MODELING NORTH FLORIDA DAIRY FARM MANAGEMENT STRATEGIES TO ALLEVIATE ECOLOGICAL IMPACTS UNDER VARYING CLIMATIC CONDITIONS: AN INTERDISCIPLINARY APPROACH

By

VICTOR E. CABRERA

A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

2004

To my wife Milagritos

ACKNOWLEDGMENTS

I want to start by recognizing the exceptional interdisciplinary and collaborative work of my supervisory committee. I would like to express my eternal gratitude and highest appreciation to Dr. Peter E. Hildebrand, my mentor and adviser, for his unconditional support, encouragement, and outstanding guidance. My special thanks go to Dr. James W. Jones for his advice and commitment, acute professional challenging, and always useful feedback during the entire research process. I am also extremely grateful to Dr. Robert McSorley for his permanent, detailed, and constructive critique; Dr. Albert De Vries for his valuable inputs and constant assistance; and Dr. Hugh Popenoe for his interesting and useful comments.

This study would not have been possible without the collaboration of stakeholders, those representatives of many organizations who were actively involved in it. I would like to gratefully recognize the involvement and the unconditional help of Darrell Smith, coordinator of the Suwannee River Partnership (SRP), who was a major actor in the networking of people and organizations, and supporting the research from the beginning. I am also very appreciative of the help and dedication provided by Chris Vann, Clifford Starling, Russ Giesy, and Marvin Weaver, —University of Florida Cooperative Extension agents, who were the liaison with the dairy farmers. I also recognize the valuable information, feedback, and help provided by Hugh Thomas (SRP), Justin Jones (IFAS REC at Live Oak), W.C. Hart (US Department of Agriculture, Lafayette), Joel Love (SRP), and David Hornsby (Suwannee River Water Management District).

I would like to particularly thank all the dairy farmers, small, medium, and large, for providing time, data, and critical feedback during the processes of creation, calibration and validation of the models created in this study. This study was conducted with the farmers for the farmers. Their participation was crucial to the successful advancement and culmination of this research. For obvious reasons their names are omitted.

Besides members of my supervisory committee, many other professionals from the University of Florida were very helpful, providing information, networking, and inputs in this study. I would like to recognize the collaboration of Dr. Lynn E. Sollenberger for information about forage systems; Dr. Jack Van Horn for information about dairy nutrient management; Dr. Jerry Kidder and Greg Means for information about soil series; Dr. Donald Graetz for information, feedback, and networking on the soil/water nitrate issue, Dr. Sabine Grunwald for providing geospatial data; Dr. Clyde Fraisse for feedback on crop models and climate components; Dr. Carrol Chambliss for information and feedback on forage systems, Dr. Ken Boote for information on species parameters of crop models; Dr. Shrikant Jagtap for meteorological information; Dr. Ramon Litell for help and inputs in statistical analysis; Dr. Norman E. Breuer for information about north-Florida forage systems and constructive feedback; Cheryl Porter for help running the crop models and using the DSSAT software, Stuart Rymph for support in creating and calibrating forage crop models; Marinela Capanu for support with statistical analyses using SAS software; Daniel Herrera and Sergio Madrid for touring dairy farms with me; and Amy Sullivan for constructive feedback. Appreciation is extended to Dr. Gerrit

Hoogenboom from the University of Georgia, for his comments on species files for the crop models.

I want to express my appreciation to the interdisciplinary Sondeo team for their enthusiastic and productive work in the early stages of this study. Thanks to Diana Alvira, Sebastian Galindo, Solomon Haile, Kibiby Mtenga, Alfredo Rios, Nitesh Tripathi, and Jose Villagomez.

I would like to gratefully acknowledge the support and unconditional help provided by a private enterprise, the Soil and Water Engineering Technology, Inc. My sincere thanks to Dr. Del Bottcher, Dr. Barry Jacobson, and Suzanne Kish not only for their direct feedback and first-hand valuable information, but also for inviting me to participate on the monthly “manure lunch” that was a great opportunity for networking and collecting information.

I want to express my thanks to Jesse Wilson, Bill Reck, and Nga Watts from the Gainesville office of the Natural Resources and Conservation Service (US Department of Agriculture) for providing feedback, constructive critique, and valuable information for the study.

I hope I am not missing anyone, but if I do, I want to express my appreciation to all and each one who in some way or another contributed to this study. Your help has been highly valued and critical for the final outputs.

This work was supported by a grant from NOAA (Office of Global Programs) through the South Eastern Climate Consortium (a Regional Integrated Science Application center) under the direction and guidance of Dr. James W. Jones and Dr. Peter E. Hildebrand.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AFO	Animal Feeding Operations
ASAE	American Society of Agricultural Engineers
AWMFH	Animal Waste Management Field Handbook
BMPs	Best Management Practices
CAFO	Concentrated Animal Feeding Operation
CARES	County Alliance for Responsible Environmental Stewardship
CP	Crude Protein
DBAP	Dairy Business Analysis Project
DHIA	Dairy Herd Improvement Association
DNFDFM	Dynamic North-Florida Dairy Farm Model
DM	Dry Matter
DMI	Dry Matter Intake
DRMS	Dairy Records Management Systems
ENSO	El Niño Southern Oscillation
EPA	Environmental Protection Agency
FDH	Florida Department of Health
FFB	Florida Farm Bureau
FGS	Florida Geological Service
FLDEP	Florida Department of Environmental Protection
FSR	Farming Systems Research
FSRE	Farming Systems Research and Extension
IC	Initial Conditions for Simulation
LDNFDMF	Livestock Dynamic North-Florida Dairy Farm Model

LN	Lactation Number
MCL	Maximum Concentration Load
MHB	Methemoglobinemia
MIM	Months in Milk
MIP	Months in Pregnancy
NAC	Number of Adult Cows
NAWQA	National Water Quality Assessment
NH_4^+-Org	Ammonium + Organic N
NO_3^- - NO_3^{2-}	Nitrites + Nitrates
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
NRCS	Natural Resource and Conservation Service
NRM	Natural Resource Management
PDWS	Primary Drinking Water Standard
PRA	Participatory Rural Appraisal
RHA	Rolling Herd Average
RRA	Rapid Rural Appraisal
SRP	Suwannee River Partnership
SRWMD	Suwannee River Water Management District
SWIM	Surface Water Improvement and Management
TWG	Technical Working Group
USDA	US Department of Agriculture
USEPA, EPA	US Environmental Protection Agency
USGS	US Geological Service
WARN	Water Assessment Regional Network
WATNUTFL	Water budget and Nutrient balance for Florida

Abstract of Dissertation Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Doctor of Philosophy

MODELING NORTH FLORIDA DAIRY FARM MANAGEMENT STRATEGIES TO ALLEVIATE ECOLOGICAL IMPACTS UNDER VARYING CLIMATIC CONDITIONS: AN INTERDISCIPLINARY APPROACH

By

Victor E. Cabrera

August 2004

Chair: Peter E. Hildebrand
Major Department: Natural Resources and Environment

High levels of nitrogen (N) in water affect human health and ecosystem welfare. Dairy waste is considered an important contributor to increased water N levels in the Suwannee River Basin. The main aim of the study was to assess management options that decrease N leaching in dairy systems under different climatic conditions, while maintaining profitability. Whole-dairy-farm system simulations were used to study economic and ecologic sustainability, which would be impractical to test with regular experiments. Dynamic, event-controlled, and empirical models were coupled with process-based and decision-making models to represent and test management strategies. User-friendliness and stakeholder interaction were always pursued. Eight focus groups and 24 dairy farmer interviews were conducted, and a collaborative user-friendly decision support system was created. The Dynamic North-Florida Dairy Farm Model (DNFDFM) uses Markov-chains to simulate probabilistic livestock reproduction, culling, milk production, and N excretion; process-based crop models to simulate forage production, N

uptake, and N leaching; and linear programming optimization to tailor management strategies. The DNFDFM is an environmental accountability tool for dairy farmers and regulatory agencies capable of simulating any individual north-Florida dairy farm. Results indicated that north-Florida dairy farmers could maintain profitability and decrease N leaching 9 to 25% by decreasing crude protein in the diet, adjusting confined time of milking cows, and adjusting sequences of seasonal forages. During “El Niño” years, when higher rainfall and colder temperatures are experienced, 5% more N leaching is estimated compared with “Neutral” years; and 13% more compared with dryer and hotter “La Niña” years.

CHAPTER 1
INTRODUCTION

1.1 Background

The presence of high levels of N in water is an environmental hazard because it affects human health and ecosystem welfare. The Suwannee River Basin has received much attention in recent years because of 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 will be among the greatest challenges they face in the near future.

Evidence indicates that farms may reduce their total N loads by changing some management strategies. Improvements in long-term seasonal predictions (6 to 12 months) such as in El Niño and La Niña forecasts, can play an important role in implementing management strategies that dairy farmers in north-Florida may adopt in order to pursue economic and ecological sustainability.

1.2 The Problematic Situation

Dairy farming is an important part of Florida's agricultural industry. The Florida Statistical Service showed 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*) (Florida Agricultural Statistics Service, 2003).

According to USDA, there were about 152,000 cows on about 220 dairy farms at the end of 2002, and more than 30% of the dairy operations (65 operations) and number of cows (> 45,000 cows) of the State of Florida are located in the Suwannee River Basin. Indeed, more than 25% of the dairy cows in the state are in four counties in north central Florida that bound the Suwannee River (Bisoondat et al., 2002): Gilchrist, Lafayette, Suwannee, and Levy.

This dairy industry, according to Giesy et al. (2002), faces three significant challenges: production, economic, and environmental. Dairymen perceive that environmental issues will be the most stressful in the near future (Staples et al., 1997). Dairies face increased regulation because social pressure, while larger herds attract the attention of neighbors and activists concerned with odors, flies, and especially potential leaching of nutrients that might influence water quality (Giesy et al., 2002).

The presence of N in surface water bodies and groundwater 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 quality (Suwannee River Partnership, 2004a). Indeed, the Suwannee River Basin has received much attention in recent years because increased N levels in the groundwater-fed rivers of the basin could seriously affect the welfare of the ecosystem (Albert, 2002). According to Katz (2000), N 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. In a 53.1 km river stretch between Dowling Park and Branford, the nitrate loads increased from 2,300 to 6,000 kg day^{-1}. They also estimated that 89% of this came from the lower two-thirds, where agriculture is the dominant land use. Soils in this region are generally deep, well-drained sands (Figure 1-1); and nutrient management is a major concern (Van Horn et al., 1998).

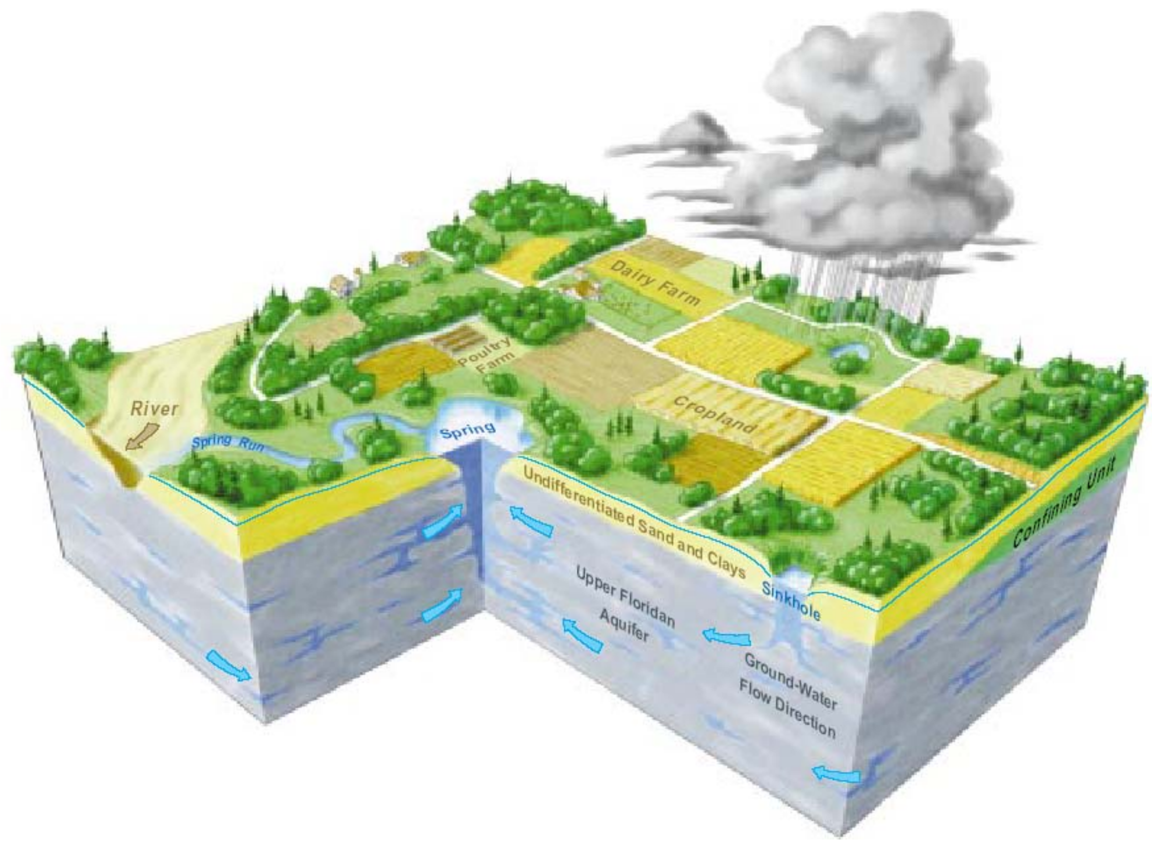


Figure 1-1. North-Florida landscape representation. Source: Katz et al., 1999, p. 1.

As Conway (1990) stated, farms in industrialized countries have become larger in size, fewer in number, highly mechanized, and highly dependent on external inputs; and can cause environmental problems by producing a number of wastes that might be hazardous. Recent evidence that agriculture in general, and animal waste in particular, may be an important factor in surface and groundwater quality degradation has created a strong interest in nutrient management research (Katz, 2000, Van Horn, 1997, Fraisse et al., 1996). Over-applying manure nutrients to land is considered a major cause of nitrates, converted from manure ammonia sources while in the soil, leaching to groundwater and contributing to surface runoff of N that contaminates surface waters. Concerns regarding nutrient losses from manure of large dairy herds to groundwater or surface runoff have been extremely acute in Florida (Van Horn, 1997). 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). Many soils in the Suwannee River Basin are excessively drained, deep, sandy, Entisols with low exchange capacity and low organic matter, which are prone to nitrate leaching (Woodard et al., 2002).

Environmental regulation of livestock waste disposal has become a major public concern, and much of the focus for this issue in Florida has been on dairies. Dairymen are now required to develop manure disposal systems in order to comply with Florida Department of Environmental Protection water quality standards (Twatchtmann, 1990). This fact has led to considerable research emphasizing N recycling and addressing issues such as maximum carrying capacity and nutrient uptake by crops (Fraisse et al., 1996).

Dairymen in the Suwannee River Basin have expressed their willingness to participate in initiatives that promote reduced environmental impacts. In fact, many of them are already involved in programs such as Better Management Practices (BMPs) to reduce nitrate overflow promoted by the Suwannee River Partnership (Smith, 2002, Pers. Comm.). Staples et al. (1997) interviewed 48 dairy farmers in Lafayette, Suwannee, Columbia, Hamilton, and Gilchrist counties. By far farmers rated their perception of anticipated costs of complying with upcoming environmental regulations as the top challenge to successful dairying in the future.

Overflow of nitrates in these dairy systems is affected by adopted management practices and by environmental conditions. Changing management practices might have a great impact on overflow amounts. For instance, Albert (2002) found that by reducing the duration of the irrigation, reducing the fertilizer application rate, and improving the timing of fertilizer applications, N leaching can be reduced by approximately 50% while maintaining acceptable potato yields in sandy soils in north-Florida. It is unknown if similar large reductions are also possible in dairy farms. Many environmental conditions are also determined by climate factors such as rainfall, temperature, and radiation (which are variable and uncertain). Dairy operations are affected by changes in climatic components at many different levels, and in many different ways. Rainfall patterns might result in very different amounts of nutrient leaching. For example, higher temperature in winter can promote more biomass accumulation, and increase plant N uptake.

Currently, better-quality long-term seasonal forecasts (6 to 12 months in advance) are available. The National Oceanic and Atmospheric Administration (NOAA) can predict—using the El Niño Southern Oscillation (ENSO) technology—accurate long-term seasonal climate patterns. These are based on predicting El Niño, La Niña, or Neutral years (which determine rainfall and temperature patterns). The ENSO signal in Florida has been well documented, in terms of its effects on climatic variables (Jones et al., 2000). Precipitation in Florida is particularly variable, with an excess of over 30% of the normal seasonal total across much of the state during an El Niño winter. La Niña has the opposite effect, with deficits of 10 to 30% lasting from fall through winter and spring. Florida and the Gulf Coast can expect to see average temperatures 2 to 3°F below normal during El Niño years. La Niña has the opposite effect, with temperatures 2° to 4°F above normal during winter months. La Niña's effect on temperature is more pronounced in north-Florida, Alabama, and Mississippi. Solar radiation decreases in association with higher rainfall during El Niño years. Notice also that climatic conditions in north-Florida allow year-round crop production, thus allowing more effluent-waste application, compared with dairy production systems in temperate areas (Bisoondat et al., 2002).

Proactive use of seasonal prediction can be adopted by dairy farmers. The opportunity to benefit from climate prediction arises from the intersection of human vulnerability, climate prediction, and decision capacity (Hansen, 2002a). This benefit from the information can be used to decrease environmental impacts, while maintaining profitability in north-Florida dairy operations.

1.3 Research Area

The study was performed inside the Suwannee River Water Management District, which encompasses all or part of 15 counties in north central Florida (Figure 1-2). The study was centered in five counties where N pollution is more problematic: Alachua, Levy, Gilchrist, Lafayette, and Suwannee.

1.4 Objectives

The main aim of the study was to assess and test management options that decrease nutrient overflow under different climatic conditions in north-Florida dairy operations while maintaining profitability. To achieve this, it was necessary to

- Thoroughly understand the north-Florida dairy system through farmer interactions
    - Conceptualize north-Florida dairy farms as systems
    - Identify dairy farm system components
    - Recognize interaction among these dairy farm system components

- Create a comprehensive dairy farm model adaptable to north-Florida dairies

- Simulate north-Florida dairy farms under different environmental conditions, different management strategies, and different climate conditions

- Identify climate-management interactions that result in lower nutrient pollution, especially less N leaching, while maintaining acceptable profit levels

- Suggest management strategies that individual north-Florida dairies could follow based on climate forecast

- Based on previous strategies, produce an extension circular with a bullet list of results to be available on paper and on the Internet for north-Florida dairy farmers and other stakeholders

- Create a user-friendly computer application with the simulation models that north-Florida dairy producers and other stakeholders can use for environmental accountability

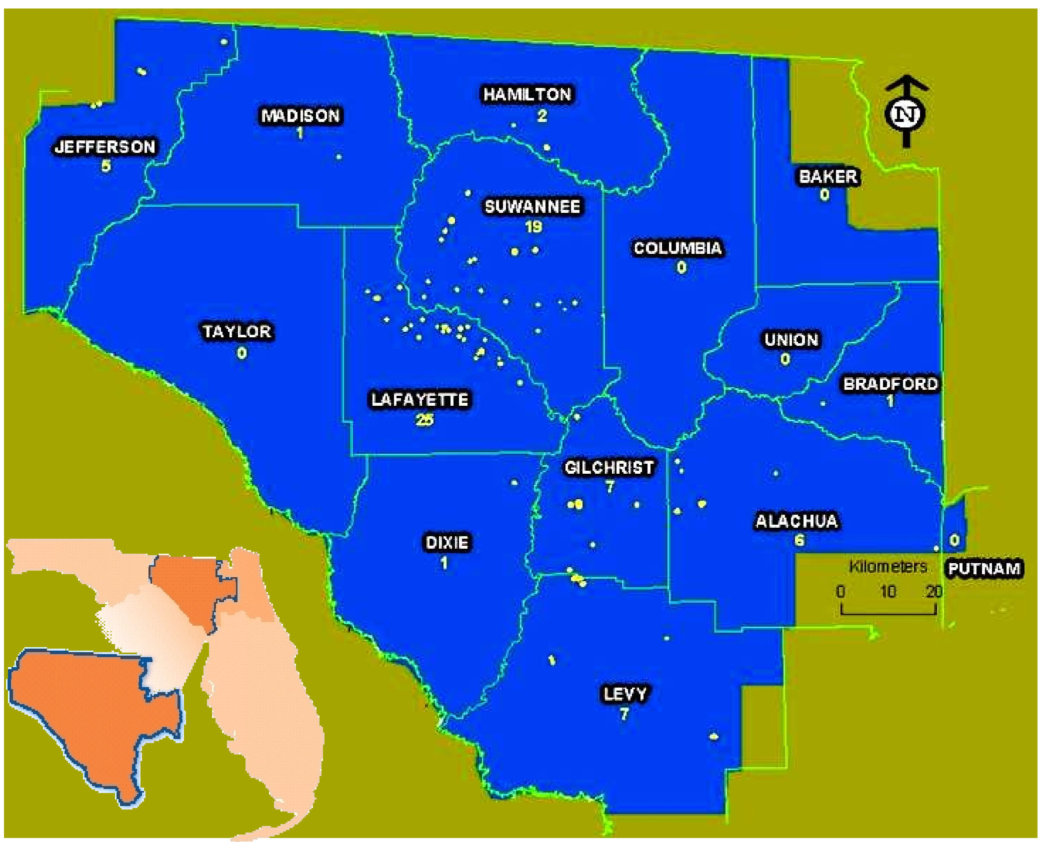


Figure 1-2. The Suwannee River Water Management District, the study area. Source: Land Use Survey, Suwannee River Water Management District, Florida Geographic Data Library, 1995. Note: Dots represent dairy farms and numbers indicate the number of dairy farms by county.

1.5 Hypothesis

North-Florida dairy farms can decrease their environmental impacts and still maintain profitability by changing management strategies, which include the use of improved long-term seasonal forecasts. This hypothesis can also be expressed as a research question: Can north-Florida dairy farms maintain profitability and decrease their environmental impacts by combining management strategies and seasonal forecasts?

1.6 Framework

Most dairies in Florida manage animals under semi-intensive or intensive systems. Florida dairies are principally in the business of producing milk: decisions are based on profit maximization and operation regulations. North-Florida dairies are business enterprises and have full access to credit opportunities, information, and new technologies (Adams, 1998). Additionally, dairy farms (which produce both livestock and crops) are composed of interconnected units; any part of which is affected by and affects the behavior of other parts, including human management decisions and strategies.

Since a whole-dairy-farm encompasses environmental, economic, and bio-physical components, its analysis is best accomplished by a systems approach (that accounts for the interactions of these components, and that can trace the consequences of an intervention through the entire system) (Kelly, 1995). While systems can be conceptualized at any of many scale levels, a systems approach defines a specific scale of interest and an appropriate boundary of analysis. Analysis in the systems approach is marked by recognition of the whole system and the interactions within that system rather than looking only at a system component. A systems approach uses specific techniques and tools (such as rapid appraisal, pattern analysis, diagrams, and modeling, often in a multidisciplinary fashion) to identify system boundaries and recognize component interactions (Kelly, 1995).

The proposed systems approach was Farming Systems Research and Extension (FSRE) as described by Hildebrand (1990). The “farm household” in livelihood systems analyses are replaced by “farm management” (Hazell and Norton, 1986) for commercial or industrial farm dimensions such as north-Florida dairy farms. The farming system is an arrangement of subsystem components that function as units. These subsystems include economic subsystems and a number of agroecosystems. The agroecosystems, as described by Powers and McSorley (2000), include the populations and communities organized in ecosystems in relationship with the abiotic factors.

To assess what would happen to the whole dairy operation and what would happen specifically to nitrate flow under different climate-management scenarios, models of these realities were set up (Thornley and Johnson, 1990). Models allow us to foresee results, when temporal or material conditions make it impractical to develop field experiments. Successful planning of an animal waste management system requires the ability to simulate the impact of waste production, storage, treatment, and utilization on the water resources; it must address overall nutrient management for the operation (Fraisse et al., 1996).

Different simulation methods were needed to accurately represent the north-Florida dairy crop and livestock systems; and to test management strategies that yield the most desired outcomes. Whole farm scale simulation models include biophysical, environmental, and economic components and relationships of the dairy operation to climate variability. Complex systems demand the study of interactions among processes acting on multiple scales. Thus, these problems require innovative approaches, combining advances in dynamical theory, stochastic processes, and statistics (Levin, 1991).

Budgeting nutrient flow through the total dairy farm system as conceptualized by Van Horn et al. (2001, 1998, 1994, 1991); NRCS (2001), Van Horn (1997); and Lanyon (1994) were adjusted, modified, and used for keeping track of dynamic N movement in all system components. Van Horn et al. (1998) mentioned the quantitative information needed on nutrient flow through all segments of the system. They listed the following critical research questions:

- How much of individual nutrients are excreted by dairy cows?
- How does the manure management system affect nutrient flow and nutrient recoveries for fertilizer use?
- What is the potential nutrient removal by plants?
- How can a manure nutrient budget be developed?
- What steps help to document environmental accountability?

Agronomic measures of nutrient balance, and tracking of inputs and outputs for various farm management units, can provide the quantitative basis for management to better allocate manure to fields, to modify dairy rations, or to develop alternatives to on-farm manure application (Lanyon, 1994).

Similarly to budgeting nutrients, The Netherlands has implemented the Mineral Accounting System (MINAS) which focuses on nutrient (N and phosphorus) flows on individual farms; and taxes farms whose nutrient surplus exceeds a defined limit. MINAS embodies a new approach to environmental problems caused by agriculture. According to Ondersteijn et al. (2002) focusing on individual farmers has two major advantages. First, individuals are considered polluters and are individually held accountable for their pollution, according to the “polluter pays” principle. Second, individuals have control over their pollution problem, and will be able to deal with it on an individual level (instead of being forced to comply with general measures that may be ineffective for their specific situation). After interviewing 240 farmers during 3 years, they also found large variation in N and phosphate surpluses within and between land-based farm types in The Netherlands. They surveyed farmers stated that MINAS provided enormous and often surprising insight into their management.

Crop models (Jones et al., 2003, Jones et al. 1998) are process-based dynamic simulation models that allow biophysical and environmental conditions to be translated into agricultural outcomes (Philips et al., 1998). Crop models can be used to estimate monthly biomass accumulation and N leaching (by a number of crop and/or pasture sequences under different climatic conditions, depending on soil conditions, manure applications, and other managerial choices).

