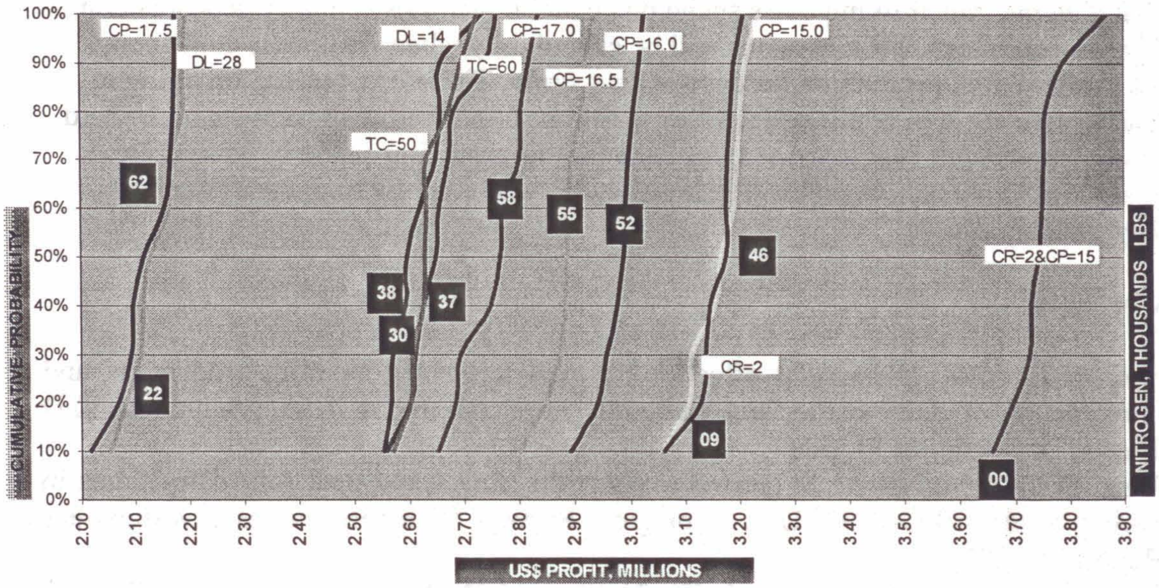

Figure 3 Profit and Nitrogen Lost with Different Treatments
Note of abbreviations: CP is crude protein, DL is days in storage lagoon, TC is time in concrete, and CR is crop rotation.

A final treatment combined the most encouraging previous results: crude protein at 15% and a crop rotation of sorghum, corn, and rye in the largest field. The results were quite revealing. First, no N is expected to be leached out of the farm, the entire N produced is recycled on farm. Second, the profit levels are far above the previous ones: it would be at least $3.66 million (90%) and at most $3.87 million. There is less risk of N lost in the system because the low protein in the diet and the high up-take capabilities of the crops. Higher profits are expected because of maximum use of the N as fertilizer and greater biomass accumulation.

8. Conclusions

- Seasonality and monthly nutrient balances make a difference compared with the traditional one-year nutrient budgeting
- Crude protein and kind of nitrogen as a feed supplement have a great impact on outputs, but experimental data are required to support and tune up interactions with N flow
- Crops are the best way of N recycling on farm. Dairy farms have to complement livestock activity with crop activity. If crops are well managed they can provide a good feed source to livestock and they can recycle large amounts of N
- Increasing the time of liquid manure storage would not be practical in real situations because facilities are designed for a specific holding time according to the herd size. Besides trying to lose N to the air intentionally (in order to decrease soil N lost) could be a bad economic decision and another environmental hazard

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