Linear programming (LP) models are optimization models capable of devising alternative management choices that maximize (minimize) an objective function according to a set of restrictions (Hazell and Norton, 1986). The LP models have been widely used for analyzing farming systems.

1.7 Methods

North-Florida dairy farmers were involved in the entire research process. They provided the base information, and they validated results of the analyses. Few studies to date have incorporated such first-hand data from interviews and validation interaction with dairy managers (which are believed extremely important). Other stakeholder agencies also participated actively as was the case for the Suwannee River Partnership (that involves 45 agencies in total); the Florida Cooperative Extension Service; and some private enterprises. These stakeholders provided relevant information and permanent feedback to the study. In all interactions, a laptop computer was used. There were two rounds of interviews and focus groups. For the first round, a "prototype" model was used (created by suggestion of one stakeholder) as a discussion, engagement, and data-collection tool. In both the interviews and focus groups, the interaction started by explaining the prototype model and demonstrating its functioning, followed by an interactive discussion of all specific points. The researcher recorded all suggestions and information. Some modifications were made during the process to the "prototype" model, however most of the suggestions were incorporated into a new model, which was then used in the second round. In the interviews of dairy farmers, an additional 1 to 2 hour conversation was used to collect information regarding biophysical farm factors, livestock, livestock feeding program, crops, crop fertilization program, waste management, perception of environmental regulations, perception of seasonal forecast use, and other factors. In several occasions after the interview, a tour of the farm followed. There were 21 interviews and six focus groups during this first round.

A second round of focus groups and interviews was arranged to validate the functioning of the model. Two focus groups and three interviews confirmed that the model was performing inside the expected ranges, and that results were realistic. Local published data from related studies were also used as baseline in the modeling.

An integrated, whole-dairy-farm simulation that links decision making with biophysical, environmental, and economic processes was developed, the Dynamic North-Florida Dairy Farm Model (DNFDFM). The simulation approach included a Dynamic event-controlled simulation model (D, driver) connected to crop models (CM) and to optimization models (OM). The driver, which had many modules, followed a dynamic adaptation of the budgeting framework for tracking the flow of N through the entire system; and for tracking production and additional economical variables, according to a pre-defined set of management and climatic conditions. Crop models assessed the N recycled by plants and the amount of N leached according to management, genetic, soil, and climatic specific conditions. The optimization models consisted of linear programming models that either minimize N leaching, or maximize profit for specific farm conditions. The DNFDFM runs monthly for all the processes following user-friendly menus.

1.8 Relevance

Results are expected to directly help Suwannee River Basin dairy operations by providing a decision tool that can be used to decrease environmental impacts by reducing nitrate pollution (currently one of the most important environmental concerns). Results should also contribute to overall Suwannee River Basin environmental health by reducing the total N load in the watershed, which has been rapidly increasing.

Innovative frameworks and methodologies used in this research could serve as baselines for other studies in which interdisciplinary and participative outcomes are desired. For example a similar approach could be used to address the phosphorus problem in the Okeechobee area.

CHAPTER 2
NITROGEN POLLUTION IN THE SUWANNEE RIVER WATER MANAGEMENT DISTRICT: REALITY OR MYTH?

2.1 Introduction

In response to increased environmental concerns, the U.S. Environmental Protection Agency (USEPA) has increased regulatory controls for concentrated animal feeding operations (CAFO) under the Clean Water Act. One of the changes is to require CAFOs that apply manure to land to meet application limits defined by a nutrient standard (USEPA, 2003). The goal of the nutrient standard is to minimize nutrient loss from fields receiving manure. Farms meet this standard by applying manure nutrients at a rate consistent with the agronomic needs of crops receiving manure. Nutrient standards can be N -or P-based, depending on the nutrient content of the soil. USDA is also encouraging the voluntary adoption of nutrient standards on all animal feeding operations (AFO) not subject to USEPA regulation (USDA, NRCS, 1999).

The Suwannee River Partnership[1] (SRP) states that over the last two decades, nitrate levels in the middle Suwannee and Santa Fe river basins have been on the increase. The SRP is a coalition of state, federal and regional agencies, local governments, and private industry representatives with 46 partners working together to reduce nitrate levels in the surfacewaters and groundwater within the basins, or watersheds. The Suwannee River Basin has received much attention in recent years because increased N levels in the groundwater-fed rivers of the basin could seriously

[1] www.mysuwanneeriver.com/features/suwannee+river+partnership

affect the welfare of the ecosystem (Albert, 2002). The federal safety standard for nitrate-N in drinking water is 10 mg L^{-1} (Florida Department of Health, FDH, and Florida Department of Environmental Protection, FLDEP). According to Hornsby (pers. comm.), a water quality analyst from the Suwannee River Water Management District (SRWMD) at Live Oak, nitrate levels in some areas have reached ranges of 20 to 30 mg L^{-1}.

Rising nitrate levels in north-Florida have been a growing concern because of the effect of nutrients on public health and the environment (Van Horn et al., 1998). Hornsby et al., 2002b alleged that the most likely contributors to contamination are farms, industry and human settlements in the region. Soils in this region are generally deep, well-drained sands; and one of the most critical concerns is N loss in the form of nitrate into the groundwater through these deep sandy soils of the Suwannee River Basin (Van Horn et al., 1998).

Changes in agricultural land use and the intensification of this land use during the past 50 years have contributed variable amounts of N to the groundwater system. In general, four main sources of N to groundwater can be recognized: fertilizers applied to cropland, animal wastes from dairy and poultry operations, atmospheric deposition, and septic tank effluents (FLDEP, 2001).

Despite the above arguments, it was found (by talking with local people) that some stakeholder groups believe that either the problem of N pollution is not as bad as many people perceive, or the problem does not exist at all. Therefore there is a feeling that the regulatory agencies are overacting and pushing excessively in protecting the environment.

Under these circumstances, it is critical to clearly understand the problem and the concerns. Clarifying the real problem and the real actors would help in promoting realistic ways of solving it. The objective of this chapter is to discuss the evidence of increasing levels of N in water bodies in the Suwannee River Basin, explore evidence of N pollution by dairy farms, and briefly address potential ecological and human implications.

2.2 Evidence of N Increase in the Suwannee River Water Management District

2.2.1 Assessments at the District Level

The Suwannee River Water Management District (SRWMD) is the water authority in the study area. The SRWMD deals with quantity and quality of water. Regarding the quality of the water, it permanently monitors the quality of the ground and surface water, and every year produces a comprehensive report. The last available report is for the year 2001/2002 (Hornsby et al., 2003).

The SRWMD has developed a comprehensive Water Assessment Regional Network (WARN) consisting of 97 Floridian aquifer wells for a trend network and 120 wells for a status network, distributed along the water management district. These are used to assess the groundwater quality in the District. In this last report (Hornsby et al., 2003) containing results only for the status wells between October 2001 and September 2002, nitrate-N concentrations above a background concentration of 0.05 mgL^{-1} existed for all or part of every county in the District. The possible nitrate sources were stated as fertilizers, animal waste, and human waste. Concentrations are elevated in the Middle Suwannee River Watershed (Suwannee and Lafayette Counties); and within an area generally defined along an axis starting in northern Jefferson County and ending in eastern Alachua County (Figure 2-1). However, the three samples that exceeded the

Maximum Concentration Load (MCL) or the Primary Drinking Water Standard (PDWS) set at 10 mg L^{-1}, were located in Levy County during May and June 2001 (10.6, 12.0, and 14.2 mg L^{-1}). By comparing overall data with the other four water districts in Florida, the SRWMD has the largest area of elevated groundwater nitrate-N concentrations in the State.

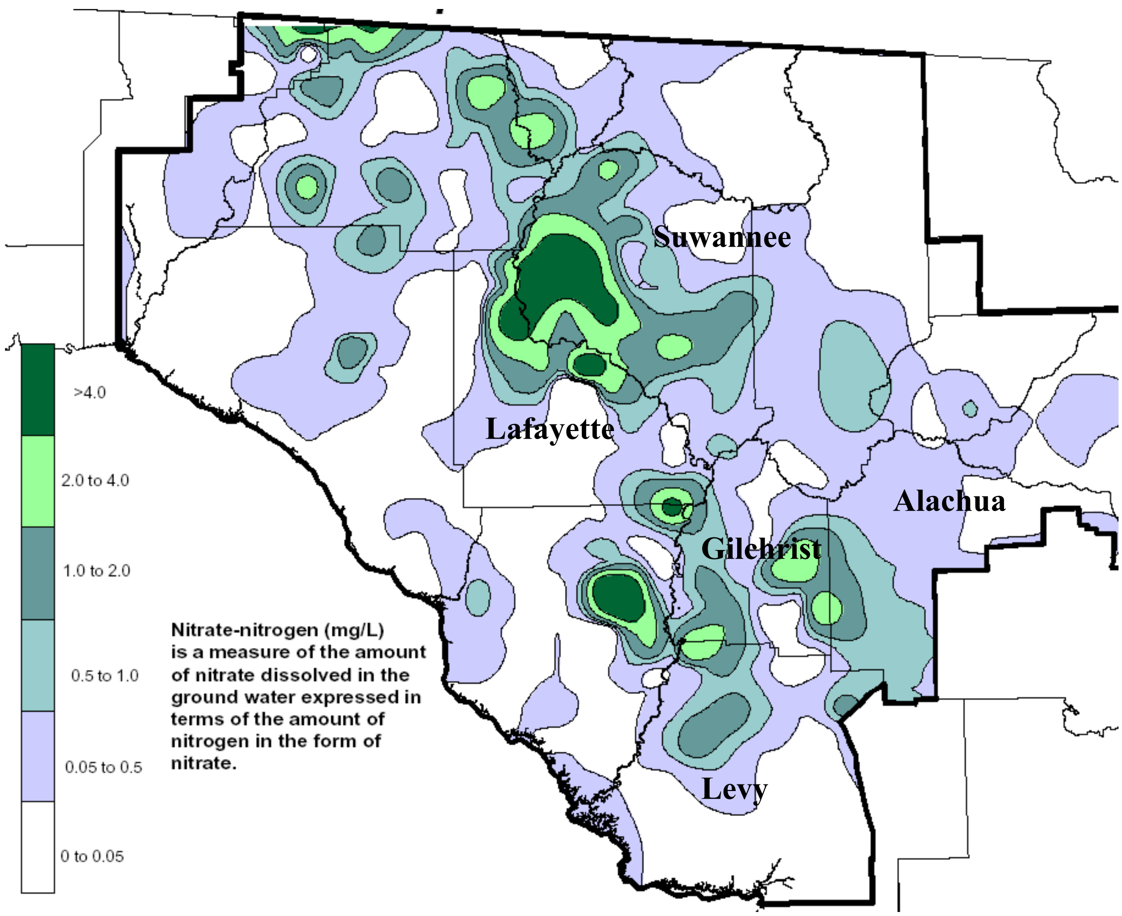


Figure 2-1. Nitrate-N concentration in the SRWMD. Source: Hornsby et al. (2003), p. 22.

Regarding surface water quality, the SRWMD has implemented the Surface Water Improvement and Management (SWIM) program, a quality-monitoring network consisting of 67 water chemistry stations. In water year 2002 (October to September), 3,012 tons of nitrate-N were transported to the Gulf of Mexico by the Aucilla, Econfina, Fenholloway, Steinthatchee, Suwannee, and Wacasassa rivers; the Suwannee river alone accounted for 98.6% of it. The middle Suwannee River Basin that accounts for only 8.6% of the Suwannee River area accounted for 29.3% of the total loading; and the middle Santa Fe River that represents only 5.7% of the Suwannee River Basin accounted for 19.6% of the total loading; those are the N hotspots.

In 2002, of the 35 springs whose water-quality standards were studied, 5 were classified as poor quality and 15 as fair quality. Of the 26 rivers (or river sections) identified in the District, 1 was classified as poor and 13 as fair quality.

Using the SRWMD database of monitoring point water quality, graphs for 3 springs in the middle Suwannee River Basin were constructed. Figure 2-2 shows N levels in 3 central springs (Blue, Ruth/Little, and Troy) with data for the monitoring network of the SRWMD. There clearly is an increasing trend. In Figure 2-2C additional data from the US Geological Service (USGS) and from the Florida Geological Service (FGS) for previous years are presented. Figure 2-2C clearly shows an increase in the N levels in this surface water body; the line indicates the increasing trend.

In previous water year, 2001, (Hornsby et al., 2002a) the total loading of nitrate-N going to the Gulf of Mexico was 3067 tons; and 97.8% was accounted for by the Suwannee River Basin. These numbers suggest a loading decrease from 2001 to 2002. However, in absolute numbers, loading was higher in 2002, since the discharge of the Suwannee River increased. The fact of increased loadings year to year is reported to be true also for many previous years.

In 1999, the FLDEP (Copeland et al., 1999) after sampling 491 wells in the middle Suwannee River, found that wells located 300 ft from poultry or dairy farms had nitrate concentrations greater than the background, with a 25% chance of exceeding the MCL.

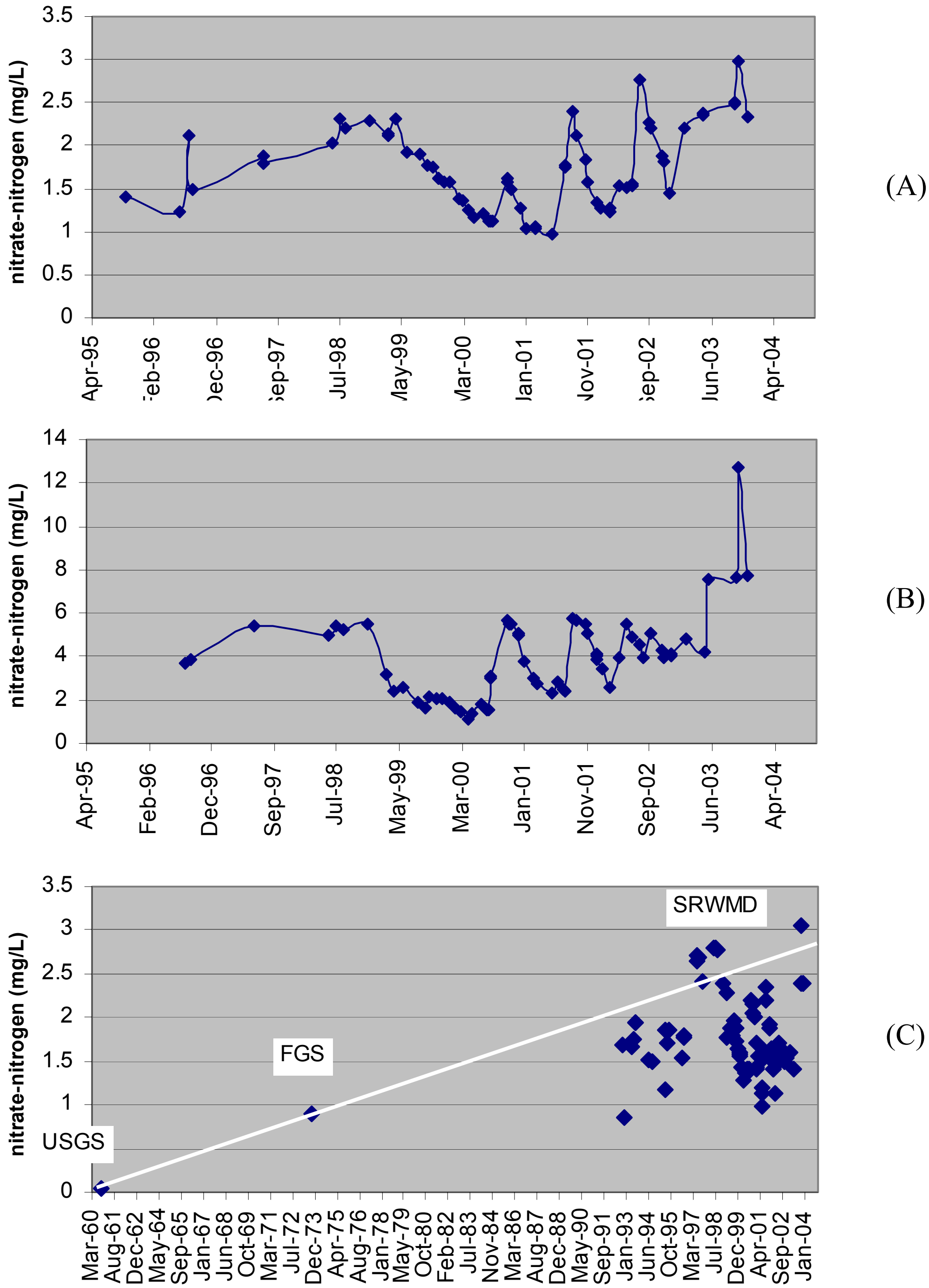


Figure 2-2. Nitrate-N concentrations in three springs in the middle Suwannee River Basin. A) Blue, B) Ruth/Little, C) Troy. Source: Prepared with data from the SRWMD, FGS, and USGS.

The 2001 FLDEP report for the Suwannee River Basin states that 7 lakes (Cherry, Alligator, Crosby, Rowell, Sampson, Santa Fe, and Hampton), 1 stream segment in Swift Creek; several segments of the Santa Fe River; the Middle and Lower Suwannee Rivers, and their estuary are potentially impaired because of excess nutrient concentrations. This FLDEP water quality report is summarized in Figure 2-3.

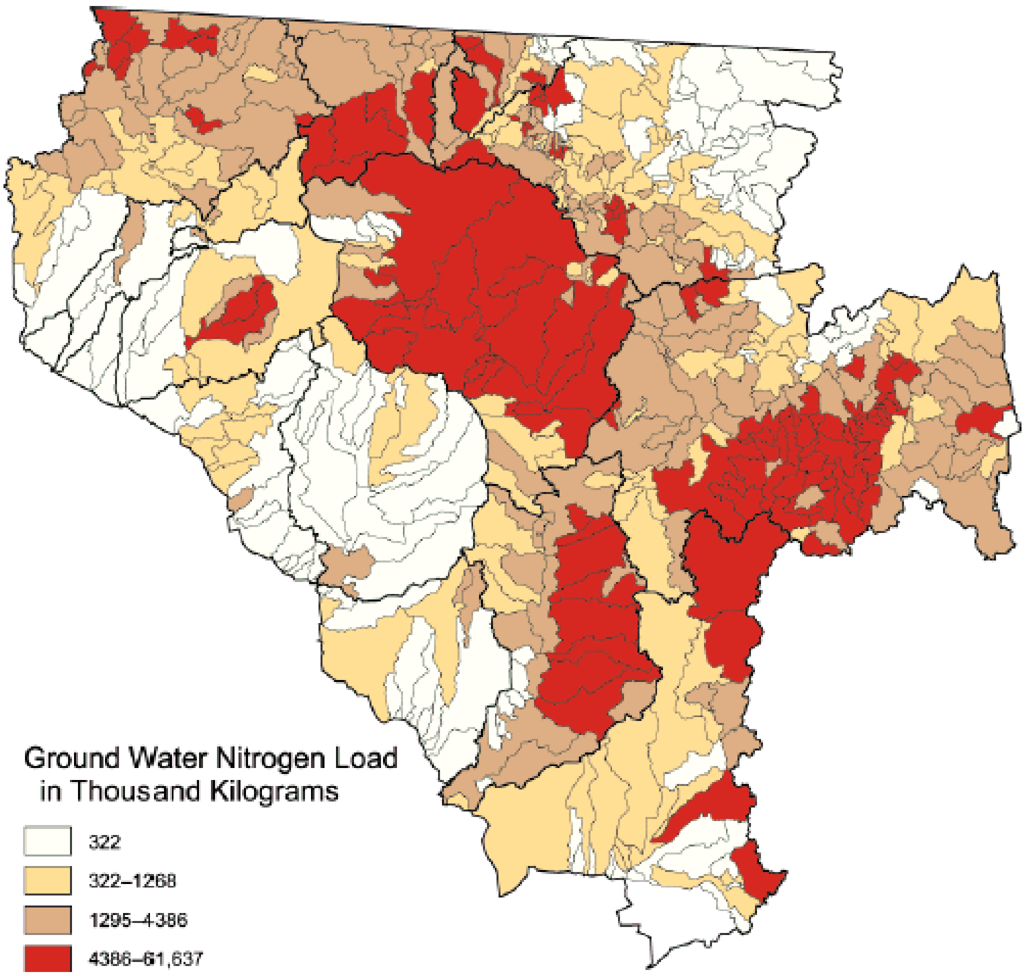


Figure 2-3. Estimated annual mean of groundwater N load. Source: FLDEP (2001), p. 81.

A study by the FGS (1992) reports that the proportion of samples of water exceeding the PDWS for Florida of 10 mgL^{-1} is low (0.6% for superficial system, 0% for intermediate aquifer system, and 1% for the Floridian aquifer system); however, it mentioned that for the Suwannee River Basin high nitrate concentrations (up to 140 mg L^{-1}) in monitoring wells associated with dairy operations have been found.

A cooperative study between the DEP and the USGS measured monthly water samples of 14 wells in the middle Suwannee River Basin (Katz and Bohlke, 2000). This study found concentrations of nitrate-N ranging from 0.02 to 22 mgL^{-1}, with large seasonal variations. The fluctuations were believed to be correlated mostly with agricultural practices and climate conditions; for example, higher concentrations occurred in winter when waste or fertilizer was applied. Additionally, the use of N isotope indicated that the most likely cause of nitrate in 5 wells were dairy and/or poultry operations (Katz and Bohlke, 2000). This coincided with the fact that these farm operations were close to the sampling sites.

A long term and comprehensive study in the Suwannee River Basin developed by the USGS (Katz et al., 1999) indicated that N levels have increased from 0.1 to 5 mg L^{-1} in many springs in the Suwannee River Basin over the past 40 years. Several sources of non-point N (fertilizer, animal wastes, atmospheric deposition, and septic tanks) increased continuously in Gilchrist and Lafayette counties. Isotope analyses indicated that the source of N was mixed between organic and inorganic, attributing them to animal operations and crop fertilizer, respectively, from nearby operations.

This study (Katz et al., 1999) compared long term trends in nitrate concentrations in selected springs with estimated inputs of N sources in Lafayette and Suwannee counties. It found a high correlation between the estimated quantity of fertilizer and the concentration of N in the springs. It showed for Suwannee a peak in the 1970s, a decreasing trend until the early 1990s, and finally an increasing trend again after 1993, while for Lafayette County there was a steady increase since 1960s.

There are historical records for 4 springs in the Suwannee River (Hornsby and Ceryak, 1999): Charles (1973-97), Little River (1980-97), Running (1980-98), and Telford (1980-97) (Figure 2-4); and for 3 springs in Lafayette county ((Hornsby and Ceryak, 1999): Troy (1960-98), Lafayette Blue (1980-97), and Mearson (1980-98) (Figure 2-5).

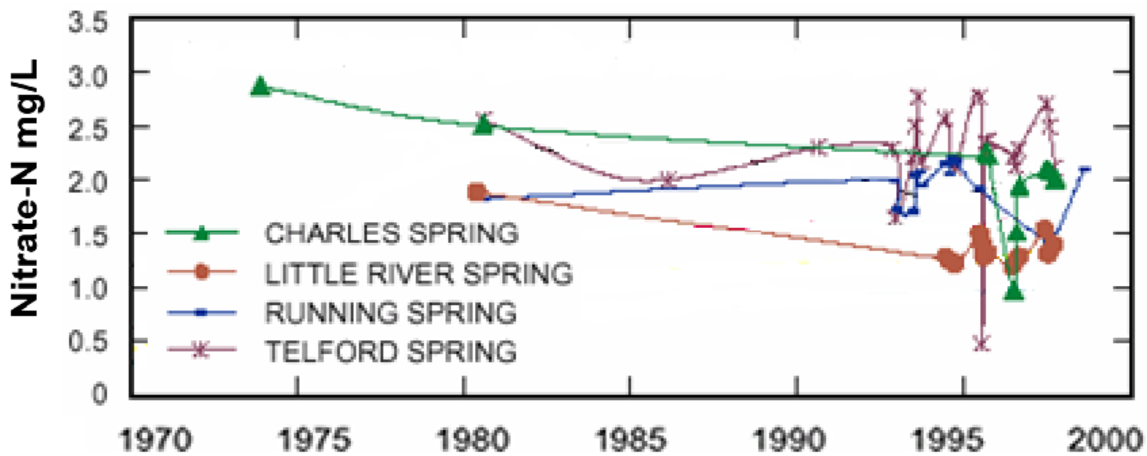


Figure 2-4. Long term records of Nitrate-N for 4 Suwannee springs. Source: Modified from Katz et al. (1999), p. 46.

Pitman et al. (1997) reported 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 53-km river stretch between Dowling Park and Branford, the nitrate loads increased from 2,300 to 6,000 kg day^{-1}. Of this total, 89% appeared to come from the lower two-thirds, where agriculture that includes crops and livestock is the dominant land use. This study found that nitrate-N concentrations in the 11 measured springs ranged between 1.3 and 8.2 mg L^{-1}, and nitrate-N concentrations for the river of 0.46 mg L^{-1} in Dowling Park, 0.46 mg L^{-1} in Luraville, and 0.86 mg L^{-1} in Branford; even though the nitrate-N concentration almost doubled from the upper to the lower part of the river, there was no noticeable difference among the contributors' springs, suggesting that other sources might also be affecting the river in the lower part.

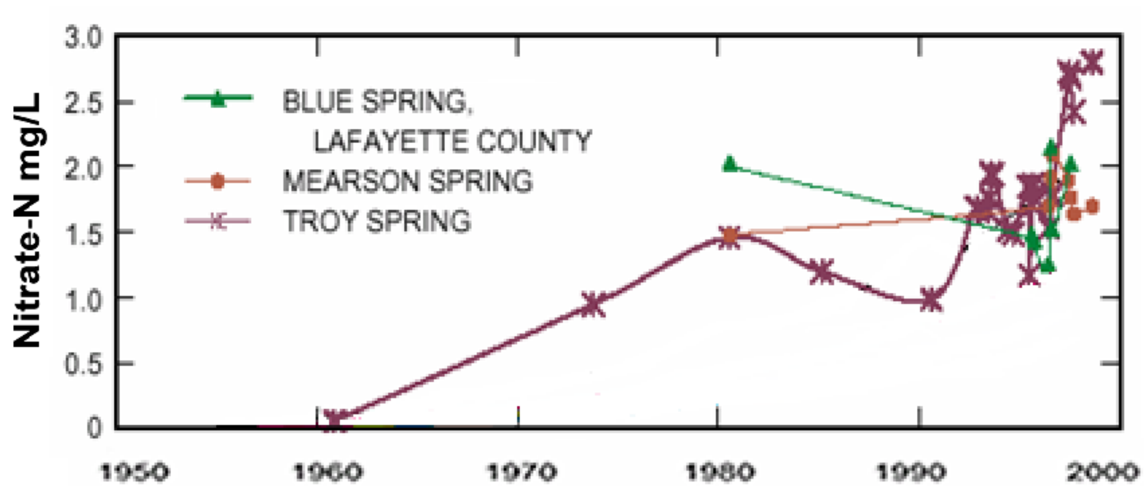


Figure 2-5. Long term records of Nitrate-N for 3 Lafayette springs. Source: Modified from Katz et al. (1999), p. 46.

2.2.2 Assessments at the Watershed Level

Asbury and Oaksford (1997) performed a study in 7 rivers in Georgia and Florida; the Suwannee River was one of them. This study found that the N input ranged from 2,400 kg yr^{-1} km^2 in the Withlacoochee river basin to 5,470 kg yr^{-1} km^2 in the Altamaha river basin, with the Suwannee input in the range of 3,939 kg yr^{-1} km^2. However, when these numbers were recalculated to in-stream loads, the Suwannee had the highest N loads (compared with the other 6): 476 kg yr^{-1} km^2 (with the range of the other 6 between 152 and 405 kg yr^{-1} km^2) and discharges in the order of 9,700 kg 10^3 (with the range of the others between 720 and 8280 kg 10^3). Additionally, the ratios between outputs/inputs of N were calculated for the 7 rivers (range 4.2% to 14.9%) and the Suwannee River was the second highest with 12.1%.

Ham and Hatzell (1996) realized another comprehensive study of N pollution in surface waters of Georgia and Florida. This study found, for the 10 major river basins in the study, that median concentrations were below USEPA guidelines of 10 mg L^{-1} for nitrate and 2.1 mg L^{-1} for ammonia, with only one exception in Swift Creek (3.4 mg L^{-1} ammonia) in the Suwannee River Basin that was attributed to waste water discharges. Although in general the nutrient levels were low, long-term increasing trends of nutrients loads were found in most of the sites. Distribution of results of nitrate-N indicated that the Suwannee presented the third highest mean but the higher variability with the highest overall value of more than 70 mg L^{-1}.

Ham and Hatzell (1996) also performed a long-term trend for these 10 major river basins. They developed graph relationships between time and N concentrations. They found a slope of +0.02 for the Suwannee River Basin, between the years 1971-1991. This means a 4.61% yearly increase over the baseline of 0.5 mg L^{-1}. This was the fourth greatest increasing trend regarding mg L^{-1} year^{-1} comparing with the other Basins.

2.2.3 Assessments at the National Level

Berndt et al. (1998) published a USGS regional study of the Georgia-Florida coastal plain that includes the Suwannee River Basin. This study was part of the National Water-Quality Assessment (NAWQA) program that includes more than 50 of the nation's largest river basins and aquifers. This study reports that in the 23 groundwater samples from the row-crop agricultural area in the upper Suwannee River Basin, 33% exceeded the drinking water standard. These samples were from aquifers that overlie the Upper Floridian aquifer, the major source of drinking water for the study area. This study also found that nitrate concentrations were generally higher in samples from agricultural areas and shallower wells and N isotope ratios indicated that both fertilizer and animal wastes were the predominant sources of nitrates in groundwater.

The study of Berndt et al. (1998) found that the nutrient more frequently found in groundwater was N, which was mostly affected by land use, geology, soils, and topography. Especially in the Suwannee River Basin, the problem is aggravated because it is a karst region with well-drained soils that have a low water-nutrient holding capacity. Also Berndt et al. (1998) found no direct relation between land uses and N concentrations. However, they referred to the previous Pitman et al. (1997) study between Dowling Park and Branford (33-mile Suwannee River reach) including 11 nearby springs that showed much higher N levels in the springs ($\bar{x}$ = 1.7, range 1.3-8.2 mg L^{-1}) than in the river (between 1 and 2 mg L^{-1}): the N levels increased when it moved to the lower parts. In this case, even though the water flow dynamics have a great effect, a clear association was found between the predominant agricultural land use and the N levels; however no specific type of farms could be identified as the sources.

A comparison of the Suwannee River nutrient concentration with the NAWQA national standards, indicate that overall the levels of N in the streams and in the groundwater of the Suwannee River Basin are between the 75th percentile and the median.

2.2.4 Assessments at the Dairy Farm Level

Andrew (1992) did a comprehensive study of nine dairy farms in the middle Suwannee monitoring waste water lagoons, monitoring wells, and supply wells and their interactions with the different land uses inside the farms (waste water, intensive areas, intensive pasture, sprayfields, and low density pastures). This study tracked the N inside the dairy farms after cattle excretion, measuring it at different depths and in different land uses. The results are quite revealing and they are summarized in Figures 2-6 and 2-7.

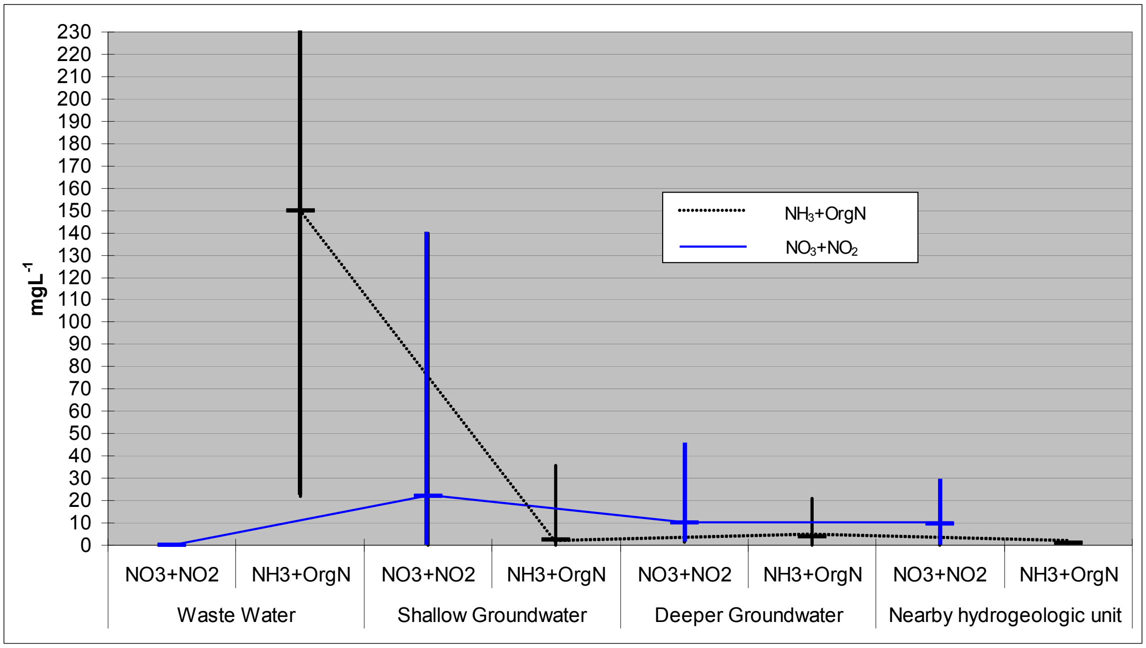


Figure 2-6. Nitrate-Nitrite and total ammonium plus organic N at different points in nine dairy farms in the middle Suwannee River Basin. Source: Prepared with data extracted from Andrew (1992).

Two main forms of N were measured, Nitrite + Nitrate (NO_3^- - NO_3^{2-}) and Ammonium + Organic N (NH_4^+ -Org). In the waste water in the lagoon (effluent) the concentration of NO_3^- - NO_3^{2-} was negligible because most of the N was in form of NH_4^+ -Org ($\bar{x}$ =150 mg L^{-1}) as seen in Figure 2-6. Because of fast decomposition and nitrification N is quickly converted to NO_3^- - NO_3^{2-} forms, which are evidenced in the monitoring wells (shallow groundwater at 3-m deep), in which the concentrations of NO_3^- - NO_3^{2-} are far higher than the NH_4^+ -Org forms ($\bar{x}$ = 22 vs. 2.2 mg L^{-1}). The trend continues in the deeper groundwater source wells (12–15 m) where the concentrations of

NO_3^- - NO_3^{2-} are substantially lower than in the shallow groundwater wells because of dilution processes, but still high for the water quality standards ($\bar{x}$ =10 mg L^{-1}). In these deep wells, the NH_4^+-Org concentrations are much lower than the waste water, but slightly higher than the shallow groundwater suggesting that some deep accumulation may occur.

In the nearby hydrogeologic unit the concentrations of NO_3^- - NO_3^{2-} are very similar to those in the deep groundwater wells suggesting that the dairy might be responsible for such an impact. As expected NH_4^+-Org forms would be negligible on these components.

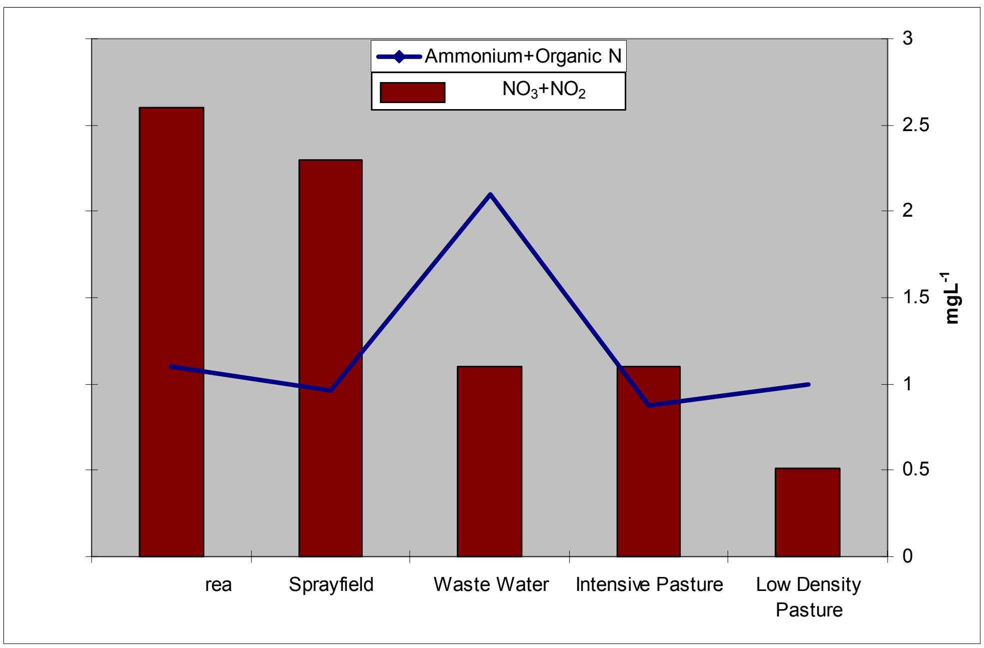


Figure 2-7. Dissolved Nitrate+Nitrite and Ammonium+Organic N in monitoring wells (3-m deep) in different areas of a dairy farm. Source: Prepared with data extracted from Andrew (1992).

Inside the dairy farms, the collected data demonstrated the movement of N downwards at different rates for different parts of the farm. Exploring the data from shallow wells, the intensive area, where cows deposited manure without regular collection, is the critical area where the highest concentration of NO_3^{-} - NO_3^{2-} is observed ($\bar{x}$ = 26 mg L^{-1}); this is followed by the sprayfields where intense applications of effluent are performed ($\bar{x}$ = 23 mg L^{-1}); followed by the wastewater area and the intensive pasture (both $\bar{x}$ = 11 mg L^{-1}). The lowest concentration was found in the low density pastures ($\bar{x}$ = 5.1 mg L^{-1}) but this is still half of the allowable limits of the PDWS. The NH_4^{+} -Org concentrations are medium ($\bar{x}$ = between 0.96 and 2.1 mg L^{-1}, taking into account that 2.1 mgL^{-1} is the USEPA limit) in these shallow wells; being higher, as expected, below the wastewater lagoons. This also indicates that there was a downward infiltration of the wastewater.

In another study from Andrew (1994), four dairy farms were closely monitored during four years (1990-1993) in the middle Suwannee. In this study, water samples were evaluated in 51 monitoring wells in these 4 typical dairy farms and 3 nearby springs in Lafayette and Suwannee counties. Results indicated that

- Water from the monitoring wells had median nitrate exceeding that in water from wells of the background groundwater quality network sampled by the FLDEP
- Nitrate concentrations near waste water lagoons and intensive livestock areas were the highest exceeding in the shallow wells the drinking standards of 10 mgL^{-1}
- Concentrations were substantially lower in pastures (less loading of manure) and in deep wells (dilution and/or denitrification)
- Nitrogen isotope ratios analyses demonstrated that animal waste was the main source of nitrates in groundwater adjacent to the lagoons and intensive areas, and animal waste and/or septic tanks were the principal source of nitrate at the three springs
- Nitrogen isotope ratios also demonstrated that synthetic fertilizers or combinations of synthetic fertilizer, soil N, and livestock wastes were the sources of nitrate in pastures and sprayfields.

Figure 2-8 shows the average of nitrate concentrations above the 10 mgL^{-1} for the 4 farms. As reported in the conclusions of Andrew (1994), the wells nearby the intense areas and the wastewater lagoons are those with higher environmental menace. Nonetheless, it was noticed with these study data, that 2 of the farms presented wells below the 10 mgL^{-1} for waste water lagoons and 1 farm showed wells of less 10 mgL^{-1} for a monitoring well near the intense areas. Also, 2 of the farms presented "high" wells for pasture fields and 1 farm additionally a "high" well for a sprayfield.

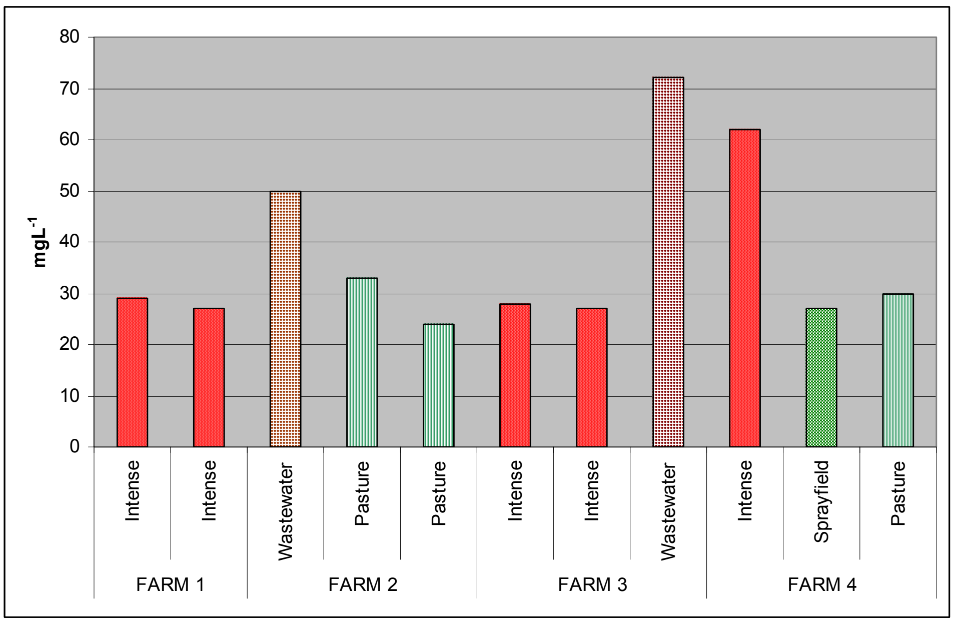


Figure 2-8. Monitoring wells with higher than drinking water allowable nitrate levels (PDWS>10 mg L^{-1}) in the four dairy farms. Source: Prepared with data from Andrew (1994).

2.3 Human and Ecological Concerns because of N Pollution

High nitrate levels in drinking water can cause methemoglobinemia (MHB) or "blue baby" syndrome in infants, a condition that diminishes the ability of blood to absorb oxygen (Vigil et al., 1965; NRC, 1985) because the methemoglobin produced by nitrates cannot carry oxygen, causing symptoms of oxygen starvation that affects primarily infants younger than six months, who suffer cyanosis and, in extreme cases, death (Andrew, 1994).

Nitrate is a precursor of carcinogenic nitrosamines, which are believed to cause stomach cancer and leukemia (NRC, 1978; Strange and Krupicka, 1984; Stewart, 1990; Mirvish, 1990; Forman, et al., 1985). Additionally, high levels of nitrates in drinking water are associated with birth defects (Fan et al., 1987), stress of the cardiovascular system with extreme artery dilatation (Vrba, 1981), enlargement of the thyroid gland, and increased sperm mortality (Scragg et al., 1982).

Kross et al. (1992) mention that about 2,000 cases of MHB have been reported between 1945 and 1990 worldwide with a mortality rate of 10%; however the NRC (1995) found no studies reporting nitrate-induced MHB since 1990; nitrate induced MBH seems rather rare now, but these rare cases are due primarily to a lack of reporting requirements, and secondarily to a lack of physician awareness (Felsot, A. 1998).

Several effects on reproduction, growth and development of animals have also been noticed because of high N levels, including mortality of larvae of Cutthroat trout, Chinook salmon and Rainbow trout and mortality of tadpoles in several frog species in Florida such as Chorus frogs and Leopard frogs (Edwards et al., 2002). In several species of frogs, reduced activity, weight loss, and deformed digestive tracts also have been detected (Edwards et al., 2002).

In addition to making water unsafe for humans and many other animals, high nitrate concentrations can lower water quality in rivers and springs because elevated concentrations of nitrate in these water bodies can cause eutrophication, which can result in algal blooms and depletion of oxygen that affects survival and diversity of aquatic organisms (Katz et al., 1999). Eutrophication is a process in which algae growth is favored and consequently oxygen is depleted. This problem happens in the surface water-bodies, which receive inflows from groundwater from springs or diffuse seepage (Andrew, 1994).

2.4 Conclusions and Recommendations

Several studies have demonstrated that there is a N pollution problem in the Suwannee River Basin. All studies reviewed for this paper agree on it. Even though the scopes, methodologies, timeframe, and location differed, all the studies found that the levels of N in groundwater and surface waters had, at the very minimum, higher N concentrations than the background. Studies are not conclusive to mention if major pollution exists in surface water sources or in groundwater sources. Temporal, spatial, and climatic conditions would have great effect on overall N pollution levels.

When comparing the Suwannee River Basin with other basins in the state, in the Watershed (including Georgia), and across states, it was found that, overall, the water in the Suwannee presents lower quality because of N pollution. The Suwannee River Basin or parts of the Suwannee River Basin are consistently mentioned by the studies as examples of extreme polluted values of any form of N either in groundwater or surface water.

Even though, in most of the cases, the N concentrations in the Suwannee River Basin are below the USEPA standards of 10 mg L^{-1}, several studies that include long term comparisons, along with hard data collected from monitoring stations, show that there is a noticeable increasing trend in the N concentrations of the surface and groundwater bodies that would tend to increase even faster if the land use conditions persist. Therefore, actions to mitigate the problem are needed.

By exploring hard data generated by monitoring efforts in the Suwannee, the middle Suwannee (between Suwannee and Lafayette counties) continues being the hotspot and the area with higher N pollution concerns; nonetheless, there are other areas and places where the N concentrations are showing as high or even higher than the middle Suwannee as is the case of areas in Jefferson, Levy, Gilchrist, and Alachua counties. The current effort to decrease N sources in the middle Suwannee should be expanded to other areas of concern.

It is reported that the possible nitrate sources are chemical fertilizers, animal wastes, and human waste. There is no clear cut conclusion as to which one of these represents the most dangerous source. Dairy operations are many times found as the most likely source of nitrate-N by several studies either by spatial proximity, temporal analysis, and/or by the use of isotopes. However, there is no clear estimation of how much N comes from dairy farms either as a whole or on an individual basis. It is believed that dairy farms are big contributors because of large amounts of waste produced; however there are no conclusive reports that estimate and/or compare them with other sources. Higher efforts are required to distinguish between point vs. non-point sources of pollution and to make any industry environmentally accountable as a way to face the problem and their potential solutions.

Two in-depth studies in dairy farms in the study area evidenced a high environmental impact of these operations regarding N pollution. These studies pointed out that there is a great variability between dairy operations and their environmental impacts. An appropriate approach for environmental solutions should be to treat dairy farms individually regarding their pollution concerns.

Also, these dairy studies found no conclusive answers to what components inside the operation are the greatest N polluters. These also vary substantially among farms. Even though only a decade has passed since these studies, the dairy farm systems have changed substantially, most of them now

- Do not have the “intense area”
- Have a concrete lagoon
- Do not use or use very little synthetic fertilizer

The “intense area” has become part of the “confined area” in a totally concreted covered space where all the manure is collected and where there is no infiltration. The manure goes to a concrete lagoon and from there to the sprayfields, in which usually only waste manure is used as fertilizer. Under this new structure, the sprayfields, primarily, and the pastures, secondarily, are the most likely zones inside dairy farms with higher N concentrations and consequently with higher N pollution impacts. Dairy farms as major actors in the N issue must be studied as a whole system with complete understanding of all their components under specific environmental and management options affected by varying climatic conditions.

There is clear evidence that water N pollution affects humans, animals, and ecosystems. In the study area, even though there are no reported direct or indirect human effects, there is major evidence of animal and ecosystem effects because increased N levels.

CHAPTER 3
NORTH FLORIDA STAKEHOLDER PERCEPTIONS TOWARD NUTRIENT POLLUTION, ENVIRONMENTAL REGULATIONS, AND THE USE OF CLIMATE FORECAST TECHNOLOGY

3.1 Introduction

Rising nitrate levels in north-Florida's Suwannee River are a growing concern (Hornsby et al., 2003). Awareness is high given the potential of excess nutrients to affect the environment and public health (Albert, 2002). It is alleged that the most likely contributors to contamination are dairy farms, industry, and human settlements in the region (Andrew, 1994).

The federal safety standard for nitrate-N in drinking water in the United States is 10 mg L^{-1}. In some areas of the Suwannee River Basin, nitrate levels have reached ranges of 20 to 30 mg L^{-1} (Hornsby, Pers. Comm.). High nitrate levels in drinking water can cause methemoglobinemia or “blue baby” sickness in infants (NRC, 1985) and other health problems in humans such as enlargement of the thyroid gland, increased sperm mortality, and even stomach cancer (NRC, 1978; Strange and Krupicka, 1984; Stewart, 1990; Mirvish, 1990; Forman, et al., 1985). In addition to making water unsafe for humans and many other animals, high nitrate concentrations can lower water quality in rivers and springs, causing eutrophication resulting in algae blooms that consume oxygen needed by fish and other aquatic animals (Katz et al., 1999).

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 challenges will be the greatest problem they will have to face in the near future. After interviewing 48 dairy farmers located in Lafayette, Suwannee, Columbia, Hamilton, and Gilchrist counties, Florida, Staples et al. (1997) found that the perception of anticipated costs of having to comply with environmental regulations was rated, by far, the top challenge to successful dairying in the future.

Improvements in long-term (6 to 12 month) seasonal climate variability predictions such as those based on El Niño and La Niña forecasts (O'Brien, 1999) can play an important role in formulating management strategies that dairy farmers in north-Florida may adopt in order to pursue economic and ecological sustainability. Specialized federal and state agencies such as the National Oceanic and Atmospheric Administration (NOAA) predict long term seasonal climate variability fairly accurately. These predictions are based upon the El Niño Southern Oscillation (ENSO) phenomenon. ENSO phases determine El Niño, La Niña, or Neutral years, which are related to rainfall and temperature patterns.

Dairy farmers may benefit from proactive use of seasonal climate variability prediction. The opportunity to benefit from climate prediction arises from the intersection of human vulnerability, climate prediction and decision capacity (Hansen, 2002a). This benefit from the information can be used to decrease environmental impacts while maintaining profitability in north-Florida dairy operations.

This paper discusses the perspectives, perceptions, and attitudes of stakeholders regarding the issue of N pollution in the Suwannee River Basin, the current regulations, and the possibility of incorporating climate variability forecast technology to initiate mitigating strategies. The principal stakeholders are the dairy farmers. The methodologies included a Sondeo with stakeholders, 21 interviews with dairy farmers, and eight focus groups with stakeholders.

Stakeholders' perceptions regarding nutrient overloads, regulations, and the use of seasonal climate information as a way to mitigate the nitrate problem are critical baseline data for designing solutions. The information is even more valuable because it is gathered in a participatory and consensual manner. This study translates the mind-set of the stakeholders about the N pollution issue and of the dairy farmers regarding environmental regulations and the use of climate variability forecast technology.

3.2 Materials and Methods

3.2.1 Study Area

The Sondeo was carried out in the Suwannee River Basin that encompasses all of nine and part of another six north-Florida counties. This represents an area of 7,640 mi^2. The area is comprised of 13 river basins and includes a population of 285,000. Within this area, the principal focus was on the middle Suwannee that includes Lafayette and Suwannee counties. These two counties are specific areas where the N issue is acute. In the middle Suwannee River there are hundreds of residential and commercial septic systems in rural areas. Some 300 row crop and vegetable farms also exist. Finally, 44 dairies with more than 25,000 animals and 150 poultry operations with more than 38 million birds are installed in the area (Suwannee River Partnership, 2003).

Interviews and focus groups were undertaken in Lafayette, Suwannee, Gilchrist, Levy, and Alachua counties, where the number of dairy farms totals 64.

3.2.2 The Sondeo

A Sondeo was conducted between the months of January and February 2003 by a multidisciplinary team of eight graduate students from the University of Florida (Alvira et al., 2003). The Sondeo (Hildebrand, 1981) is a team survey developed to provide information rapidly and economically about agricultural and rural problems. It is structured around a series of informal, conversational interviews between the team and stakeholders. It is a multidisciplinary process from data collection through report writing. Each team ideally includes members from the social and agricultural sciences, as well as other disciplines. When members write the final report there is much interdisciplinary cross fertilization. In the Sondeo, data are shared among the different teams and report writing is done as a group so that observations are confirmed, debated, and analyzed with members of the other teams. The results may be quantified or not but the accuracy of the findings is strengthened by the cross-checking process.

During the Sondeo*, 13* stakeholders were interviewed. This sounding out was undertaken to get a better understanding of the broad issue of N pollution in water and collect the perception of stakeholders regarding this issue in the study area. Sondeo team members represented a number of disciplines including agronomy, animal science, agricultural extension, natural resource management, forestry, and community development. Two to three-person teams conducted initial transects and stakeholders' interviews. The interviews were conducted as informal, open-ended conversations. After a team introduced itself and explained the subject of the research, the stakeholder and the team conversed about any aspects of the topic that were relevant. This open-ended approach enabled topics to emerge and be pursued that might have been missed if the researchers had been constrained by a pre-formulated questionnaire. Despite the open-endedness, a set of core themes was discussed in almost all interviews. Notes were not taken. Following each interview, the partners wrote individual notes, compared them, and then wrote a joint report for the interview. Finally, the joint reports were shared and thoroughly discussed among all Sondeo members. Each team presented its findings, which could be clarified, challenged or contrasted with the results of the other teams. This process of reporting and discussion served as the opportunity to begin noting trends, gaps in information, sources of initial inferences, and identifying new questions to pursue.

3.2.3 Interviews

Personal interviews (Bernard, 1995) were undertaken with dairy farmers and/or dairy farm managers during the fall/winter seasons of 2003/2004. Open-ended interviews were targeted to a purposeful sample of 21 farmers (30% population). The number of interviewees was chosen in order to attempt to capture the broad variability represented in the area in a collaborative manner with the Suwannee River Partnership and the University of Florida Extension Service agents in the area. A voice recorder was used in every interview after requesting permission from the interviewee. Interviews included a series of topics, but emphasized farmers' perceptions regarding the N pollution regulation issue and the potential use of climate forecasts to address the problem.

3.2.4 Focus Groups

Eight focus groups (Bernard 1995; Stewart and Shamdasani, 1990) with stakeholders were held between November 2002 and February 2004. Focus groups were open discussions among 5 to 15 people. Topics focused on perceptions regarding nitrate pollution, regulation, and seasonal climate forecast innovation technologies as an aid to mitigate the problem.

Focus group participants ranged from specialists from official agencies such as the Suwannee River Partnership (SRP), the Suwannee River Water Management District

(SRWMD), the Florida Department of Environmental Protection (FLDEP), the Natural Resources and Conservation Service (NRCS) from the United States Department of Agriculture (USDA), the University of Florida IFAS Cooperative Extension Service (CES), to private sector companies, technicians and farmers. These participants were typically called to meetings by the Suwannee River Partnership and/or by extension agents from different counties in the research area in coordination with the researcher.

3.2.5 Analysis

All participatory interactions were recorded, classified, organized, analyzed, and described. This paper summarizes the results of all the above interactions in a descriptive/narrative manner. Names of the participants are not revealed to protect the anonymity of informants.

Emphasis has been placed on a qualitative rather than quantitative description and analysis of farmer perceptions. The interdisciplinary approach to the complex problem of nitrate pollution in the Suwannee River Basin requires the use of methods from social sciences such as applied anthropology and rural sociology for a more holistic view.

3.3 Results and Discussion

3.3.1 Stakeholder Perceptions of the N Issue

3.3.1.1 Perception of water contamination

During a discussion in an initial focus group, one stakeholder, supported by several participants, challenged two main points: does water quality degradation caused by N pollution really exist in the Suwannee River; and if the problem exists, how bad is it? Stakeholders argued that is not easy to know if there is a real problem, and even more difficult to determine the source of the problem. Additionally, an actual timeline of events that may have led to the current situation is unknown. Farmers present in the meeting perceived that the 10 mg L^{-1} standard of N concentration in water enforced by the regulatory agencies is too strict compared to other parts of the world (Europe for example, has a 40 mgL^{-1} limit). This perceived low threshold is also believed to exaggerate the real problem. The dairy producers expressed that to their knowledge, there are no indications of humans being affected by N concentrations in local water. Farmers also believed that eutrophication of local water bodies is not as evident as media reports suggest. In their eyes, the appearance of streams and springs is similar today as it has always been.

Some farmers present at this meeting believed that there is a misconception of the link between the N issue and dairy farms. Participants indicated that dairy farms in the study area do not always have overflow problems. Most indicated that in general terms, large operations have higher chances of overflows. Additionally, many of the participants indicated that they were not convinced that dairy farms in general are the biggest polluters.

Conversely to these opinions, the Sondeo found that ten years earlier, an increase of nitrate concentration was recognized by the Suwannee River Water Management District in the Suwannee River Middle Basin. The increase in nitrate concentration in the Suwannee River Middle Basin as a problem was clearly evident to all stakeholders who participated in the Sondeo. A veterinarian working for a dairy farm expressed his concern for the pollution, and its potential for driving them out of business in the future. It seems clear that dairy farming is perceived as the most contaminating activity in the area. Poultry is perceived to be the second source of contamination. Row crops are usually perceived as the least contaminating of all food producing activities in the area.

However, one interviewee pointed out that greater leaching might result from fertilizer in row crops compared to the slower decomposition of manure from dairy operations. This would occur when precipitation follows an application of fertilizer in row crops, or if they over-irrigated. Moreover, the informant perceived that all farm activities might contaminate much less than non-agricultural industrial activities and waste outputs from concentrated urban dwelling in the area.

Even though the main focus in the discussions had been N loads, phosphorus (P) was also mentioned as a potential contaminant by participants in the Sondeo. A problem expressed about both these contaminants is that they may take many years to reach the groundwater. Nutrient pollution has a long term cumulative effect that results from slow processes. This makes it much more difficult to pinpoint sources of contamination and consequently potential ways of mitigation.

The Suwannee River Partnership was formed to determine the sources of N loads in the basin. The other important and connected objective was to work with local users to minimize future nutrient loading through voluntary, incentive-based programs. Therefore, the Partnership works under a non-regulatory precautionary approach. This is envisioned as being accomplished through monitoring pollution, education, promotion and adoption of best management practices (BMPs).

The Partnership is focused on the middle river basin. The main activities in that area i.e., dairy, poultry, beef, and row crop farms are the foci of the Partnership. Currently, there is little population pressure since the middle river basin is not very densely urbanized. However, a recent geographic extension of the Partnership to the southern part of the basin towards the Santa Fe River includes more densely populated areas. A logical step then would be for the Partnership to focus more deeply on septic tanks and human dwelling waste outputs.

3.3.1.2 Reasons to mitigate contamination

The main reasons identified by the stakeholders for mitigating water contamination are to preserve the ecosystem, protect human health, protect fresh water bodies that provide environmental services, and support economic activities such as tourism.

It is important to note that nobody mentioned that the water quality has an impact on their herd, poultry, or crop. It is also recognized that pollution in the river basin can have a negative effect in shellfish production in the Gulf of Mexico.

3.3.1.3 Existing and potential means of mitigation

Stakeholders were proactive about avoiding potential regulations, which did not seem a good choice for addressing the problem to them. Many farmers might find themselves in a difficult situation to fulfill imposed regulatory levels. Farmers did not want to be regulated to have to implement conservation measures. Lake Okeechobee (South Florida) regulations, which were imposed to reduce the P load level, were not successful in the sense that 50% of the dairy farms in that area went out of business. Based on this past misstep, stakeholders worked under a non-regulatory, preventive, or precautionary approach, through the creation of the Suwannee River Partnership (SRP).

The recognition of rising nitrate concentrations was the leading factor behind the creation of SRP. The idea of forming a Partnership took years. According to some stakeholders, just a few people started the partnership in the mid 1990s. More institutions progressively joined in the following years. In 2003, there were 24 members, and currently (2004) the number of partners has increased to 45. The long-term goals of the partnership are to

- Reduce pollutant loading
- Establish interstate watershed management
- Increase number of acres covered by conservation and land management plans
- Assure flow of information
- Secure cooperative long-term funding to maintain a cooperative interstate program
- Improve water conservation between two states (Florida and Georgia).

Several agencies and individuals are part of the Partnership that collaborate to monitor and to reduce the levels of nitrates in their groundwater and surface waters. For example, the USDA/ NRCS PL-566 Small Watershed Program for the Middle Suwannee assists dairy and poultry farmers to improve animal waste management and fertilization techniques. The NRCS inspects soil types, number of cows and area in pastures, and then decides the minimum set of measures to be followed. The Florida Farm Bureau (FFB), that represents farmers' interests, is also involved in developing policies to mitigate nitrate pollution in the area. The FFB annually publishes a book containing all of its policies. The Farm Bureau supports technology-based BMPs and their voluntary implementation. The U.S. Geological Survey (USGS) also has ongoing studies of water quality within the Suwannee River Basin

The Partnership focuses on finding the most economical and technologically feasible management techniques (BMPs) available to help farmers and other land users to satisfy regulatory requirements for protecting public health and the environment. Through education and outreach programs, the group continues to increase public awareness of the issues, and encourage citizen and community participation in working together to find solutions. Other components of the initiative that are contributing to the Partnership's success include the BMP Quality Assurance Program, County Alliance for Responsible Environmental Stewardship (CARES), and the On-farm Research Programs

As one component of Partnership activity, several University of Florida departments and centers, as well as state and federal agencies are cooperating on project 319 entitled "Effectiveness of Best Management Practices (BMPs) for Animal Waste and Fertilizer Management to Reduce Nutrient Inputs into groundwater in the Suwannee River Basin." Project 319 addresses BMPs on a dairy, a poultry operation, and a vegetable farm in Lafayette and Suwannee Counties in the Middle Suwannee River Basin. Each farm has been instrumented with a groundwater monitoring well network. Wells and soil profiles are being intensively monitored to determine pre- and post-BMP nitrate concentrations on each of the farms. An one-year pre-BMP monitoring phase has been completed on all the farms, and BMPs are now being implemented to address the elevated nitrate concentrations observed in some of the monitoring wells. The overall goal of this project is to demonstrate that BMPs can be implemented to reverse the increasing trend of nitrate concentrations in the groundwater and springs of the Middle Suwannee River Basin.

The BMP Quality Assurance Program verifies that BMPs are operated and maintained over a long period of time, and provides assistance to farmers in resolving problems with the BMPs. The Partnership, in cooperation with Florida Farm Bureau, has also initiated the CARES Program to certify and recognize farmers participating and following directives in the Partnership program. Finally, the Partnership has developed a joint strategy with the SRWMD to monitor groundwater and surface water on a regional basis to identify trends in water quality over time through an extensive network of monitoring points.

Technicians from the Partnership visit farms on a regular basis to monitor their N loads and to help with the implementation of BMPs. One of these technicians pointed out that many farmers were formerly wasting money buying fertilizer. With new techniques such as use of a cement pool and mixer in the lagoon to separate solids from liquids, the farmers are able to recycle their own manure, buy less fertilizer, reduce costs, and reduce N loads.

In general, farmers who have been applying BMPs feel comfortable with the results achieved. Most farmers are cooperative and eager to follow SRP directives and the suggested BMPs. Nevertheless, some practices (such as treatment lagoons or solid separators), require large investments. Money is required up-front to modify facilities, train personal and to make other adjustments. In most cases the SRP has funding available to cost-share initiatives that protect the environment.

The modality of implementation for most BMPs is completely based on voluntary participation of farmers and aims at helping them avoid stricter regulations. However, certain activities are already subject to regulatory programs.

3.3.1.4 Implementation procedures for Best Management Practices (BMPs)

BMPs for nitrate reduction in the Suwannee River Basin refer to good stewardship of land and water management that help farmers reduce nutrient contamination to water systems. There is general acceptance among stakeholders that such management practices are sound and positive for the environment. Management practices mainly include nutrient and manure management, disposal of wastes, irrigation water, technical design and engineering aspects in farming enterprises such as row crop, dairy, beef cattle and poultry farms. By large, the concerned stakeholders see BMPs as research-generated solutions to reduce potential environmental hazards from farm enterprises.

Implementation procedures are specific to each program and farm enterprise. All programs aim at implementing BMPs that reduce the loading of N contamination to groundwater while helping farmers to remain profitable. It is worth mentioning that at present, attaining the twofold objectives is at an early testing period in which cost-sharing is crucial to ease associated risk for farmers.

Based on the information gathered by the Sondeo, a picture of the step by step process of BMP implementation in the study area can be drawn. Creating and raising awareness among public agencies, landowners, agricultural producers and other stakeholders about existing water quality impacts resulting from human activities is the first step. It is necessary for recognizing that a new approach in management practices is needed to address the issue within the area. It is perceived that education on the issues and solutions, including effective transfer of knowledge and technology, are essential components of the implementation efforts of the technical working groups in the Partnership. As part of this process the Partnership conducts meetings for agricultural producers. During 2001 over 1000 farmers participated in such meetings. Gatherings included two row crop growers' meetings, a forage field day, five dairy farmers' meetings, two poultry growers' meetings, a cattlemen's meeting (beef), and a large-scale growers' meeting.

In the CARES program, growers fill out a self-evaluation regarding their farm operation to assess environmental practices. One objective of this self-assessment is to increase farmers' awareness in perceiving their own status.

The next step is that farmers show interest in joining the Partnership. At this stage agencies in the Partnership help farmers in selection and implementation of BMPs. The partnership has a Technical Working Group (TWG) in the areas of fertilizer, animal waste and human waste management. Each TWG assesses sources of nutrients within its area of expertise, develops and implements a plan of work to fulfill the mission of the Partnership, and provides updated recommendations for action. BMPs are highly decentralized and tailored to suit the diversity in size and complexity of farm operations. Initially, the focus is on management approaches, which are technically viable, economically feasible, and environmentally friendly. The study team feels that BMPs on dairy farms are far from being financially feasible. Up-front costs for implementation are especially hard to recoup. Additionally, BMP on-farm trials are conducted to verify the technical viability of the recommended practices.

Financial commitment and debt responsibility is required from farmers during implementation of BMPs. To date, BMP implementation has been very successful. Out of 144 crop farms, 115 have adopted conservation measures; out of a 35 poultry farms 34 participate; and out of 44 dairy farms, 43 are involved in the SRP. Before the Partnership, only 3 dairy farms were able to pass environmental quality standards.

After the farmers adopt BMPs that have been promoted by the participating agencies, a presumption of compliance with state water quality standards can be established. This places farmers in a much better standing of willingness to cooperate with environmental stewardship with authorities.

3.3.1.5 Impacts of BMPs on farms

Most stakeholders perceive that farmer participation in BMPs has many economic, environmental and social benefits. Stakeholders agree that after the initial investment, dairy, crop and poultry enterprises save money by implementing BMPs since they recover their own nutrients, which have a value. In the case of dairy farms, the savings could be important since no fertilizers would be needed for crops. However, stakeholders perceive that poultry farmers have only modest economic benefits because the processing of dry litter does not return much income. An additional benefit indicated was that livestock farmers who implemented BMPs are usually allowed to expand herd or flock size.

Regarding row crops, stakeholders indicated that the BMPs being promoted for crops reduce yields. This reduction in crop yields seems to be inevitable because of the reduction in fertilizer and irrigation contained in the BMP recommendation. Additionally they would require farmers to spend more time and money on management and equipment. Both aspects would decrease profitability. A major challenge then, is how to maintain row crop farmer profit margins while implementing BMPs.

In spite of difficulties, adopting BMPs may help farmers to remain in business in the long run, which is critical to the Partnership. The initial investment that farmers are supposed to share may still be a big challenge considering the returns that farmers obtain as a result of adopting BMPs. But ultimately, middle Suwannee farmers will be able to choose from one of the three options: receive financial assistance to practice BMPs and stay regulated under incentive-based programs; receive a certain amount of money and leave the land; or comply with regulations under permit on their own.

3.3.2 Perceptions of Regulations by Dairy Farmers

During the interviews, dairy farmers expressed their concerns that regulations are currently stricter than in the past, and that they will become even stricter in the future. At the same time, several farmers expressed that the manure and all its by-products have a tremendous commercial potential as a source of energy and nutrients. Potential benefits from by-product sales could mitigate stronger future regulations.

Sixty-two percent of interviewed farmers participate in incentive-based regulatory programs. One third of them work under permit, and one farm has no regulation at all. Incentive-based programs are voluntary commitments between the farmer and the regulatory agency as promoted by the SRP. Farmers under permit are those that are enforced by the regulatory agency. Usually medium and small farms (up to 700 cows) are under incentive-based programs and larger farms are under permit. Also, it can be said that newer farms are under permit and older farms are more likely to be under incentive-based programs.

All farmers expressed a clear message. They wanted to make sure the general public understands that producers are not trying to pollute the environment. Farmers only seek to earn their living and to do their best to protect the environment.

Eighty-one percent of dairy farmers interviewed agreed or felt comfortable with current regulations. However, the remaining 19% disagree more or less with the current environmental regulation framework (Figure 3-1).

The one farm that is not regulated is a small farm that received an invitation, but does not want to participate in the cost-share program because the owner believes that they can protect the environment in their own way. Fundamentally, the farmer does not want to be controlled at all times. He is confident the problem will not increase from present levels and that his farm will continue functioning as it has done for more than a half century. However he is aware that if they are forced into compliance with regulations, he would probably go out of business.

3.3.2.1 Farmers in disagreement with regulatory measurements

One of the farmers in dissension was very disappointed and very upset about the regulatory agencies, especially with the Florida Department of Environmental Protection

(FLDEP). He felt betrayed in the fact that he was once told that he runs an exemplarily clean farm and was even publicly recognized for that fact on one occasion. Later, after activists groups sued the FLDEP, the department requested he make a cumbersome investment on his own. The farmer stated

> Their stuff is not scientific, they listened to what people say and they got scared. They do not have any money for me, as they have been able to provide for many other dairies. They have put 18 people out of work on this farm because I had to reduce the herd size by half. If they place just one more regulation on me, I will be out of business

The indispensable requirement for scientific studies in the eyes of this farmer is an interesting and novel point. Often, the opposite view might be expected. Apparently, the FLDEP in this case is regarded as a politically driven agency that does not necessarily back up their case with science. A perception of inequitable treatment on the part of the cost-share program with regard to this farm might be regarded as a strong motive for this farmer's ill feeling toward the regulation process.

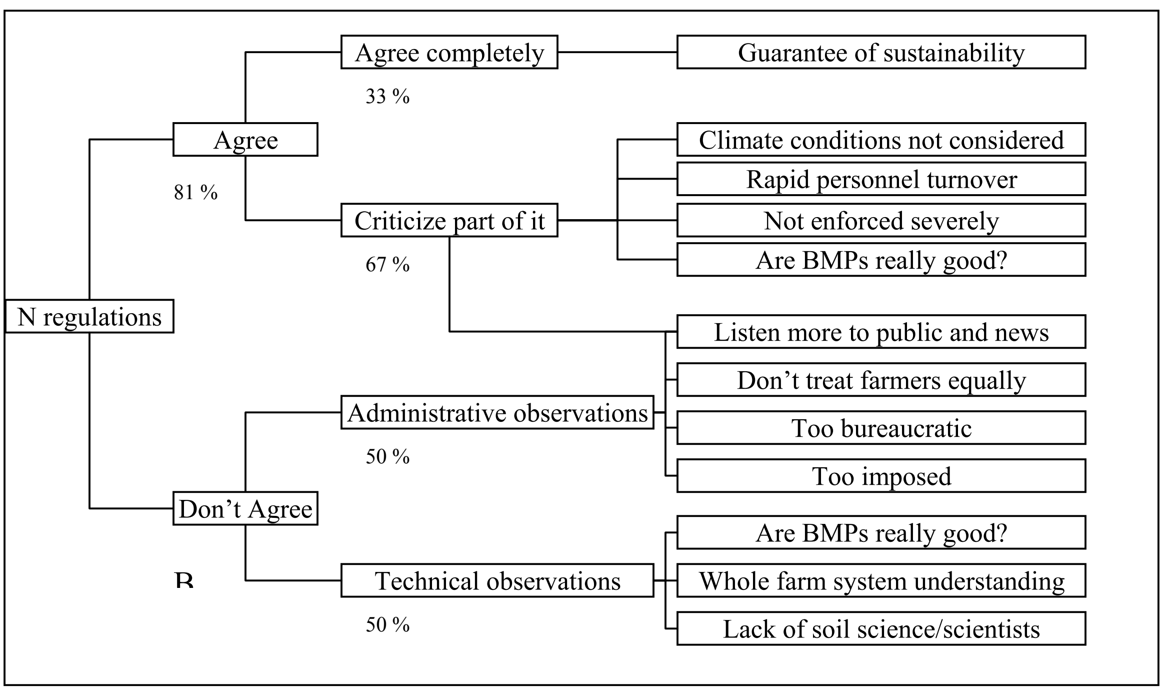


Figure 3-1. Farmers' perceptions of environmental regulations in north-Florida

This farmer elaborated further saying that the FLDEP requested he install more concrete free-stalls to collect manure and more irrigation systems to dispose of the effluent in the fields. He thinks that is not a correct solution because it would create even more problems with neighbors concerned with odors. He added

> I did not even have a chance to discuss my options. The regulation was imposed. They told me: do all this or reduce your herd size. I decided to reduce the herd size because I felt that I could not trust the regulatory people any longer. It would not be surprising if, after I make all these investments on my own, after a few years they would come again and ask me to change all over again because the neighbors are not happy

This farmer expressed a common complaint in processes of this nature. He was left out of the process and not consulted from the beginning. Furthermore, it is apparent to the farmer that no matter how hard he tries; the dairy farm is in a vulnerable position with respect to new regulations in the future. In this farmer's opinion, the interests of the farmer will always be secondary to those of the "neighbors."

Another complaint regarding the regulations was from one relatively new farmer, who had to fight for more than two years to get a regulatory permit approved for a small dairy operation. The farmer considers himself to be over-regulated compared with other much larger dairies in the area. The farmer also mentioned that the approval process has been very costly and the farm could not count on any financial aid. He felt that he was forced to go through the process. This farmer mentioned I have fewer than 400 cows and they made me install and monitor six wells with all the expenses it implies while there are farms with thousands of cows who do not have this type of control. This farmer feels that reports in the news have been particularly prejudicial to his situation and probably one of the causes of this very strict permit. The other two farmers who do not agree with current regulations based their perceptions more on technical issues. Both considered that the suggested BMPs would not be the most appropriate either for the environment, or for the farms. One important point was the fact that the main BMPs promoted include a flushing system (dilution of manure to spray it in fields) that, to quote one of the farmers:

> Seems to be aimed at losing most of the N to the air instead of trying to use it as fertilizer. Besides, the promoted system requires a big investment and is fixed to a physical space. Why do they not promote a system, like the one in the northern part of the country that uses slurry (with minimum flushing) and gives the farmer the flexibility to apply it to different plots or even easily export it off the farm?

The farmer offered a strong critique in this statement of the technical expertise of those in charge of designing and implementing BMPs. The producer apparently perceives that the system proposed simply postpones further regulation for the moment by converting a local negative externality into a diffuse global one. In essence, N is being spewed into the atmosphere instead recycling it for other uses.

The other important point was the lack of understanding by those creating BMPs of the dairy farm as a whole system. One of the farmers mentioned that very capable people exist on the regulatory teams, but there is a lack of personnel with an interdisciplinary understanding of the dairy system. He has witnessed problems other dairies have had because the engineered designs did not take into account all the components of the system and their interactions. Indeed, he is aware that some BMPs are being revisited and redesigned after several failures have been detected.

These two dairymen think that the soils are the main component in solving the N issue. They think that farms and regulatory agencies should work more aggressively with a focus on soils. They both believe there is a lack of soil scientists on the regulatory teams. The result is that regulatory agencies are not doing a good job protecting the environment taking into account soil dynamics. One of these farmers added that the regulatory agencies should clearly distinguish between real data and perception information regarding water pollution by N

> I am not completely sure if a real problem exists. Studies of the trends of N pollution are not completely conclusive. Nor do I recall were they conclusive in the case of the P issue in the Okeechobee area, where regulatory agencies imposed a limit of P run-off discharge lower than what common rainwater would have

Some farmers hold a less than credible reputation of the FLDEP. This poor perception dates at least as far back as the years of regulation in the Okeechobee area. The loss of dairy farm livelihoods in that area was never proven conclusively to be the result of a tangible problem, at least in their minds.

Another informant also corroborated this last point regarding mistaken regulation standards. The last two farmers mentioned apparently feel that precaution is not necessary and that only when science proves without a shadow of a doubt that something is harmful should regulations be imposed. These farmers apparently did not consider the notion that it might be too late for action by then.

3.3.2.2 Farmers who agree with regulations but criticize part of it

Among respondents who agree with current regulations, some criticized some particular aspects related to the regulations. Two farmers mentioned that FLDEP fines farms without taking into account the climatic conditions that, for example, determine inevitably high N measurements in lysimeters when wet periods follow dry ones. Another point was the constant change of personnel in the regulatory agencies that could be disadvantageous to farmers. This is because over the years, officials become acquainted with specific farm situations. When new agents are hired, there is a period required for building-up new relationships and understanding site-specific problems. Besides this, new, usually young agents, tend to be more environmentally oriented. Often, they fail to grasp the fact that farmers also need to make a living.

On the other hand there was also one farmer who criticized FLDEP and the regulations as being relaxed, implying that the regulations should be enforced more aggressively in order to avoid intervention by the federal Environmental Protection Agency (EPA). He perceived EPA regulations and enforcement as potentially much stricter, which would be very difficult for all in the area.

Another criticism of farmers who do agree with the regulations came from one farmer who believes that a third party plays a role too important in the regulations. This "third party" is a term used to refer to activist groups that raise public concerns about environmental issues. In this farmer's opinion, FLDEP takes their opinions into consideration disproportionately. The argument was that these third parties have nothing to lose and that the FLDEP listens more to activist groups and the public, and takes farmers' concerns and situations little into account.

Other respondents corroborated the fact that the news media have a great impact on regulations and on FLDEP enforcement of regulations. In terms of regulations and enforcement, the opinion of one journalist could have a greater worth than the opinion of a number of farmers.

Some other farmers, who in general agree with current regulations, mentioned their concerns about the scientific basis behind the requested technical actions, which may not be the most appropriate for specific farms. This is related to the previously mentioned perception that the regulatory agency is not looking at the overall system. One farmer expressed: some times it is easy for them to tell you what you have to do. But, usually they do not know how difficult it is to implement these actions, and what other impacts could result from implementing the management changes.

Many of the farmers expressed their concerns regarding other non-point potential sources of pollution. The main argument was centered on challenging the fact that dairy farms are the most contaminating of all. They believe that this statement still needs to be proven, and in any case they ask why are not row crop farms, golf courses, human settlements, among others regulated in the same way as dairy, poultry or pig farms?. One farmer mentioned: they count every pound of N the cows excrete on this farm but they do not control the neighbor's farm that uses two to three times more fertilizer than the recommended rates for vegetable crops.

Another point mentioned by several farmers may have important implications for regulations. Many people are regularly moving to live in the countryside in Florida. Often, these newcomers find that they do not like the manure odors until after they are well established. Most farmers think that newcomers should be aware of what they are buying into, and expect and accept normal rural odors. However, there are a few farmers who actually believe that just because farmers were established first is not enough argument to disregard odor problems of newcomers and they should work trying to mitigate it. One farmer is convinced that in the future, odor problems, more than any other issue, will put his farm out of business.

Farmers are also looking for permanence and consistency in the regulations. Some farmers are concerned about potential changes in the set of regulations that might turn out to be disastrous for their conditions. Farmers have learned to survive under current conditions as long as the FLDEP does not change the basic, initial guidelines. This fact is related to a concern expressed by several other farmers regarding the potential that regulations might become unreasonable or impossible to implement if they change. This eventuality is perceived as even more uncertain because farmers understand that the FLDEP follows directions from the EPA. Farmers feel a total disconnect from the federal agency.

Almost all interviewed farmers agree that the compliance process with the regulatory agencies is not a money-making adventure. All are conscious that it costs money, but they have no choice but to comply.

3.3.2.3 Farmers who completely agree with regulations

At least 33% of the 81% of producers that agree are completely at ease with the regulations. All of them believe that they are working towards a sustainable way of doing business. Thus, the regulations are perceived as a guarantee of survival in the long run. For many of them there is a history of success in north-Florida because of the cost-sharing program that is allowing them to work together with the research, extension, and regulatory agencies in searching for regional and site-specific solutions. One farmer mentioned: the Partnership and the incentive-based program in the Suwannee River Basin are wonderful things. These will help farmers to be better off in the future. Although many farmers realize that mistakes have been made in the past, they believe that all parties are learning from the experience and that everyone together is building expertise to protect the environment and keep farmers in business.

From all these farms there is a sense of engagement in the program for protecting the environment that makes them proud and eager to implement environmental friendly practices even if they do not have an economic return. They believe in general that the regulations and mostly the participatory approach have been correct. Also, many of them appreciate the fact that the program is flexible and can be discussed with the regulatory agencies.

One farmer mentioned that they are trying not only to comply with the current regulations, but are proactively seeking to exceed these regulations. This producer warns that he is not necessarily looking for a new set of rules, but rather embracing the regulations to become better stewards. This farmer predicts that FLDEP will be willing to face the public for a farmer if the farmer is on the right side at all times. This fact would be much more important in the future because regulations will become much stricter, not only in the dairy farm industry, but in all aspects of human life. This farmer feels farmers will be better prepared for those times thanks to the Partnership's efforts.

3.3.3 Perceptions of Climatic Technology Innovation

Recent advances in atmospheric research have made it possible to predict climate variability with a relatively high level of probability. Knowledge of climatic conditions may allow improved seasonal management strategies for dairy production in Florida. Once again the opinions were divided. Of the 21 farmers interviewed, 14 (67%) mentioned that they would use improved forecast information, 5 (23%) would not use this technology, and 2 (10%) were not sure (Figure 3-2).

3.3.3.1 Farmers that would use long-term climatic forecast

All 14 farmers who believe they would use improved long-term climate variation forecasts say that their main use of the information would be in planning crop systems. One producer mentioned he already uses ENSO phase information to plan the farm's crops:

> I make decisions every year based on my beliefs of if the seasons will be dryer/wetter, cooler/hotter. For example, for winter, if I expect an El Niño, I will plant oats because they do well in moist conditions. If it will

> be a La Niña, I will choose rye because it handles drier conditions much better. Of course, I will always plant ryegrass and clover, no matter what the climate prediction

This farmer thinks that forecasts would also be useful for adjusting planting dates in order to obtain better yields and more N uptake. He has yet to implement this management strategy. Another farmer also uses long-term forecasts but not based on ENSO phases. He relies instead on the experiential knowledge of an old, experienced person who predicts the up-coming seasons in terms of wetter/dryer and colder/warmer. This in turn determines the crops to be planted. This farmer was very interested in the ENSO forecast information and tools and inquired as to its availability.

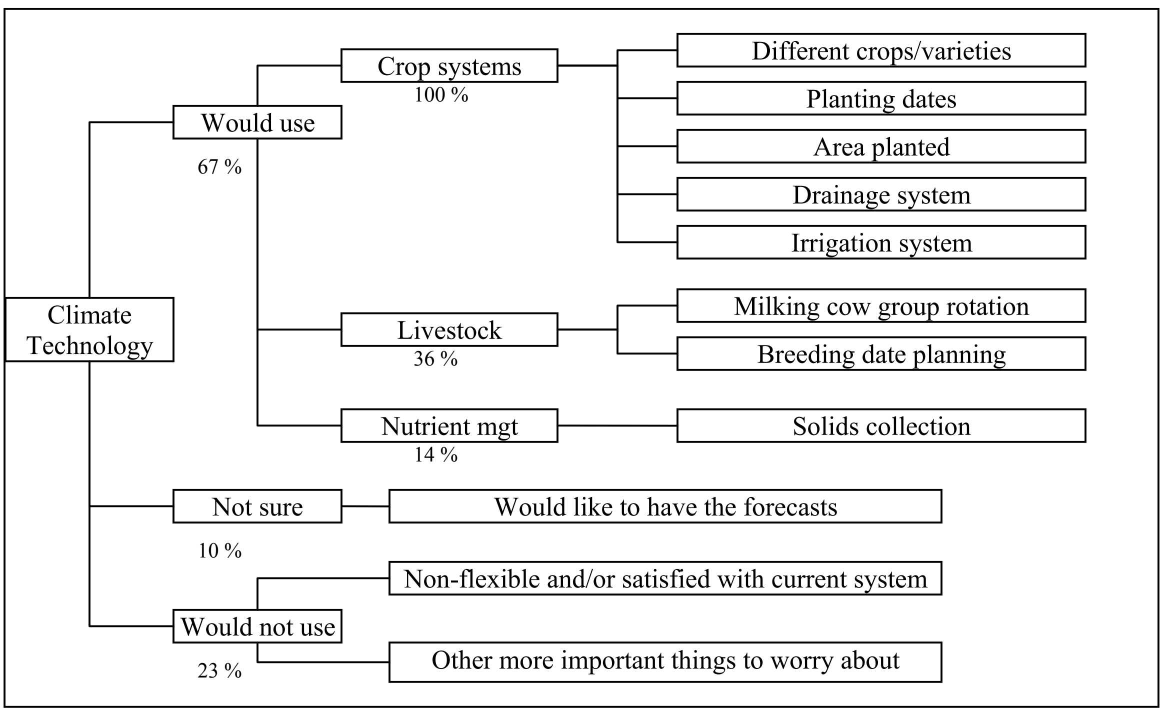


Figure 3-2. Farmers' perceptions of climate technology adoption

In the same manner as the farmer who already uses ENSO forecasts, most of the farmers believe that the use of the forecast would be in crops. Mainly, the producers would use information for substituting crops in specific seasons and to change planting dates. For the winter season, oats and rye were mentioned several times as interchangeable crops. Most agreed that drier years (La Niña) are better for rye, and wetter years (El Niño) better for oats and/or ryegrass. However, some other producers mentioned that temperature is the most important variable, and that hotter winters with less chance of freezes (La Niña) would be better suited for oats. For the case of freezes, some farmers agree that if the prediction could address those events, they would be very useful because that would let them know how much crop production to expect in winter. Based on this they would adjust crop plans. For example, if there were going to be more than the typical 20-25 freeze days, winter forages would be affected. Therefore, they might plant more area in order to produce the required amounts of feed.

Climate forecasts for the spring/summer season would be more beneficial for planning the planting date for corn. Those who plant corn say that the earlier you plant, the better the results. If farmers know there will be little risk of late freezes, they could plant as early as possible, for example in the first week of March.

For the summer/fall season another important decision would be between planting a second crop of corn or sorghum. Farmers mentioned they would plant a sorghum crop if they know that drier than normal conditions are expected. Potential changes in choice of crops refer not only to different species, but also to cultivars within species. Some varieties have different responses to climate conditions. Farmers mentioned these possibilities without entering into specifics.

Another group of informants mentioned an additional possible use of climate with respect to crops. One farmer mentioned they could use the prediction information to alter the area of planted crops. In wetter conditions area would increase. In drier seasons, less area would be sown. Another farmer mentioned that climate data would be useful for planning drainage systems, especially before a wetter summer. A further potential use mentioned was in planning irrigation systems management. Although these systems are mostly fixed, farmers could make some adjustments if they know what the seasonal climate would be like, especially regarding rainfall.

Besides the use of forecasts for crops, another potential use of climate forecasts would be for the livestock. Three out of the fourteen interviewees who would use the forecast elaborated on this issue. One farmer mentioned that she could plan her cow rotations differently. Holstein cows are very sensitive to "heat stress" calculated by an index that takes temperature and humidity into account. When the index is high, in hot and humid months, milk production is affected negatively. If seasonal variability toward hot, humid conditions is known ahead of time they would be able to better plan the development of cow groups. This farm, like others, has comfort facilities where milking cows are protected from heat stress, that is, climate effect is diminished. However, on almost all farms, these milking cows spend part of their time outside. The farmer found it logical to think of planning ahead of time to provide the most protection time to the most productive group of cows.

One more decision that could be managed in light of climate forecasts is breeding time. This would be done by changing the number of cows entering the milking group in a certain season according to the forecast. For example, if a mild summer were expected, then the farmer would breed the cows in time to have more milking cows than normal in production for that summer. Climate knowledge would allow higher than normal amounts of milk to be produced in summer. Similarly, decisions regarding purchases of replacements heifers could be improved based on expected climatic conditions.

Typically, farmers buy replacements in fall. If spring or summer were going to be colder, they could take advantage to buy less expensive replacements before those seasons.

An additional possible use of forecast mentioned for livestock was for the winter season. Specifically climate forecasts would be used to anticipate colder than normal winter seasons, which are also detrimental for the cows. In those situations, farmers could plan ahead of time to have more forage (either planted or purchased) available. Extra amounts of fiber would help cows stay warmer.

Another two farmers mentioned the potential use of the forecasts for planning feedstocks. The inventory of feed is a major management task on dairy farms. Therefore, knowing the climatic conditions ahead of time would be important to preparing feedstocks (either produced or purchased). For example, one farmer mentioned that if he would know ahead of time that the next season is going to be dryer, he would plan to have more forage for his heifers and dry cows. The farmer mentioned additionally that not only would it be good to plan for feed shortages, but also to plan for excess feed produced. Too much feed on hand is also a problem. If the predicted conditions for next seasons are good for forage production, then producers could plan not to buy feed. They could also sell feed in advance, or decrease acreage planted.

Additional to the use of forecast for crops and/or livestock, three farmers mentioned that the information could be used for improving N and P management on the farm. Waste management systems are mostly fixed, so considerable changes to this system is not an option. Farmers usually change daily management based more on daily weather than long-term climate, however there are some things that could be planned, as is the case of for example, of collecting or not collecting solids from the waste management system. These farmers mentioned that if they know that there will be wetter conditions, they would prefer to prepare the whole system to not collect solids because the pile of solids resulting from the collection would be difficult to handle under wetter conditions. This major change would determine that the effluent will have more solids in solution. Therefore, the irrigation must have higher pressure and the crops must be prepared to receive a slightly higher percent of N in the effluent. If they know that the conditions would be dryer than usual they would prepare to collect all the possible solids from the waste management system and together with this action they would plan what to do with these solids, apply to fields of the farm or export out of farm.

3.3.3.2 Farmers who would not use long-term climatic forecast

Farmers that mention they would not use climate forecasts as a technology to help in decision-making argue that they have relatively "fixed" systems. In their rather tightly–bound systems, no changes in management need be planned. One farmer mentioned: I am married to my system operation… it works and I don't want to change anything that could mess things up. These farmers said that their decisions are based more on the short term. If they knew there was no rainfall predicted in the following week, they would cut hay. It is difficult for them to envision how they might change tasks months in advance. One producer noted: unless something as disastrous as a hurricane is forecast, I would not do anything different. Another farmer argued: we have much larger problems to worry about. When we solve those other problems we might start thinking about incorporating climate forecasts in our planning. Another farmer was very convinced that:

> We are not going to change anything even if we know that a very abnormal season is coming. Even then, we would continue to do as we

> always have, that is, adapt to the weather conditions, making changes to respond to the weather conditions

Other farmers may share this farmer's skeptical view of the technology. Those who are naturally averse to change or have not been exposed to new technologies will exist.

3.3.3.3 Farmers who are not sure they would use long-term climatic forecast

The two farmers in this category had never previously thought about climate-related management changes. They mentioned that the entire concept was completely new to them, so they would need time to digest the idea. Initially, however, they were not sure if they could incorporate climate variability forecasts into their decision-making process. Both these farmers mentioned that, even though they did not know if they would use the technology, they would like to be aware of the forecast to consider it in regard to their performance in the following seasons.

3.4 Conclusions and Recommendations

All stakeholders included in the Sondeo had a general consensus that growing N levels in the Suwannee River Basin is a real and current problem. However, stakeholders included in the focus groups, and especially dairy farmers challenged this fact during the personal interviews. People interviewed during the Sondeo showed more awareness of the real consequences of increased levels of N in water bodies. Dairy farmers and other stakeholders involved in the interviews and focus groups, even though they recognized that the presence of high levels of N is detrimental for the environment, showed a certain degree of skepticism regarding the gravity of the problem.

Every effort needs to be made to communicate more clearly to the general public real trends of N in water bodies and their potential consequences. The message must be conveyed using consistent scientific data.

Most of the informants perceived that dairy farms are the highest polluters. However, many stakeholders included in the Sondeo, focus groups, and interviews questioned this popular belief. Dairy farmers in particular, perceive that there is a misconception of the dairy farm industry and its environmental impact. Further research should be devoted to investigate the contribution to contamination from each potential source. It is important that individual operations be held accountable. Point vs. non point N source pollutions must be further studied. Analyses of long-term monitoring studies comparing different industries and their environmental impacts must be undertaken.

Farmers are willing to participate in incentive-based programs such as those promoted by the Suwannee River Partnership. The principal driver behind this willingness is a desire to avoid being regulated by official agencies. The Suwannee River Partnership has a very positive perception and support from the stakeholders. Most of the stakeholders perceive that the promoted BMPs are beneficial to the environment but are not cost effective to the farms. Some farmers believe that the BMPs could be re-engineered to better serve their purposes according to specific farm conditions. Further research and validation of BMPs must be conducted. A guideline describing the steps to develop BMPs should be created, and an economic feasibility study on BMPs that takes heterogeneity of farms into account should also be conducted. Extra funds should be devoted to expanding the impacts of the Partnership.

Farmers feel that environmental regulations are becoming stricter and more uncertain in time. These regulations represent one of the biggest challenges for the future. Farmers want to express that they are doing their best to protect the environment. A vast majority of them agree with current regulations but they have serious observations to make regarding the technical and administrative procedures. The Partnership is helping to change farmers' attitudes, but still more communication and outreach work is needed to gain the complete understanding from farmers.

Two-thirds of the interviewed farmers believe they can use climate variability forecast proactively. All of them would use it primarily for crop management. Additionally some could use it for livestock management. Some could use the seasonal climate variability information for feedstock management, and some could apply this technology to the management of the waste system.

Further research calls for the inclusion of climate variability forecasts into existing BMPs experiments. Studies that explore the interaction between climate and nutrient overflow in dairy farm systems must be promoted. Farmers should be involved from the early stages of these research processes.

The main barriers for potential adoption of climate forecast technology by farmers are the "rigidity" of dairy farms and the lack of management resources. Agencies interested in delivering climate forecasts as an innovation must identify the narrow niches where they may be used based on the experience of others. The technology should be translated into clear and rapid management adjustments that farmers could apply without involving excessive administrative transaction.

The fact that some stakeholders have never before thought of the potential application of climate forecasts denotes a lack of awareness of available forecast innovations among the stakeholder community. Step one in any diffusion process, i.e., awareness of the existence of a given technology, is missing among dairy farmers in the study area. Commitment to extension and outreach programs that make this information available to all networks of stakeholders and especially to dairy farmers is essential to the future success of incorporating climate-based management into overall schemes to reduce N loading into the environment.

The participative process described in this study underscores the critical need to include farmers and other major stakeholders in every stage in order to assess real perceptions that further will be used for consensual problem-solving. Its relevance is even higher when complex problems exist as is the case of the interactions of N pollution, its regulations, and the potential use of climate forecasts as a way of mitigate them.

CHAPTER 4
A METHOD FOR BUILDING CLIMATE VARIABILITY INTO FARM MODELS: PARTICIPATORY MODELING OF NORTH FLORIDA DAIRY FARM SYSTEMS

4.1 Introduction

Much work has been published on the mathematical description of models and model outputs. Conversely, little effort has been invested to date to describe a process of stakeholder interaction or participatory modeling that might be essential for increasing adoptability of models among end users. Models are often created to simulate real conditions, predict potential outcomes, and ultimately be a tool used by stakeholders. Many models have failed in this last requirement because they do not represent the conditions relevant to stakeholders nor do they comply with requirements of the final users for simplicity and user-friendliness.

Substantial changes must be incorporated into all phases of model development to improve end-user adoption. One important aspect required is intensive and effective participation of all stakeholders (Stoorvogel et al., 2004). This study highlights the use of stakeholder interaction methodologies—originally developed for use in international rural development—to first gauge the need for, then refine these management products and tools. Working with stakeholders in a learning process involving as many feedback loops as necessary will increase the probability of higher adoption rates.

The traditional system analytic approach emphasizes the importance of quantitative modeling, rational planning, and economic analysis. This is closely linked with operational research that looks for optimal solutions for complex problems (Rosenhead, 1989). However, the application of traditional system analytical methods to complex societal and policy problems has not always been helpful because problems of validation and because the absence of adequate social scientific theories and empirical data (Stoorvogel et al., 2004; Jones et al., 1997). One efficient way to elicit up-to-date and high quality empirical data is through stakeholder interaction (Geurtz and Joldersma, 2001).

During the 1980s, systems analysts realized that much of the understanding of the problem is generated in the process of model building; consequently, participation of the stakeholders in the model building process is useful (Geurtz and Joldersma, 2001). Therefore, the participation of the potential final users should enable the researcher to enrich the model by including subjective sources of knowledge in addition to the "objective" knowledge derived from theories and empirical studies (Geurtz and Vennix, 1989; Verburgh, 1994).

Systems approaches at the farm scale must include not only the biophysical component, but also the social, economic, political environment of the farm together with a "bottom-up" approach (Jones et al., 1997).

Development in methods of modeling analysis and in practice shows a shift from a uni-central, analytic, scientific approach to a more multi-central, interactive stakeholder approach. These shifts are accompanied by a growing interest in participatory styles of policy making and participatory methods of policy analysis. The application of the participatory methods generally follows the paths of logic-in-use, which shows the need for a methodology for participatory policy analysis (Geurtz and Joldersma, 2001).

Participatory Rural Appraisal (PRA) describes a growing family of approaches and methods to enable local people to share, enhance and analyze their knowledge of life and conditions, to plan and to act. PRA has sources in activist participatory research, agro-ecosystem analysis, applied anthropology, field research on farming systems, and rapid rural appraisal (RRA). Natural resource management (NRM) and agriculture are fields in which PRA finds applications (Chambers, 1994).

Farming systems research (FSR) advocates for interdisciplinary/participatory approaches to deal with farm scale simulations (Norman and Collison, 1985). Nevertheless, some authors have pointed out that FSR is often location specific and descriptive (Dent and McGregor, 1994; Jones et al., 1997). An alternative approach is to study the complete regional production system in close interaction with farmers. Vereijken (1997) developed prototyping as an alternative to the more model-oriented and farming system approaches. Prototyping procedures have a participatory character of scientists directly collaborating with farmers.

Simulation-aided discussion about crop management has underpinned advances in farming systems analysis as a vehicle for management intervention (Keating and McCown, 2001). Similarly, McCown (2001) and Hammer et al. (2000) both argue that connectivity and dialogue among key players is essential for achieving relevant and significant intervention. In this sense, the dialogue around the simulation process could be as important as the underpinning models, although it is clearly reliant on their existence and influenced by their reliability (Nelson et al., 2002). Meinke et al. (2000); Robertson et al. (2000); Keating and McCown (2001); and Meinke et al. (2001) provide examples of participatory approaches using simulations to drive relevant and significant results. These approaches are not about science simply providing the answers for management to practitioners, but rather employing cooperative learning to develop solutions (Nelson et al., 2002). Direct participatory action research with farmers has helped establish credibility of models and simulation analyses (Meinke et al., 2001).

According to Archer et al. (2002) if the model simulation software is created for farmers, extension agents, and/or farm advisers, it should be designed to be user-friendly and to require minimum data inputs. Also, Archer et al. (2002) argue that it is not only important that the model be able to predict what is required, but also to make the predictions quickly and easily, in a readily accessible form, for site-specific conditions, in real time. Both the participatory and the user-friendly approach were used as the methodological basis for developing a climate-influenced dairy farm model for North-Florida. The benefits of involving farmers in research to encourage engagement and learning for scientists and farmers are well documented (Paine et al., 2002; Onema et al., 2001).

North-Florida's climate is highly affected by El Niño Southern Oscillation (ENSO) (O'Brien, 1999). Since agriculture is the activity most vulnerable to climate variability (Hansen, 2002b), farmers might benefit from new methods of seasonal climate forecasts connected to system simulation models to tailor management options regarding agricultural, economical, and/or environmental outputs. Intensive technologies offer a broad range of options for adaptive responses to climate information (Hammer et al., 2000). Dairy production in sub-tropical north-Florida is a very intensive system. The Southeastern Climate Consortium (formerly Florida Consortium) was created as an interdisciplinary, multi-institutional partnership involving researchers from 6 universities in the states of Florida, Georgia and Alabama. The research group found that it is critical to involve stakeholders actively from the beginning of a process to understand the effects of climate variability on water and agriculture. Agencies with strong established relationships and trust with end-users must be engaged to improve the chances of delivering operational applications of climate information to final users (Jagtap et al., 2002). One such application to emerge is the dairy model whose development process is the subject of this paper.

It is not the aim of this paper to describe the mathematics of a dairy farm model. The main aim is to describe the process of collaborative creation of a regional north-Florida dairy farm model adaptable to any individual farm. The purpose of the model is to tailor management strategies for different climatic conditions by estimating monthly rates of N leaching and profit. An overriding objective of the model as expressed by stakeholders was to decrease environmental impacts while maintaining profitability. Specifically, the study sought to engage stakeholders in the process of creating, calibrating, and validating a whole north-Florida dairy farm model (Figure 4-1).

4.2 Materials and Methods

The study was undertaken in north-Florida's Suwannee River Basin, covering part or all of Alachua, Gilchrist, Levy, Lafayette, and Suwannee counties. An adaptation of the emerging approach in Farming Systems Research and Extension presented by Bastidas, 2001 (Figure 4-2) was used. Interviews and focus group meetings were carried out on a continuous basis, divided into five phases. Phase One consisted of the initial developments. Phase Two was about the sounding out or rural appraisal. Phase Three consisted of greater stakeholder involvement. Phase Four included meetings and interviews to elicit feedback from stakeholders on the prototype model. And in phase

Five, the tentative final model was taken to stakeholders for the validation, their final suggestions, and recommendations.

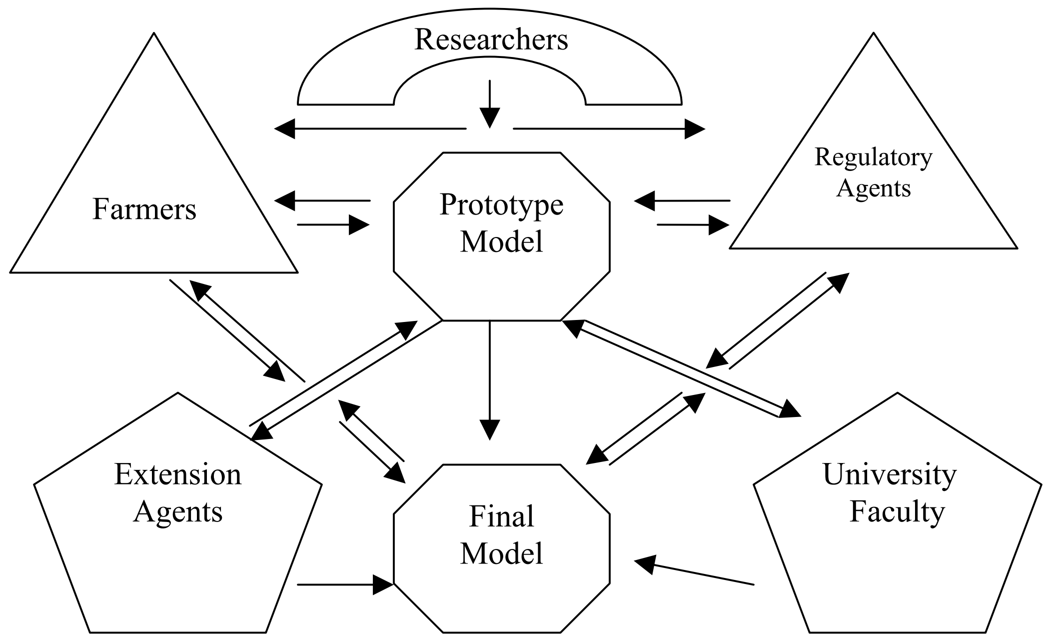


Figure 4-1. Schematic of participatory modeling

4.2.1 Main Framework

In Figure 4-2, all stakeholders involved in the issue of N pollution in groundwater by dairy farms are referred to as "users." Users must be identified and their differences recognized. Diverse users have specific and diverse needs. These needs must be identified and considered before starting the modeling/simulation process. PRA methods are ideal for initiating and maintaining high stakeholder involvement. This can be characterized as a continuous learning process.

In Figure 4-2, arrows among users, needs, and PRA indicate the iterative and dynamic process among researchers and stakeholders to determine felt needs that must be incorporated in the modeling. A following step includes the integration, creation, and improvement of models. Once again, the arrows indicate the iterative and dynamic researcher-stakeholder process to improve models in order to make them more amenable to final users. Inclusion of prototype models during this time is useful.

The process in which adjustments to models are made in order to better represent reality is called calibration. Because it is a continuous process, calibration moves seamlessly into validation when fewer and fewer major changes are required. Validation is the part of the process that is undertaken after researchers and stakeholders agree the model fits real conditions adequately. At this point testing models against independent data, i.e., data from stakeholders who had not participated in the creation of the original models is used.

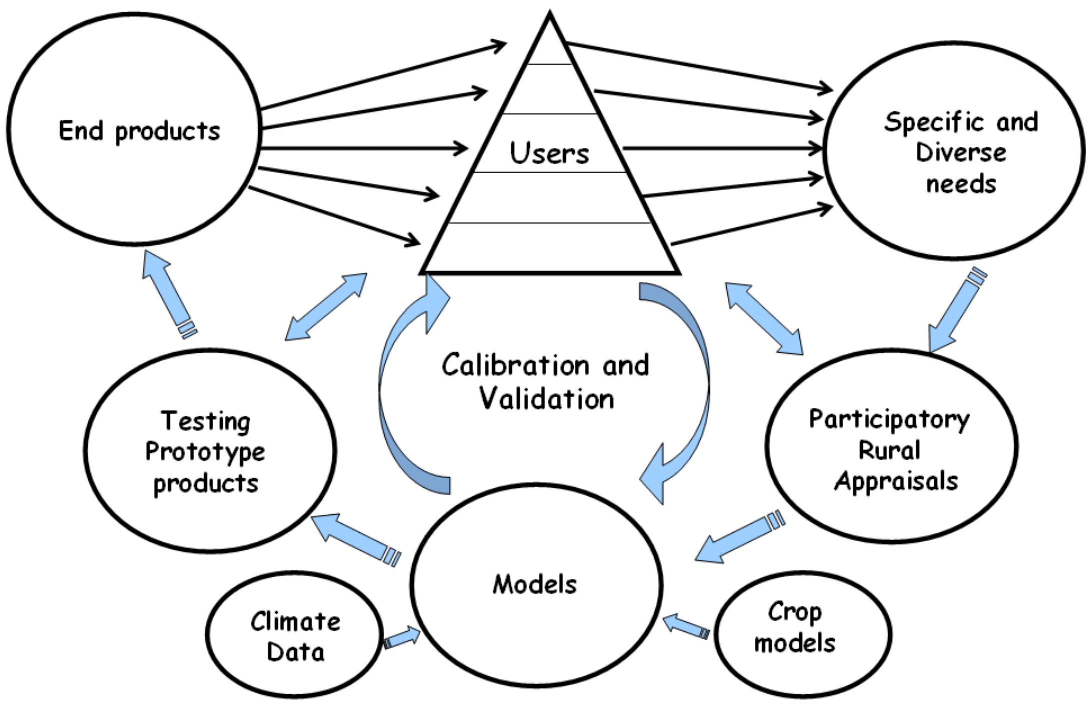


Figure 4-2. Methodology of participatory modeling. Source: Adapted from Bastidas (2001), p. 19.

After final adjustments and validation, a final product flexible enough to fit the diversity of all users is the goal of the interactive process. Because it has been a participatory product, higher than normal adoption is expected along with higher than ordinary usefulness.

4.2.2 The Sondeo

A rapid rural appraisal or Sondeo (Hildebrand, 1981) was conducted between the months of January and February 2003 by a multidisciplinary team of eight graduate students from the University of Florida (Alvira et al., 2003). During the Sondeo 13 stakeholders were interviewed. This sounding out was undertaken to get a better understanding of the broad issue of N pollution in water. Another objective was to understand the dairy farm systems in the Suwannee River Basin and initially identify the type of modeling products that might be helpful for proactive management in light of climate variability forecasts.

The Sondeo team consisted of graduate students from a number of disciplines including agronomy, animal science, agricultural extension, natural resource management, forestry, and community development. Two to three-people teams conducted transects and stakeholders' interviews. The interviews were conducted as informal, open-ended conversations. After a team introduced itself and explained the subject of the research, the stakeholder and the team conversed about any aspects of the topic that were relevant. This open-ended approach enabled topics to emerge and be pursued that might have been missed if the researchers had been constrained by a pre-formulated questionnaire. Despite the open-endedness, a set of core themes was discussed in almost all interviews. Notes were not taken. Following each interview the partners wrote individual notes, compared them, and then wrote a joint report of the interview. Finally, these joint reports were shared and thoroughly discussed among all Sondeo members. Each team presented its findings, which could be clarified, challenged or contrasted with the results of the other teams. This process of reporting and discussion served as the opportunity to begin noting trends, gaps in information and new questions to be pursued.

4.2.3 Interviews

Personal interviews were undertaken by the researcher with dairy farmers and/or dairy farm managers during the fall/winter seasons of the years 2003-2004. Open-ended interviews (Bernard, 1994) were undertaken with a purposeful sample of 24 farmers (~35% of population) with the main aim of engaging these actors. Specific operation information was elicited and obtained as feedback in the modeling process. The sample size and the people to be interviewed were chosen in order to obtain as much of the existing variability as possible. Selection of participants was done in a participatory manner with the coordination of the Suwannee River Partnership (SRP) and the University of Florida Extension offices in the area.

Interviews started with the presentation of either the prototype or the final model on a laptop computer. A voice recorder was used in every interview after requesting permission. The first step was to explain the purpose of the visit and then to provide a general description of the model. This was followed by a detailed explanation of every component in the model, including those that were as yet not active, and their mechanics. After discussing similarities and differences between the model and the farmers' specific production units, a demonstration of the running of the model was presented and discussed.

Later, dairymen had the opportunity to input their specific data and run the model for their own specific conditions. Similarities and differences with what farmers expected were recorded and taken into account. If observations were easy to adjust for, they were tried “on-the-fly,” taking advantage of the user-friendliness of the model’s interface. If specific comments would require more work, they were incorporated in the lab and tested in later interviews.

Interviews highlighted farmers’ reactions to the models. All possible suggestions to be incorporated in the models were taken into account in successive steps. Two rounds of interviews were conducted. Twenty-one farmers observed the prototype model in October-November of 2003. In February-March 2004, the definitive model was used for validation purposes with 3 farmers.

4.2.4 Focus Groups

Eight focus groups (Bernard 1994; Stewart and Shamdasani, 1990) with stakeholders were held between November 2002 and February 2004 in the study area. Focus groups consisted of open discussions among 5 to 15 persons. A stakeholder in coordination with the researcher called these meetings. The researcher facilitated the meetings around the different topics of research. The first two focus groups did not include any model as a basis for discussion. Rather, because the creation of a prototype model was suggested and encouraged during the second focus group, one was created and became the focal point for discussion in all groups save the last. In the last focus group, the final model was discussed.

Focus group participants ranged from specialists from official agencies such as the Suwannee River Partnership (SRP, www.mysuwanneeriver.com/features/suwannee+river+partnership), the Suwannee River Water Management District (SRWMD, http://www.srwmd.state.fl.us), the Florida Department of Environmental Protection (FLDEP, http://www.dep.state.fl.us), the United States Department of Agriculture (USDA, http://www.usda.gov) Natural Resources and Conservation Service (NRCS, http://www.fl.nrcs.usda.gov), the University of Florida IFAS Cooperative Extension Service (CES, extension.ifas.ufl.edu), to private sector companies, technicians and farmers. These participants were usually called to a meeting by the Suwannee River Partnership and/or by extension agents of different counties in the research area.

Focus groups lasted between two and three hours and their main purpose was to listen to feedback on the modeling process and to actively increase involvement and diffusion of the research to a more target public.

4.2.5 Other Stakeholder Interactions

The principal researcher approached many other stakeholders between fall 2002 and spring 2004 in order to receive additional inputs into the modeling process. Initially, the discussion centered on the intended idea of a proposed simulation methodology. In a second phase, the discussion was based on the prototype model. Finally, interaction with the clientele was based on the final model and its final tune-ups. These interactions were meetings with specialists in the issue of the N leaching and the dairy industry and included private consultants, officials from regulatory agencies, and university faculty, among many others.

4.2.6 Analysis of Information

All participatory interactions were recorded, classified, organized, analyzed, and described. The feedback received was included in the modeling process in one way or another in successive steps. This paper summarizes the results of all the above interactions in a descriptive/narrative manner. Names of the participants and some organizations and companies are not revealed to protect the anonymity of interviewees. A summary of stakeholder interactions can be found in Table 4-1.

4.3 Results and Discussion

Results of interactions are described in five phases that detail the iterative process, step by step, of creating, calibrating, and validating the dynamic north-Florida dairy farm model, DNFDFM with participation of stakeholders. This process is summarized in Figure 4-3.

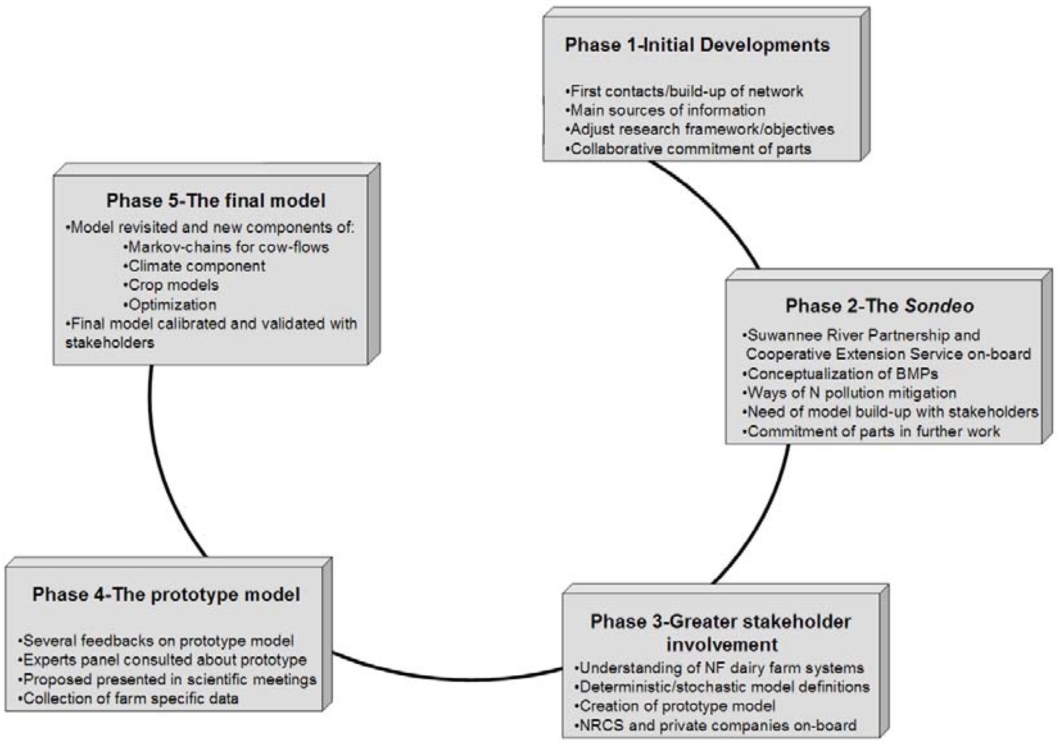


Figure 4-3. Phases of the participatory modeling for creating the DNFDFM

4.3.1 Phase One: Initial Developments

In July 2002, four well-known scientists in Florida, each from a different discipline, were approached looking for specific information and at the same time ideas about the original research idea. The scientists were from the areas of forages on dairy farms, dairy waste management, soils, and crop modeling, respectively. During this first exploration, confidence was gained in the fact that most of the soil series in Florida are contained in a database that could be accessible to use in later phases of the research (G. Kidder, pers.

comm.). Also, the current system of crop models contained in the Decision Support System for Agricultural Transfer (DSSAT) (Jones et al., 2003) would be ideal to use in the research for the estimation of N leaching according to climate variability, after major adjustments. Furthermore, it was known of the existence of a growing body of research related to environmental issues and dairy farms in Florida and north-Florida that the study should take advantage of (annual reports on water quality from the SRWMD, basins status report from DEP, water resources investigation series from the USGS, water quality assessments from the EPA, studies on natural resources management from the NRCS, among others). Above all, important contact information with end users and other stakeholders was gained that would be needed in the following phases.

In August 2002, a telephone conversation was held with a dairy farm manager to get an initial grasp of the N issue on dairy farms and how it is potentially affected by climatic variability. The conversation was enlightening in capturing the sensitivity of dairy farmers to the issue of N pollution and the need for alternative ways to estimate environmental accountability of dairy farms. This manager set forth the notion that climate variability would have little effect on livestock performance. However climatic variability was thought to have a very high impact on forage field yields.

In September 2002, 3 contacts were made with soil scientists working in the study area in a project regarding N pollution from farm activities, including dairy farms (Florida Department of Environmental Protection, 2004). These scientists provided further contacts and references to add to the research. Additionally, suggestions from the contacts led to one-day field visits and participation in the collection of soil and water samples was achieved through the contacts' suggestions. This last task was very important to help understand the methodology being used in current experiments and the implications that results might have on the modeling process.

During September and October, stakeholders in the research area were contacted for the first time to get them acquainted with the research project and, most of all, to get them involved in the project. Stakeholders whose farms were located in the heart of the research area, the middle Suwannee River Basin, were very receptive to the idea because environmental degradation from dairy farms is an issue that is very much on the agenda of official agencies. Contacts included members of the SRP and CES agents. During the first contact a verbal idea together with a small paragraph of intention was handed to the stakeholders. Discussions were based on an initial idea. While support for the main idea was expressed, a fuller understanding of the research was still lacking. Nevertheless, the general reaction on the part of stakeholders was “let us begin and involve more stakeholders so we can all better understand the project and define further steps.” This was the beginning of a very rich feedback loop process with stakeholders.

In November 2002 the first focus group was held in the Suwannee River Water Management District (SRWMD) at Live Oak. The SRP called the meeting officially and 6 people attended. Attendees included members of the SRWMD, the SRP, and the CES. This meeting was critical to understand the interests that all sides had in the project and where the project was heading. It was agreed that there were commonalities between the proposed work and current work already underway within the Partnership. Interest existed in supporting the research and benefiting from the outputs. Specifically, the group committed to contacting farmers and convincing them to participate in the research. It was agreed that a purposeful sample of 20 farms (out of 64 in the area) would be enough to get acquainted with the diversity present in these systems. The stakeholders all agreed that the researcher should prepare a short document explaining the potential outcomes of the research together with a list of topics to be included in interviews. Topics could be handed to farmers ahead of time in order to gain insights even before the interviews were conducted. A time limit of one hour for interviews was established because dairy farmers "are really busy people and they don't have much time." The protection of the anonymity of participants was set forth as a must because the nitrate issue is very sensitive. Neither farmers nor their management practices regarding estimations of waste should be identified in the work.

Also in November 2002, a visit to a dairy farm and an informal interview with its owner was conducted to gain general insights of the dairy farm systems, the recycling of nutrients, and the potential to benefit from climatic forecasts. This visit was very instructive to understand activities that are dynamically happening in the system and that can be represented by simulation models. The owner highlighted the fact that the farm was following environmentally friendly practices suggested by regulatory agencies.

4.3.2 Phase Two: The Sondeo

The very participatory and interdisciplinary approach revealed many characteristics that needed to be incorporated into the participatory modeling process. Background information indicated that ten years ago an increase in nitrate concentration was recognized by the SRWMD in the middle Suwannee River Basin (Hornsby et al., 2002a). Sondeo results found that it was believed that if the problem were not solved, there would be a time when the government would impose regulations. Regulations were perceived as one of the main drivers for farmers to uptake Best Management Practices (BMPs) (Katz and Bohlke, 2000). If regulatory measures had been imposed at that time, some farmers would not have been able to comply. This could have forced them out of business as happened earlier with some dairy farmers in the Lake Okeechobee area of southern Florida (Alvira et al., 2003). The SRP was formed to determine the sources of N loads in the basin, and to work with local users to minimize future nutrient loading through voluntary, incentive-based programs. The Partnership works under a non-regulatory, preventative approach, through monitoring pollution, education, promotion, and adoption of BMPs (FLDEP, 2001). Informants in the Sondeo generally recognized that the problem of the increase in nitrate concentration in the middle Suwannee River Basin was very evident and that dairy farming was perceived as the most contaminating activity. Even though farmers were aware of the presence of nutrient contamination, they had differing views on the primary source of contamination (point versus non-point source pollution) and potential effects on human health (Alvira et al., 2003).

The SRP group is focusing on finding the most economically and technologically feasible management techniques (BMPs) available to help farmers and other land users to satisfy regulatory requirements for protecting public health and the environment. These management practices mainly include nutrient and manure management, irrigation water, technical design and engineering aspects in dairy farming (Suwannee River Partnership, 2004b). By large, the concerned stakeholders see BMPs as research-generated solutions to reduce potential environmental hazards from farm enterprises. From the simulation point of view, modeling would be in essence an opportunity to help these stakeholders to experimentally test BMPs without disturbing the actual dairy farms. Simulation could reproduce farm conditions and test the environmental and economic impacts of intervention, without risking the normal functioning of a farm. Outputs of the simulations could be used to verify technical viability of BMPs before their implementation by state, federal, and private agencies.

Adopting BMPs may help farmers to remain in business, which is critical to stakeholders. However, initial investment in BMPs, even though costs could be shared with official agencies, can be cumbersome (DEP, 2001; Ribaudo et al., 2003). Therefore, it is important that the proposed practices to protect the environment be cost effective taking into account that dairy farmers first will look for survival strategies and then for good stewardship, just as any other enterprise. This last statement would have great implications in the modeling process since the economic outputs of the whole farm would be vital in determining which practices a north-Florida dairy could implement as a technological choice. It was commonly agreed by participants in the Sondeo (Alvira et al., 2003) that the model must have an important economic component and this component must be taken into consideration for potential proposed practices.

The Sondeo team had several interesting findings. It concluded that

- Perceived benefits exist in implementing BMPs
- However no data exist to support the fact that BMPs are economically and ecologically viable in the long run for farmers
- Further research and validation of BMPs needs to be conducted
- A guideline describing the steps to developing BMPs is needed
- An economic feasibility study on BMPs that takes heterogeneity of farm sizes and types into account also merits research
- Further research should be devoted to investigate the contribution to contamination from each potential source or to investigate the point-source pollution sources that make each party accountable for their contribution to the overall problem.

The powerful implications mentioned in the above paragraph definitively implied the development of the modeling work in successive steps. First, BMPs require validation. The model or the models would help in this task. Second, the simulation has to be performed in a way that incorporates diversity of farms and allows for individual farm analysis as complete and separate units.

4.3.3 Phase Three: Greater Stakeholder Involvement

In February 2003, 3 dairy farms in the study area were visited. From these visits the components of a dairy system in north-Florida to be used in the model took shape. All dairies have a livestock component, forage fields, feed facilities, and some means of disposing of waste produced by confined cows. Some differences exist on specifics, e.g., some farms do not raise heifers or some farms raise more forage crops than others. Nevertheless, it was believed that common components could be found in order to represent all north-Florida diaries in one general model that could be adjusted for any peculiarities to represent specific farms. Farmers noted “the only thing dairy farmers have in common is that they all produce milk… other than that they can be very different.”

Also in February 2003, a second focus group with eight stakeholders was held. This meeting was very powerful for the next advances in the research. First, a deeper discussion on the climate component was achieved. These key stakeholders felt that uncertainty and low accuracy in climate (or seasonal) variability forecasts could create problems in the models. It was proposed that a way to handle uncertainty and low skill forecasts was to present results in a probabilistic way. However, a consensus of farmers was that they wanted to have outputs available in as simple a form as possible. It was agreed by all that deterministic results would be the default output but an option to also see results under other climatic scenarios would be created. If for example an El Niño prediction exists, the model should present the results for an El Niño year. Additionally, an option to present results in case it is not an El Niño year but La Niña or Neutral is necessary. It was argued that not all El Niño years are the same in intensity so there should be a distribution of results instead of just one outcome. Farmers counter-argued to be very careful not to over-complicate the already existing uncertainty. They warned that if it happened, farmers would lose interest. It was during this discussion that that a producer proposed that a probabilistic distribution should instead be applied to milk prices in the economic portion of the model. Farmers clearly understood that there is no true factor that explains price variations and they are in fact, stochastic. Another important point of this second focus group was that the participants better understood the research idea and found similarities between it and the "nutrient budgeting" approach that the Natural Resource and Conservation Service (NRCS) is using for planning environmental accountability (NRCS, 2001). The NRCS was invited to become involved with the research project and also participate actively in order avoid duplicate efforts. Also in this meeting it was re-affirmed that user-friendliness of the model is extremely important. It is also very important to stakeholders that the model(s) be easily adaptable to different farms because no two dairy farms are the same.

Another important decision was taken during this meeting. A stakeholder, supported by all others including the researcher, suggested that a "prototype" model be created to clearly show what it was intended to accomplish. The idea was to have a prototype model to use as a tool for increasing farmer and other stakeholder involvement.

The model should be constructed in a user-friendly manner so that it could be shaped and molded through further stakeholder interaction.

Finally, farmers encouraged continuing with the work, since they were beginning to see how they could benefit from the final product. They mentioned that they could directly test BMPs on their system and that this would be useful to them. Large dairy farms that usually do not participate in cost-share programs might see the advantage of decreasing potential risk of fines from regulations. Additionally, dairy people were eager to see the economic impacts of any potential management changes.

At the beginning of March 2003 a meeting with a private consulting company was held. The company worked with some dairies in north-Florida on the N issue. They prepared compliance reports, advised farms on how to decrease environmental concerns, and carried out experiments to gain more insights on the pollution issue. Company professionals quickly understood the aims of the research. The consulting firm expressed its interest in the outputs and was willing to share their expertise and information for the creation of the simulation models. Furthermore they provided other important contacts. Both companies suggested the research might benefit from the incorporation of a hydrological-soil model called GLEAMS that stands for Groundwater Loading Effects of Agricultural Management Systems (Leonard et al., 1987). This would facilitate the estimation of N leaching in the soil. This idea was later aborted because crop models would be used, however the consideration is worthwhile to mention.

This meeting with the private consultants highlighted 3 other important points. These were the incorporation of the climate component, the economic module, and contact with another network of stakeholders. The consultants agreed that climatic variability would affect dairy farm outputs through its effect on crops. According to their experience, even when crops are irrigated, they respond to rainfall patterns and temperature. The incorporation of crop models would be extremely important for taking these responses into account. Private consultants also mentioned that if the research includes a strong economic module, it would be an important addition. Inclusion of this module might be sufficient to gain farmers' attention and eventual adoption of the models. Finally it should be noted that the consultants regularly promote and participate in a network of stakeholders on the nutrient issue. An invitation to form part of these meetings was extended. On a monthly basis meetings are held and novel aspects of the nutrient problem are discussed.

Also during March 2003, a third focus group was held, this time at the facilities of the NRCS-USDA in Gainesville, FL. A discussion based on the research proposal was opened and specialists were able to input their expertise. Three professionals very knowledgeable on the topic agreed that the research was relevant even though a similar product, The WATNUT software (NRCS, 2001) or Worksheets for Water Budget and Nutrient Management), already existed. They clearly understood that the research was going beyond the WATNUT application because it would have dynamic, economic, and user-friendly components that are not included in WATNUT. The USDA researchers expressed a willingness to work collaboratively in order to obtain a relevant final product. Researchers provided literature and the WATNUT v 2.0 software for use as a baseline on the modeling enterprise.

At the end of March 2003, a second meeting with the private consulting company was held. During this meeting the company provided a CD with detailed information of several years of experiments on a dairy farm in the study area. The CD contained spreadsheets with records of experiments on waste handling and crop systems. This information is not published and was delivered under the consent of the dairy owner. All this information was a very useful reference for the further modeling process.

4.3.4 Phase Four: The Prototype Model

In May 2003, a fourth focus group was held in Live Oak, FL with the participation of 6 people. The prototype Dynamic North-Florida Dairy Farm Model (DNFDFM) was presented for the first time. Specialists, extensionists, and technicians participating were impressed with the model performance, considering it was still a prototype. The following adjustments were suggested before the model should be presented to more dairy farmers:

- Improve the visuals, including more figures and visual aids that would attract farmers' attention
- Use clear labels for the different components and if possible reduce the number of cells to make it easier for farmers to understand
- Slow down the run so it could easily be tracked by farmers
- Put money components in green and the N leaching in red to call farmers' attention
- Include number of times cows are being milked in a day

It was suggested that after the adjustments the prototype be shown to a list of suggested producers. They would provide rich feedback. In May the model and its documentation were discussed with a specialist at the University of Florida. The main suggestion was that it should be presented at a scientific meeting because the framework could be useful for many people and there could be very interesting feedback that could be incorporated in the final model. In this way, types of stakeholders involved in providing feedback to models would be expanded beyond farmers, extension agents, government agents and private consultants to the scientific community.

In July 2003, the fifth focus group was held in Mayo. Seven people participated, including 4 farmers, 2 extension agents, and 1 technician. The prototype model was presented and explained. A number of unanticipated uses were suggested for the model such as to keep economic records and as an accounting tool. One farmer, especially interested in the work, asked to input his own data into the model to see how well it would perform. After running the model he took a hand-held calculator and started making calculations to compare with the model outputs. The farmer put forth several questions for general discussion. The farmer finally concluded that the model output numbers were “reasonably” good and that he would like to see more and would be glad to work directly in calibrating and validating the model. Many suggestions were collected at this important meeting. Among them:

- The model was estimating that the number of replacements should be between 60 and 70% of the adult cow total. The correct range should be between 50 and 60%
- The model was estimating that the number of freshening cows was about the same the year round, however in reality roughly 60% of births occurs between August and December, so that seasonality should be incorporated
- Farmers thought that prices received for milk were overestimated in the model since official prices were used. The model should use mailbox prices that farmers would be glad to provide
- Farmers liked the stochastic component in the prices, but asked if it would be possible to have the option for the user to choose between fixed and stochastic prices for the final model
- It was realized that not all the options of crop/forage sequences were included in the model. These should be in the final version
- It was also suggested that the confined time milking cows spend on concrete should be divided by seasons since this changes with conditions through the year

- The model required input of specific cow categories before starting. This process was overly time consuming. Farmers wanted to be able to obtain similar results with less input data

- The model raised all heifers on farm. Farmers suggested the option to not raise or only raise part of the heifers on farm

- Even though most of the cattle used in the area are Holstein, the model should incorporate an option to handle other breeds

In August 2003, the sixth and in September 2003, the seventh focus groups were held at the county extension offices of Suwannee and Lafayette counties, respectively. At the Suwannee meeting a great deal about crop and forage rotations was learned and noted to take into account in the model. At the Lafayette meeting, a group of 5 farmers, a technician and, an extension agent participated. Once again feedback was elicited and collected. The main suggestions were

- There is a need to clearly include all options of crop/forage rotations in the study area. It was agreed that the stakeholders would make a comprehensive list of practices

- The prototype model included only “sprayfields” where effluent was applied, however dairy farms have many pastures where dry cows, heifers and milking cows (when not confined) graze and deposit manure directly and these should also be incorporated in the model

- The model should maintain an already existing option that lets the user input specific data regarding N content of the manure effluent at different points of the handling system

In September 2003, a specialist in “climate applications to reduce risk in agriculture” from the Southeast Climate Consortium had the opportunity of seeing the prototype model and to input relevant ideas. Input regarding how to incorporate the climatic component using crop models from the DSSAT family (Decision Support System for Agricultural Transfer; Jones et al., 2003) was obtained. These function with daily weather data. In order to incorporate this component in the model, climate would be analyzed for a long time series (50 years) and results would be classified by ENSO phase (O'Brien, 1999). Years would be divided into El Niño, La Niña, and Neutral year categories. An important contribution obtained was that crop models should be pre-run and organized in a database, then incorporated in the dairy farm model.

Table 4-1. Stakeholder interactions, suggestions and changes made to model

Date	Interaction Format	Participants	Changes Suggested and Incorporated
July 2002	Interaction	4 UF Scientists	Use soil series data Use DSSAT
August 2002	Interview	1 farm manager	Climate important for crop yields
September 2002	Interview	3 soil scientists	Participate in sample collections
September-October 2002	Interviews	3 farmers	Involve other farmers
November 2002	1st Focus group	6 stakeholders	Use 20-farm sample One-hour limit to interviews
November 2003	Dairy farm visit	1 farmer	Main components of a dairy farm
Jan.-Feb. 2003	Sondeo	13 stakeholders	Take heterogeneity of farm sizes and types into account. Use model to test economic feasibility of BMPs
February 2003	Dairy farm visit	3 owners	Diversity stressed
February 2003	2nd Focus group	8 stakeholders	Deterministic outputs requested
March 2003	Meeting with private consulting company	2 consultants	Importance of crop models, economic module and climate component
March 2003	3rd Focus group	3 people	WATNUT offered as data
March 2003	Private consulting company	2 consultants	Waste management and experimental data provided
May 2003	4th Focus group	6 stakeholders	Improve visuals. Slow down runs. Use color. Follow herd flow
July 2003	5th Focus group	7 stakeholders	Adjust replacement and freshening coefficients. Raise heifers off farm. Reduce prices. Use deterministic prices as well. Include more crop sequences
August 2003	6th Focus group	5 stakeholders	Include more crop rotations
September 2003	7th Focus group	5 stakeholders	Include all sprayfields. Need a place to input N data
September 2003	Meeting	1 Climate specialist	Refined use of DSSAT with daily weather data
September 2003	Meeting	2 Dairy Specialists	Importance of user friendliness
October 2003-January 2004	Meetings	Farmers	Outputs in tables and graphs. All coefficients calibrated
February 2004	8th Focus Group	8 stakeholders	Keep model in Excel. Keep model user friendly. Use Markov chain flow model

Also in September 2003, a meeting with two dairy specialists was held to discuss the implications of the model and to gain more access with farmers in other counties. During this meeting it was suggested that a component similar to N should be incorporated for P in the final model. After discussion of the scope of the study and the importance of concentrating only on the current problem (N), it was agreed that the current model could provide a useful framework for P in future research. The fact that user-friendliness had to be maintained at all cost and that the final model would be an important tool for farmers was emphasized. The specialists offered to arrange contacts with stakeholders from other counties, mostly Alachua, Gilchrist, and Levy, all in the Suwannee River Basin.

In the first round of interviews with farmers many feedback points already discussed during previous focus groups were repeated. Farmers encouraged continuing with the dynamic simulation in monthly steps instead of weekly or yearly. Also, user-friendliness was again highlighted in all. Farmers and extensionists were surprised that the model could be handled in a program that most of them frequently use, Excel ®. Producers asked that the use of Excel® be maintained because that would insure that they themselves would be able to use the model.

Two interviewed mentioned that they would use the model as a complement to tools they already possess for their nutrient balance (Van Horn et al., 1998; NRCS, 2001). The opinions regarding the use of climatic information to change management strategies were split. About 67% of interviewees believed that they could proactively use climatic variation information for decreasing N leaching and/or increasing profitability. Farmers who favored the use of climate forecasts were inclined to include it as a user choice option.

The interviews were very useful for sensitivity analysis and calibration of the model since all the different conditions observed in these varied farms were run in the model. In the same way, hard data such as number of cows, size of land, type of waste management systems, crop systems, etc. were recorded for future modeling use.

4.3.5 Phase Five: The Final Model

A new model was built taking in account all possible previous suggestions of stakeholders and the prototype experience. Four main components were new and all the rest were completely revisited. The new components were

- The Markov-chain probabilistic simulation of the cow flow
- The climate forecast interface
- The crop models, and
- The optimization module that helps in decision making

These new components were included in response to needs expressed during the many meetings. With the incorporation of feedback from all stakeholders, the new model began to take shape. This did not end the participation process, rather, interaction continued as actively as during the first phases. The farmers suggested that a forage crop specialist from the University of Florida should be incorporated in the discussions. A meeting was held and the sequences of forages were completely determined in their final form to be included in the model. It included the list of sequences tillage options, the intercropping options, and the harvesting choices. Between September and November 2003 a new cow-flow model was created with help and feedback from a dairy science professor who was able to validate it for North-Florida conditions.

Intense work on climate and crop models started in order to incorporate them into the main shield or interface of the north-Florida dairy farm model. Because the detailed nature intrinsic to this phase work, more specialized people were contacted for feedback at this time. Between October 2003 and January 2004, some 10 meetings were held and several contacts made by email. Even though during this time no model was presented, contacts were already aware on the project behind it and were able to collaborate. Input was provided not only for the specific crop models or climatic components, but also for the whole simulation approach. During these exchanges feedback loops were incorporated into the model and decisions were made regarding the pre-run simulations of crop models. These are closely linked to the climatic component since they use daily weather. At the end of January 2004, a specialist validated the main results of the crop models before they were incorporated into the main model.

In February 2004, the eighth focus group was held at Live Oak with 8 stakeholders. The meeting was a discussion of the final Dynamic North-Florida Dairy Farm Model, which was presented in detail during an one-hour meeting. An one-and-half hour discussion followed. Attendants were encouraged to test the model to its limits in order to find any potential deficiencies that could be corrected. Farmers attempted to confound the model but fortunately the model responded very well. All appreciated the reduced need for initial data to start runs. Farmers also approved of the improved user-friendly interface, and the integration of models in a simple Excel® application. An example of a hypothetical farm was run and results were compared using the optimizer. Stakeholders appreciated the possibilities to arrange management options in order to decrease N leaching without decreasing profit. At the end of the meeting farmers asked for and received a copy of the model.

The ultimate validation of the DNFDFM was through interaction with 3 additional farmers. Producers were able to compare outputs from the model with their own farms. Farmers agreed that although the output numbers did not correspond exactly to the real data from their farms, the similarity of the outputs to real numbers gave them confidence that the model worked correctly. They expressed their willingness to adopt and use the model in their management strategies.

4.4 Summary, Conclusions, and Recommendations

Participatory modeling can enhance the creation of adoptable and adaptable user-friendly models that include environmental, economic and biophysical components. Multiple feedback loops were used during a two-year process of interaction with stakeholders. An iterative process involving creation of a prototype, interaction with stakeholders, improvement of prototype models according to suggestions at meetings was undertaken. Improvements included the incorporation of climate, crop, cow-flow, and optimization. Many adjustments were made to coefficients originally obtained from secondary data. Expert advice was incorporated from specialists in the government, private, extension, university and production sectors, following suggestions made by farmers during focus group meetings.

The reality of using secondary information as a starting point and then calibrating and validating "in the field" has especially strong implications for adoption and long term use of the model. A feeling of ownership was created within the focus groups by listening attentively to all suggestions. An especially strong interaction among farmers and researcher occurred during the calibration and validation process. Models were run with default data and farmers compared outputs with their personal knowledge of farm outcomes. The researcher and farmers were then able to backtrack into the model to adjust coefficients that were deemed to be skewing results. Producers expressed reasonable ranges within which model parameters should be confined. Through this process each farmer felt included in contributing to the success of the final model.

Climate is especially relevant as a problem considered by all members during many meetings. In the past, it has been difficult to get extension agents and producers "to buy into" the idea that management can be tailored in light of climate forecasts based on

ENSO phenomena. By working together on the model and incorporating typical rainfall and temperature data for different ENSO phases, producers were able to understand the effects of seasonal variability on production and N leaching. Understanding the climate-cow-crop-nitrate interaction at the early stages of model development will greatly increase the probability of proactive use of climate information to mitigate negative environmental impacts.

After undergoing an arduous but fruitful stakeholder interaction process to develop the North-Florida dairy farm model the following is recommended as a procedure for participatory model development. Initial contacts should be made with local producers to sound out felt needs. If models are useful for addressing the felt needs, a prototype should be developed using secondary data if available. The prototype model should be thoroughly discussed using focus groups or other methods common in Participatory Rural Appraisal. The concept of stakeholder should be understood in its broad context. A stakeholder analysis is useful for learning the relative position and networks that exist. Farmers, private consultants, extension agents, officials of government agencies, university faculty, and the researchers, among others, should be included in the model building process. After adjustments to the prototype, a final model should be developed and taken back to the stakeholders. Researchers should elicit comments on structure and function, parameters, coefficients, and individual modules from stakeholders.

In order to insure long-term adoption of the model, good science must be used to respond to specific concerns of stakeholders. When farmers or consultants suggest that crops will be highly affected by climate variability, then modelers should respond by using state of the art crop models such as DSSAT. When producers call for a user friendly, simple interface, modelers should respond by using visual basic to create an interface that is usable from the farmers' point of view. By following these relatively simple steps, which are not always in the mindset of scientists, use of climate-based agriculture and natural resource models can be greatly improved.

CHAPTER 5
HOW MUCH MANURE NITROGEN DO NORTH FLORIDA DAIRY FARMS PRODUCE?

5.1 Introduction

The presence of high levels of N in water is an environmental hazard because it affects human health and ecosystem welfare (Fraisse et al., 1996). The Suwannee River Basin has received much attention in recent years because increased N levels in water bodies (Albert, 2002; Katz et al., 1999; Pitman et al., 1997). Dairies have been identified as an important source of nitrates in the Suwannee River Basin (Andrew, 1994; Katz and DeHan, 1996; Berndt, 1998).

It is critical to accurately estimate the amount of manure N production because it directly impacts environmental accountability of dairy farms, and the expense of farmers to comply with regulations. It is also important to perform these estimations seasonally because this determines potential for nutrient recycling, utilization, or loss because climate variability through the year. Other important estimations are those of manure N produced by non confined milking cows, dry cows, young stock, and bulls; interviews showed evidence that these could also be important factors in analyzing entire systems.

For Florida, two approaches are being widely used to estimate manure N produced by dairy cows. One is that proposed in several publications by Van Horn et al. (1991, 1994, 1998, 2001) that consists of a sink-source balance, and the other is that presented by the Natural Resource and Conservation Service, NRCS, through an application called WATNUTFL Version 2.0 (NRCS, 2001), that is based on body weight of ruminants.

According to Van Horn et al. (1998, 2001) the undigested (or unutilized) amount of N by the digestive system of a cow is the amount that will be present in the manure (feces and urine) of this cow, and undigested N can represent as much as 67% of the ingested N. In other words, the amount of N excreted by a cow will be the difference between the quantity ingested and the quantity of digested or utilized. N, which cows use to produce milk, gain weight, and reproduce.

$$N(\text{excreted}) = N(\text{feed}) - [N(\text{milk}) + N(\text{tissue}) + N(\text{off spring})] \quad [5\text{-}1]$$

This relatively simple approach requires estimations of total amounts of N entering the system and total amounts of N leaving the system. Farmers have detailed records of milk production and they could estimate the quantity of N contained in this milk. They also know the total dry matter intake (DMI) for the whole herd and thus the total amount of N entering the system. But it is difficult to specify what group of cows received what quantity in each season of the year. Nennich et al. (2003) also criticizes this methodology indicating that errors in the estimations may occur since nutrients consumed by animals could vary greatly from what was formulated because cows select feed and the feed mixing process always has errors. The gross yearly differences in feed input and output would also include errors in measuring starting and ending inventories and the individual nutrient content of feedstuffs (Nennich et al., 2003).

WATNUTFL, the application created by the NRCS, uses standardized estimations based on live weight of animals (NRCS, 2001). This methodology allows the user to standardize different species of animals by the common factor of body weight and benchmark parameter values. This methodology disregards a very important factor in manure N excretion, i.e., milk production, which many researches have pointed to as the driving factor in N excretion (Nennich et al., 2003; Van Horn et al., 1998, 2001; Tomlinson et al., 1996). In fact, milk production level, under intensive dairy farm systems, is the single most important factor to take into account regarding N excreted (Nennich et al., 2003).

Both Van Horn and NRCS methods use standardized book values (benchmarks) of manure, DMI, water used, basic N excretion, and other parameters from those listed by the Agricultural Waste Management Handbook (AWMFH) of the NRCS (USDA, 1992a, 1992c, 1996), and its AWMFH Florida supplements (USDA, 1992b); several documents from the Department of Environmental Protection (FLDEP) and the Environmental Protection Agency (EPA); those from the American Society of Agricultural Engineers (ASAE, 1990); and other standards like those of digestibility of feed sources and N in diets from the National Research Council (NRC, 2001). These standards are the best sources or "book values" for which estimations can be supported and these are continuously being reviewed and updated; in some cases, location-specific values are also being released. This present study also bases the values of estimations on these standards.

Van Horn et al. (2001) and NRCS (2001) estimate N excretion in whole-year values, ignoring completely the inherent seasonality present in north-Florida dairy farm systems. Dairy cows are highly sensitive to seasons, and in subtropical climate conditions such as north-Florida dairy cattle are negatively affected by high temperature and high humidity. Reproduction and milk production are completely changed by seasons of the year. For example, lowest milk production as well as lowest conception rates occur in summer (De Vries, 2004; personal interviews); consequently, a much higher rate of manure N is expected to be excreted during winter months, not only because milking cows are more actively producing milk at that time, but also because many more cows are in the high-peak milking production stage because there is a higher proportion of freshening cows in late fall. Manure N produced in mid spring will have more opportunity to be used by rapidly growing plants than that produced in a very cold winter season where less chance of plant utilization would exist and higher amounts of manure N applied in rainy seasons would be more prone to leach. That is why, for example, a study with application of dairy effluents to pastures in New Zealand (Williamson et al., 1998) concluded that effluent applications should be avoided in winter when they detected highest amounts of N leaching by soil lysimeters. The present study included inherent seasonality based on historical Florida dairy herd data (Dairy Herd Improvement Association (DHIA), De Vries, 2004) contained in seasonal conception rates, seasonal culling rates, and seasonal milking production rates.

Nennich et al. (2003) suggest, after studying data from several universities in the United Sates for a series of historical records, that separate categories should be used to estimate excretion and nutrient content for calves, replacement heifers and mature cows. Even though previous studies made an effort to include them in balances, this study emphasizes their inclusion for a more accurate estimation of the manure N at the farm level.

The objective of this study was to estimate monthly N levels that north-Florida dairy farms deposit onto their farmland. The specific objectives were to perform a survey of dairy farmers to collect information; develop a model that allows final users to have an easy but accurate monthly manure N estimation for specific farms, based solely on number of adult cows (NAC) and milk production (rolling herd average, RHA); compare the performance of this model with the Van Horn and WATNUT approaches; and assess the monthly N amounts applied to sprayfields and pasturelands by a number of north-Florida dairy farms.

5.2 Materials and Methods

The study was conducted in cooperation with dairy operations of the Suwannee River Basin in the counties of Suwannee, Lafayette, Gilchrist, Levy, and Alachua (21°20' – 30°22' N, 82°26' – 83°21' W) during the period October, 2002 to December, 2003. Information from 21 dairy farms was collected by a survey. Additional secondary information was obtained from the Dairy Business Analysis Project (DBAP) of Florida (http://www.animal.ufl.edu/dbap), the Dairy Herd Improvement Association (DHIA) (http://www.dhia.org and http://www.animal.ufl.edu/dhia), the Dairy Records Management Systems (DRMS) (http://www.drms.org), and many other published studies.

A sample of 21 dairy farms (~35% of the population) to participate in the interviews was obtained in coordination with the Suwannee River Partnership and the University of Florida Extension offices in the area. The sample was intended to cover the variability in north-Florida dairy farm systems with respect to herd size, farm size, manure handling systems, management operations, and environmental conditions. Interviews were arranged to be conversational in nature without an instrument, but with a guideline of topics. Interviews lasted between one and two hours and in several occasions, tours to the farm followed. Conversations were recorded, transcribed, and classified.

5.3 Model Development

5.3.1 General Characteristics

A Markov-chain cow-flow model was created to account for the growing, probabilistic reproduction, and probabilistic culling of young stock (calves and heifers) and for adult cows in different lactation cycles (1 to 9). Additionally, the model was set up to use monthly milk production rates according to production curves for Florida. Milk production, culling rates, and reproductive rates were adjusted using real data collected by the southeast DHIA in Florida (De Vries, 2004). The model starts in September of the first year and it run monthly for as many years as desired. The user must input the total number of adults cows (NAC) and the rolling herd average (RHA); however for more customization the user can input other information. Using these initial conditions, the model is capable of self-adjusting to reach a seasonal steady state of cow flow. That is the way north-Florida dairy farms operate, and any planned change to increase or decrease herd size can be accounted for by different model runs.

5.3.2 Markov-Chains, Culling Rates, Reproduction Rates, and Milk Production Rates

St-Pierre et al. (1999) indicated that herd milk production through time can be modeled as a discrete stochastic process using finite Markov-chains. Markov-chains are widely used to predict economic outputs (De Vries, 2001; Mourits et al., 1999; Mayer et al., 1996). Cows at time $t = 0$ are assigned to homogeneous production cells in three-dimensional arrays with coordinates determined by months in milk (MIM = 1 to 32), months in pregnancy (MIP = 0 to 9, where 0 is not pregnant), and lactation number (LN=0 to 9, where 0 are calves and heifers). The processes of aging, pregnancy, involuntary cull, voluntary cull, abortion, dry-off, and freshening from month *i-1* to month *i* for any month *i* are accounted for using seasonal probabilities. Estimates of transition probabilities are derived from historical herd data from the databases of the Florida DHIA (De Vries, 2004). Moving animals from one production cell to the next, based on the transitional probability assigned allows the inclusion of the inherent probabilities in the process of reproduction and culling in a dairy operation.

Markov-chains represent the cycles that milking cows follow. When a female calf is born, she will be raised and will gain weight for 12 months. When she is 12 months old a pregnancy program starts for her through artificial insemination (AI) or by bulls. The pregnancy rate of heifers is much higher than adult cows: about 60% of the heifers will be pregnant on the first attempt. The estrus cycle in cows lasts 21 days, which is the time needed to know which heifers are pregnant. In the next attempt another 60% of the rest (40%) will become pregnant, etc. If the heifer is not pregnant when she is 24-months old, after 12 attempts, that heifer will be voluntary culled. The proportion of voluntary culling of heifers for not being pregnant is very low. After 9 months of pregnancy the heifer will deliver her first offspring, and she will become a fresh cow, first lactancy, first month, open cow in the milking group. The survey found that not all farmers raise their own replacements needed to maintain the herd size. In those cases, the model can be easily adjusted by a percentage of estimated replacements raised on-farm, with a range of 0% (no replacements at all) to 100%.

During the first lactation cycle, Markov-chains divide cows into different categories according to whether or not they are pregnant, how many months they are pregnant, and how many months they have been milking. Similar situations will happen in the following lactation cycles. The number of possible categories in which cows can stay at any point in time depends on the model dimensions: 10 (lactation stages) x 32 (months growing or in milk) x10 (pregnancy stages) = 3,200.

A voluntary waiting period (VWP) of 45 to 60 days will be observed before starting the reproductive program again in this first lactation cow. For adult cows in milking stage, the probability of reproduction is considerably reduced, and it depends on the season. An average value for Florida is 16%, meaning that only 16% of the cows of first lactation (or higher) will get pregnant in an attempt, De Vries (2004). But this varies and the model accounts these variations using DHIA data as seen in Figure 5-1. The pregnancy rate that encompass heat detection and conception rate decreases with months in milk and increases with colder months.

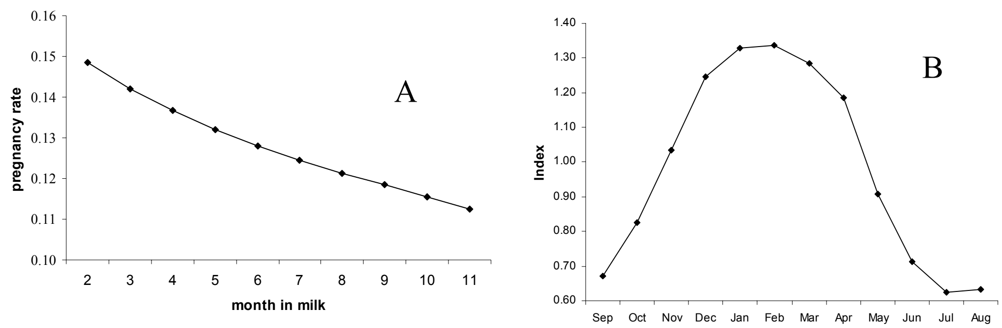


Figure 5-1. Pregnancy rates of adult cows according to A) month in milk; and B) seasonality index of pregnancy rate by month of the year. Source: Prepared with data from De Vries, 2004.

If after 12 months in milking the cow is not pregnant, she will be voluntarily culled from the herd; adult cows have much greater chance of being culled for reproductive problems than heifers. Two months prior to the delivery, the cow is dried off, preparing her for delivery. As soon as she delivers, she enters as a fresh cow, first month, open cow of second lactation. The offspring, if female, will enter the calf group. Calves will become heifers, heifers will become cows, and cows will age through successive lactation cycles.

Fewer cows will arrive at higher lactation cycles because there is always a chance for any cow to be involuntarily culled. The involuntary culling rate depends of cow stage: heifer or adult, months in milk, and the season, as can be seen in Figure 5-2. For example, higher culling rates are expected in warmer months and in the first months of milking.

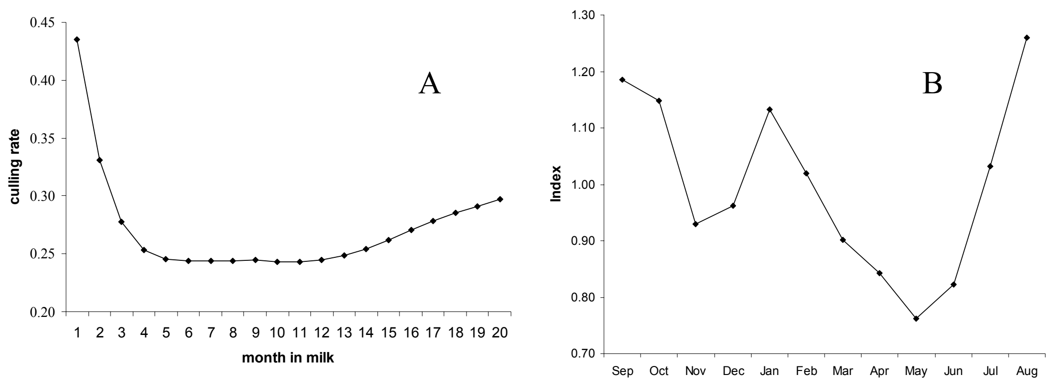


Figure 5-2. Culling rates of adult cows according to A) month in milk; and B) seasonality index of culling rate by month of the year. Source: Prepared with data from De Vries, 2004.

Adult cows as well as young heifers or calves always have a probability to leave the herd for many reasons. Farmers call involuntary culling as the probability that an animal leaves the herd by an unfortunate event such as death, sickness, injury, etc. and voluntary culling as the probability that the animal becomes unpractical or un-economical to keep in the herd as in the cases of low production or low fertility. There are several studies and controversies about the theory of culling cows; for this study, involuntary culling was adjusted to the DHIA Florida averages (De Vries, 2004) as seen in Figure 5-2. The voluntary culling was based on months after which the cow is not pregnant: for adult cows at 12 months and for heifers at 24 months.

Under this model structure, milk production standards for Florida were installed using information from the DHIA (De Vries, 2004). Since the model bases further calculations on milk production ratios, this was a very detailed component. Cows produce different amounts of milk depending on lactation number, months in milk, and season of the year. Curves show this seasonality according to months in milk for different lactations, Figure 5-3.

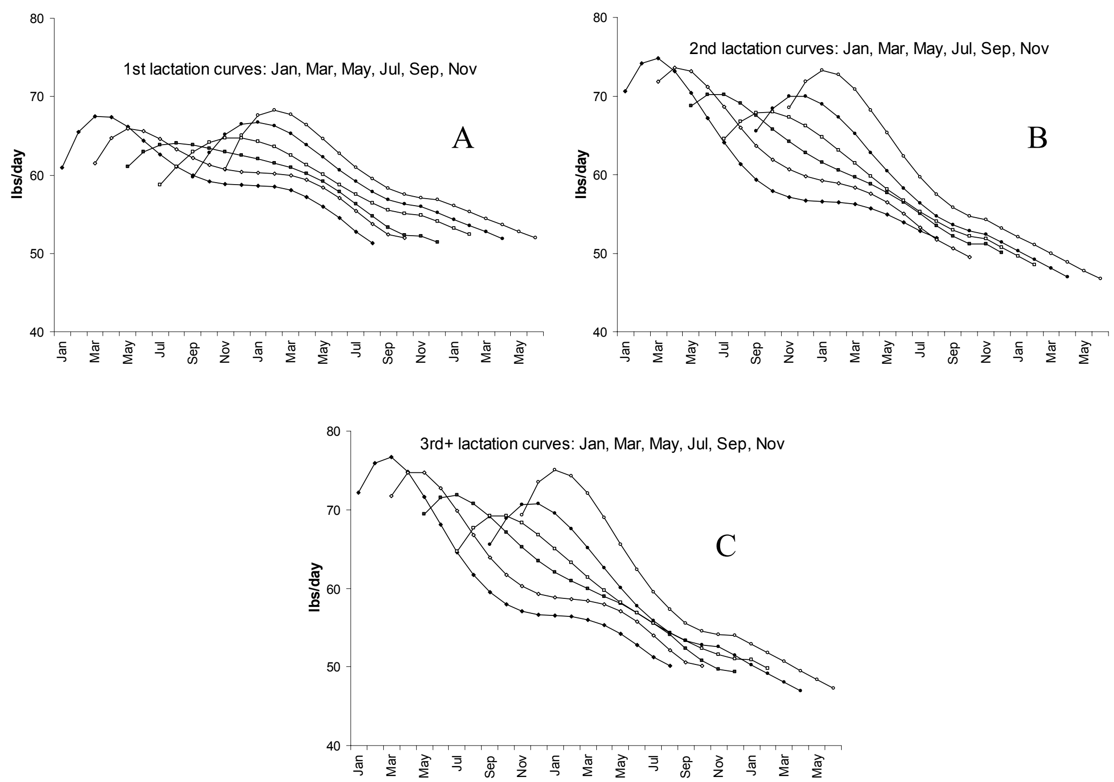


Figure 5-3. Milk production rates of milking cows according to A) month in milk and season of the year for cows in first lactation; B) cows in second lactation; and C) cows in third to ninth lactation. Source: Prepared with data from De Vries, 2004.

Figure 5-3 shows average rates of milk production for Florida based on lactations, months in milk, and seasonality. These milk production values can be adjusted for every specific farm based on the rolling herd average (RHA, average milk produced by a cow in the herd over the last 12 months) by running the model and comparing total milk production with the RHA target. The model will self-adjust to reach the RHA for that specific herd with less than 1% of error.

5.3.3 Manure N Produced by Milking Cows

Well documented studies such as Van Horn et al. (1991, 1994, 1998, 2001), Tomlinson et al. (1996), Wilkerson et al. (1997), Nennich et al. (2003) have found that excretions are highly variable depending on many things, among them dry matter intake (DMI), nutrient concentration, and digestibility. Different approaches to estimate manure N in Florida have included these factors as well as estimated body weight as predictors (Van Horn et al., 1998; NRCS, 2001). However, all these data are not always available and/or are not totally reliable. This study proposes a simpler way to estimate manure N based only on milk production. Knowing the digestibility (N used in milk, maintenance, and offspring) (Van Horn et al., 1998; Wu et al., 2001), we can estimate the N excretion as a function of the amount of milk produced. A study carried out across the United States (Nennich et al., 2003) found that the single best predictor for N and manure excretion is milk production. Nennich et al. (2003) concluded that milk production drives feed intake and ultimately nutrient excretion values reflect the relationship among feed intake, milk production (nutrient utilization), and nutrient excretion.

Crude protein content in the diet also affects the N flow amounts. Wu et al. (2001) mention that 25 to 35% of the N consumed in cows will go with the produced milk, almost entirely the difference (65 to 75%) will be in the manure. Several studies (reported by Van Horn et al., 1998) have found that milk production is correlated with manure production and most importantly with N excretion. Higher manure production in higher milk production months (winter) also has been reported in the direct farmer interviews.

Table 5-1 shows a direct relationship among milk production, DMI, and excretions. High milking cows will consume more dry matter (DM) and excrete more manure and more N. If these high producers consume less DM for any reason, they will produce less milk and consequently less manure and N. Low milking cows will consume less DM and produce less milk compared to high milking cows and consequently excrete less manure and less N.

Table 5-1. Dry matter intake, manure, and N excretion by Florida dairy cattle based on milk production. (lbs cow^{-1} day^{-1}) and “low” and “high” (NRC standards) crude protein (CP) content of diets

			N Excretion	
milk	DMI	manure	“low” CP	“high” CP
100	55.8	195	0.899	1.030
70	46.3	160	0.727	0.846
50	39.2	125	0.601	0.698
0	25.2	80	0.364	0.439

Sources: Modified from Van Horn et al. (1998), p. 3.;USDA (1992a), p. 8., USDA (1992b), p. 8. Note: NRCS uses these values for estimations.

If high and low producers are fed more than required they will not produce more milk but they will tend to gain body weight and will excrete more manure and N. This is not desired by the farmers (found in the interviews) because it is a waste of money and an unhealthy choice for the cows (fat cows have more health problems and higher risks in pregnancy and delivery). Thus, farmers will always try to give only enough feed to achieve optimum performance. Therefore, farmers group cows by production performance, preparing different rations, and giving different feed amounts. It is assumed for the model that the amounts of feed are based on milk production rates and farmers will feed their cows accordingly.

Van Horn et al. (1998, 2001) and NRCS (2001) estimate the total N excreted assuming fixed days in lactation stages in continuous identical cycles for all cows. In this study, great effort has been devoted to incorporating milk production by north-Florida herds using historical data of culling, reproduction, and milk production rates based on seasons. These calculations are used to estimate N excretion.

5.3.4 Nitrogen and Crude Protein

Nitrogen is a component of amino acids and ultimately proteins, therefore, protein content of the diet has direct repercussion on quantities of excreted N. Evidence exists that farmers may over-enrich cow diets with proteins; consequently it would be possible to decrease amounts of N overflows in dairy systems by decreasing cow protein intake without decreasing productivity (Van Horn et al., (1998, 2001); Wu et al. (2001); Jonker et al., (2002); Børsting et al. (2003)). Also, studies indicate that the source of N or protein can make a difference in the quantity of excreted N (Wu et al. (2001); Børsting et al. (2003)). Van Horn et al. (1998) present a table with the differences in N excreted by two different ratios of crude protein (CP) in the diet based on the NRC indexes: one that uses "high" protein to assure that true protein needs are met and the other "low" that minimizes dietary N intake. For cows producing 100, 70, 50, and 0 lbs of milk the "high" CP rations were 17.5, 16.4, 15.3, and 12%, respectively and the "low" diets were 16, 14.8, 13.8, and 11%, respectively. With these two formulations, the milk production remained steady, but the amount of N produced changed. Van Horn et al. (1998) estimate for a year, for a 1400-lb cow, producing 20,000 lbs of milk and consuming 15,099 lbs of dry matter, an N excretion of 234 lbs with the "low" CP diet, while it would be 273 lbs with the "high" CP diet. This would mean that a 15% of change in N excretion would be expected by these changes in diets. Additionally, CP in the diet will impact the feeding costs.

Wu et al. (2001) conducted a study on dietary manipulation to reduce N excretion by lactating cows in Pennsylvania, concluded that dietary protein can be moderately manipulated without affecting milk production. They recommended other means of balancing rations for maximal microbial protein production using synthetic limiting amino acids. Strategies to reduce N excretion may include eliminating excess dietary protein, maximizing microbial protein production, and using protected amino acids for reductions in total protein that needs to be fed.

Using these estimates, and based on milk production for every cow group in the model, good estimations of DMI, manure, and N can be calculated for high and low CP diets (Figure 5-4.).

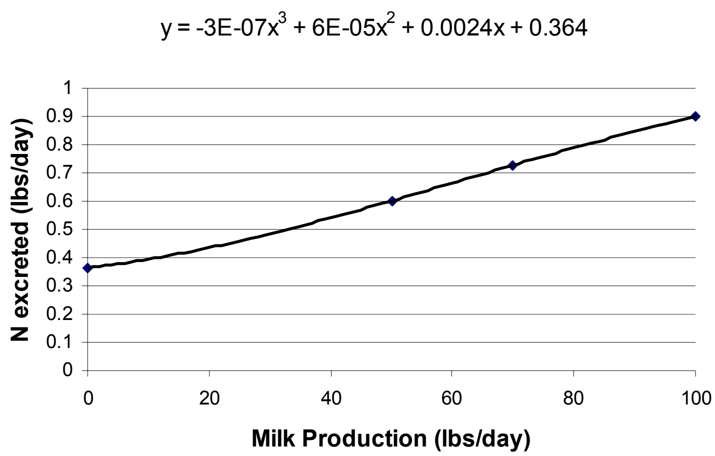


Figure 5-4. Manure N produced by low-CP diet cows according to milk production

The function presented in Figure 5-4 can be corrected based on overall CP in the diet (weighted average of crude protein received by the 100, 70, 50 and 0 milking cow groups) that are estimated as 13.947 for a low-CP diet and 15.034 for a high-CP diet (NRC averages). A function with a slope of 0.096 for the average CP diet above 13.937 performs this correction.

5.3.5 Milking Times and Cattle Breeds

There is a dilemma regarding the effects of number of milking times per day on milk production. Farmers in north-Florida use two or three times a day milking (2X-3X), or even, in exceptional cases, four times (4X). Using 3X compared with 2X is reported for Florida to increase milk production (Giesy, R. 1995. Another look at 2x-3x milking. University of Florida Cooperative Extension Service, Unpublished. Dep. of Animal Science, Gainesville, FL.), although these results are not conclusive (Hoekema, 1999). It seems that 3X will produce more milk, but at an elevated production cost, which is why some dairies prefer to reduce 3X to 2X in summer months when overall lower production rates are observed. Direct effects of different milking times on manure N production were not included in the model since it only depends on the quantity of milk produced regardless of the times cows were milked.

Another dilemma is variation in N production with cattle breeds. All estimations are based on experiments with Holstein cows, which are dominant in the study area (probably 95% of cows in north-Florida are Holsteins). However, there are a few farms that manage Jersey, Shorthorn, or, more commonly, crosses of these breeds with Holstein. There will be differences between herd breeds and manure N produced. For example Jersey cows are expected to produce less N, but based on previous assumptions, the best indication is the amount of milk produced, which will determine manure, N and DMI. In fact, Knowlton (2000) affirms that Jerseys and Holsteins metabolize nutrients similarly and consequently the amount of manure and N excreted per body unit weight is the same in both breeds; results shown by Knowlton (2000) also demonstrate that the direct relationship between milk production and waste excretion are similar in both breeds. Additionally, using Jonker et al. (2002) assumptions of manure N production by different breeds, including Holstein, Brown Swiss, Ayrshire, Guernsey, Jersey, and

Milking Shorthorn, we can safely estimate manure N production across breeds based solely on milk production.

5.3.6 Manure N Produced by Dry Cows, Young Stock, and Bulls

Less information regarding manure N production is available for dry cows, young stock and bulls because they are not usually recognized as environmental hazards. They produce less manure N proportionally, and they are usually kept in open areas under grazing conditions (contrary to confined areas as is the case of milking cows). This study emphasizes the importance of accounting also for these sources of manure N inside the dairy farm system, but through less elaborate estimations.

For dry cows, the estimations were based on several references (Van Horn et al. (1998, 2001), NRCS (2001)) that indicate that a dry cow produces 0.364 lbs of N day^{-1} and this value can be corrected as above, according to CP intake.

Estimations for calves and heifers are made using body weight, assuming that a newborn calf weights 90 lbs and gains approximately 40 lbs per month. For this group, book values from Table 4-5 of the AWMFH (USDA, 1992a) for heifers indicate that a heifer of 1,000 lbs produces 0.31 lbs of N (in 85 lbs of manure). With this information as a benchmark, and interpolating by body weight, the model estimates that a heifer of 5 months that weighs 90 + 5 * 40 = 290 lbs, would produce (290 * 0.31) / 1000 = 0.0899 lbs of N in (290 * 85) / 1000 = 24.65 lbs of manure. There are no correction numbers for low/high CP according to NRCS (2001) because their diet is assumed to be standard.

For bulls (which are used for reproductive purposes in many dairies) there is not much information about their DMI and/or manure N production. They could be estimated based on their bodyweight and under the parameters of heifer cows in distinct stages. Bulls are usually larger than cows; they weight 10 or 20% more than the 1400-lbs for average cows. But because they do not produce milk or become pregnant, they require lower feed intake and, consequently their manure N production would be less. It is estimated that bulls consume similarly to dry cows or heifers in relation to their body weight, 25.2 lbs of dry matter/day and produce 80 lbs of manure with 0.364 lbs of N for each 1400 lbs of body weight. Bulls go with the milking cows in order to breed them; their manure joins that of the milking cows.

5.3.7 Manure, Feces, Urine, and Dry Matter Intake Estimations

The amount of manure excreted by milking cows can be estimated with the function presented in Figure 5-5 based on values presented by Van Horn et al. (1998), Table 5-1. An estimation for cows producing 20 lbs of milk in a day has been added considering that a milking cow always will produce more manure than a dry cow (more than 80 lbs) and that there will not be milking cows producing less than 20 lbs/day.

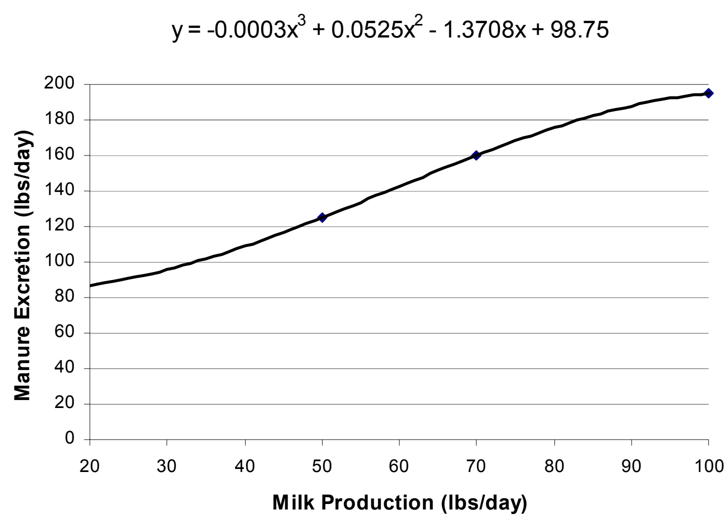


Figure 5-5. Manure excretion based on milk production

Manure produced by dry cows can be estimated as proposed by Van Horn et al. (1998, 2001) and NRCS (2001) at 80 lbs/cow/day. For heifers, the estimation can be performed similarly to that of N, based on body weight (age) and according to Table 4-5 of the AWMFH (USDA, 1992a). From the total manure, according to Van Horn et al. (1998, 2001), 61.35% and 38.65% are the proportions of feces and urine in the manure, respectively.

Dry matter intake (DMI) for milking cows can be estimated based on milk production following the function presented in Figure 5-6, based on Van Horn et al. (1998), Table 5-1.

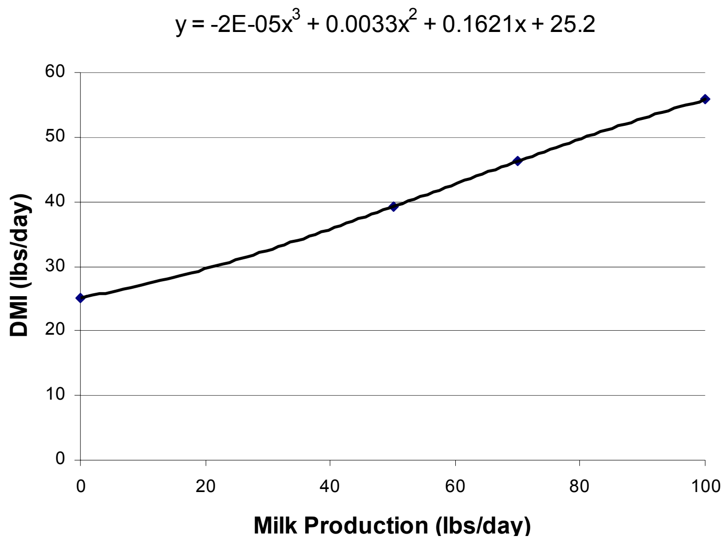


Figure 5-6. Dry matter intake (DMI) based on milk production

Amounts of DMI by heifers were estimated based on body weights using averages of adult cows. Adult cows, according to Van Horn et al. (1998, 2001) consume on average 15,099 lbs of DMI in a year (1400-lb cows); this is about 3% of their body weight in a day as DM. Interpolating that to calves and heifers, a recent born, 90-lb calf will consume 2.7 lb DM and a 32 month old heifer (40 * 32 = 1280 lb) will consume as a dry cow = 25.2 lbs. Therefore, for a 16 month old heifer the DMI will be 2.7 + 0.7031 * 16 = 13.95 lb. DMI for bulls is assumed to be similar to dry cows, 25.2 lbs/day.

5.3.8 Water Utilization for Manure Handling

Many components determine the total amount of water (drinking water for cows, cleaning equipment, cooling system, flushing manure, etc.). Van Horn et al. (1994) estimated that the amount of water used for a milking cow in a day could vary from 49 gallons (187 L) for minimum usage (no flushing) to 171 gallons (650 L) in high usage (with flushing). Further, this has a direct relationship with the season of the year: hotter months will require more water than cooler months. Water is critical for the dairy operation; in the case of the north-Florida waste management systems it is also the carrier of the manure and N. All farms studied had some kind of flushing system. Using the above values, an interpolation can be performed to estimate the amount of water used by milking cows, assuming that approximately the use of water in the coldest month will be half of that in hottest month (found from farmers during interviews), and therefore the amount of water used in every month can be expressed as a percentage of the amount used in the hottest month. Amounts of water required by heifers and dry cows will be much less than the milking cows and those will not enter the manure flushing system. These estimations are presented in Table 5-2.

Some dairies recycle water from the manure system. Recycle means that they use the flushing water more than once, saving fresh water in the process. Because there are great differences among farms, a user-defined input in the model allows the user to adjust the amount of water they use as a function of the maximum water used in a single month and the percent of water recycled. Water usage for any month will be estimated by multiplying the maximum water used in the hottest month, the percentage of use in a specific month, the number of milking cows, and the percent of water recycled.

Table 5-2. Water utilization by milking cows during months and percentage use relative to month of maximum use (July)

	Gal cow^{-1} day^{-1}	%
September	146.93	85.90
October	134.87	78.85
November	122.81	71.79
December	110.75	64.74
January	98.68	57.69
February	110.75	64.74
March	122.81	71.79
April	134.87	78.85
May	146.93	85.90
June	158.99	92.95
July*	171.05	100.00
August	158.99	92.95

*Month of maximum water utilization.

5.3.9 Waste Management Handling Systems

All visited north-Florida dairy farms handle their waste through a liquid manure system, but there are variants according to how they collect, store, process, transport, and utilize the waste. These variants are important because they determine how much manure is recovered and how much is potentially lost to the air.

North-Florida dairy farms have some variants from a usual waste management system, consisting of a water flushing system, a storage pond, and an irrigation system. Additionally they may also have a solid screener and/or a treatment lagoon. The flushing system uses great amounts of water to move the manure (feces and urine) deposited in the concrete; the storage pond receives and stores the liquid manure for variable time; and the irrigation system applies the liquid manure to the crop systems. Both, the solid screener and the treatment lagoon are designed to separate solids from the flushed manure: the first one by mechanical action and the second one by gravity or precipitation. Both, if present, are located before the storage pond.

As soon as the manure is deposited on the concrete, variable rates of ammonia will be lost to the air as volatilization. If solids are screened, the manure that reaches the storage pond (in which it remains a variable time) will be a solution with less than 5% solids. Nitrogen in this liquid manure will be ammonium and organic compounds in solution. Extra amounts of ammonia will still be lost by volatilization to the air during the holding time in the storage pond and during the spraying application in the fields. If solids are not screened, the liquid manure will have greater than 5% solids but it still will be sprayed on the fields using high pressure equipment and an agitator to maintain it liquid.

The proportion of solids collected by separators varies greatly among systems; for example a stationary separator can take 20 to 30% of the solids, while a well-designed gravity separator can collect up to 60% of the total solids (Van Horn et al., 1998). However, at least 80% of the N is contained in the liquid solution and is not possible to recover through solids (Tomlinson et al., 1996). If the separation is through a stationary separator, the solids collected will have 72% moisture and from the remaining 28% of DM, only 1 to 1.6% will be N (Van Horn et al., 2001). If it is separated by gravity, the separation has more moisture and is unlikely to be used as bedding, feed or composting; this is usually spread on the land (Van Horn et al., 1994).

Even in the most controlled manure systems, loss of N in relatively high quantities will be expected. Between 41 and 50% of the N in manure is in the form of urea or ammonia, which can easily be volatilized (Van Horn et al., 1998). Urea in contact with the ureasa enzyme, present almost everywhere, will convert to ammonia (NH_3), and the ammonia as a gas, volatilizes to the air. Even though the fecal form of N, mostly in the feces, is more stable, it could also be freed up by anaerobic digestion. Alkaline conditions in the collection pathways and lagoons will result in more volatilization, while acidic conditions will decrease volatilization. Once the liquid manure reaches the irrigation system, a last amount of volatilization, proportional to the water evaporation during irrigation can be expected.

Amounts vary greatly in different management systems, but Van Horn et al. (1998) presents the result of several University of Florida studies throughout the state (Table 5-3), in which the following indexes of N lost were calculated:`

Table 5-3. Nitrogen lost in the waste management system: a baseline

	%
Volatilization before flushing	2.38
Collected solids	6.5
Volatilization in lagoon and or pond	9.21
Sludge accumulation in lagoon and/or pond	5.74*
Volatilization during irrigation	11.48
Total N lost during manure handling	35.32

* Estimated based on surveyed north-Florida operations. Source: Several University of Florida studies, Van Horn et al. (1998).

According to these values, 35.32% of the manure N is lost, and the difference 64.68% reaches the crop fields. Because these great variations, it is important to let the user select his/her system and N indexes. The model allows the user to input these values based on real analyses and reports made to the regulatory agencies.

5.4 Results and Discussion

5.4.1 The Model (Livestock Dynamic North-Florida Dairy Farm Model, LDNFDFM)

The main result of this study was the Livestock Dynamic North-Florida Dairy Farm Model. The LDNFDFM is capable of giving accurate manure N estimations solely based on number of adult cows (NAC) and rolling herd average (RHA) of any north-Florida dairy farm. NAC and RHA are always available in any north-Florida dairy farm and they are highly accurate. An approximation of the amount of crude protein (CP) in the diet, degree of seasonality in operation, confined time, and characteristics of the waste management system can also be manipulated to better mimic specific farm conditions. The LDNFDFM was implemented in Excel ® using Visual Basic ® programming as a user-friendly application.

5.4.2 Model Comparison with Other Widely Used Estimations

Estimations of Van Horn et al. (1998 and 2001) and WATNUTFL (NRCS, 2001) were compared with estimations from the model. To achieve such comparisons, a hypothetical farm was set up with the following characteristics: the farm had 100 producing cows, which weigh 1400 lbs on average and were confined 100% of the time.

A first comparison was performed using "low" protein diets for cows with a RHA of 18,250 lbs of milk/year. Results are shown in Figure 5-7.

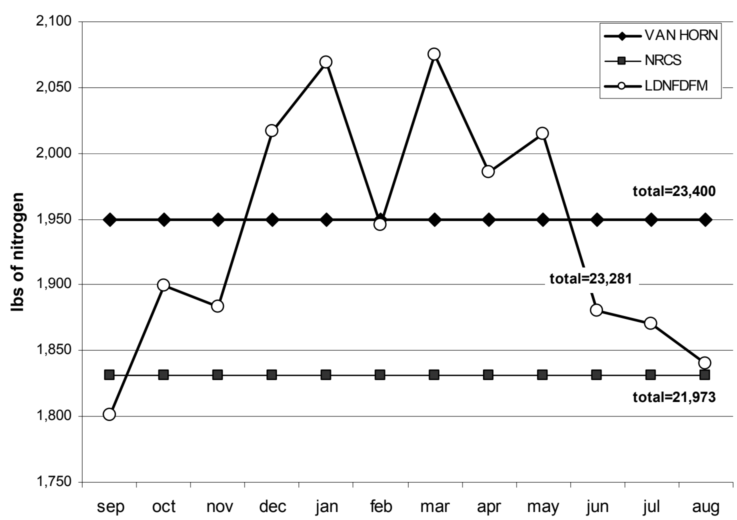


Figure 5-7. Nitrogen excretion by a "low" protein diet in a 100-cow dairy estimated by different models

Overall yearly estimation of the LDNFDFM (23,281 lbs of N) was between values estimated by Van Horn (23,400 lbs of N) and NRCS (21,973 lbs of N), but closer to that estimated by Van Horn. Since Van Horn and NRCS calculate values on a yearly basis, they assume steady monthly values as seen in Figure 5-7. However, the DNFDFM shows a more realistic seasonal variation throughout months of the year, following the common seasonality in dairy operations.

Another comparison was performed using "high" protein diets for cows with a yearly milk production of 21,900 lbs. Results are shown in Figure 5-8.

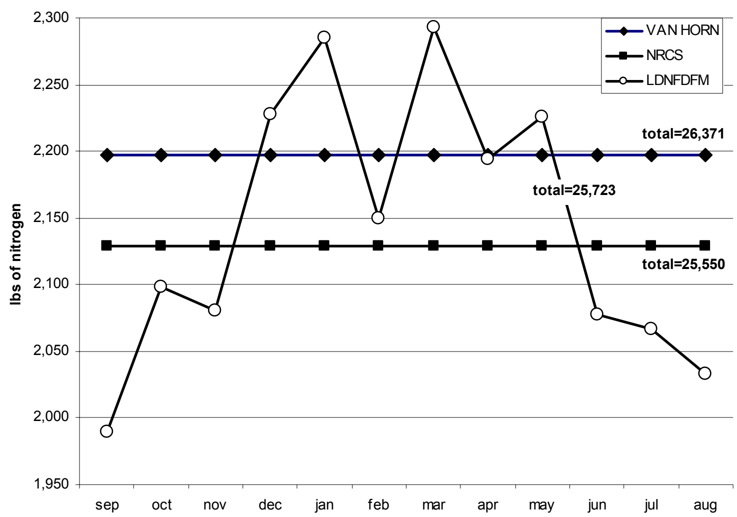


Figure 5-8. Nitrogen excretion by a "high" protein diet in a 100-cow dairy estimated by different models

Annual estimation by the LDNFDFM (25,723 lbs of N) was between Van Horn (26,371 lbs of N) and NRCS (25,550 lbs of N), but this time estimation was closer to that of the NRCS. Figure 5-8 shows these three estimations and the seasonality present only with the LDNFDFM model.

5.4.3 Estimation of Manure N Produced in North-Florida Dairy Farm Systems

In order to keep confidentiality of dairy farms, five hypothetical farms were constructed using data from the farm interviews. Hypothetical farms were created to give real information about the manure N production of north-Florida dairy farms without pointing to specific farms. For every dairy, inputs consisted of a set of information that included the total number of adult cows (NAC), number of bulls, the percentage of replacement animals raised on the farm, the rolling herd average (RHA), the estimated percentage of confined time of milking cows, the general characteristics of the waste management system, and the area of land devoted to sprayfields and pasturelands. This information was used in each case as the initial conditions (IC) inputted in the model before running (Table 5-4). The ratios of N per area (lbs ac^{-1}) to be applied to sprayfields and to be deposited in pastureland were estimated for each of these hypothetical farms.

Table 5-4. Five hypothetical north-Florida dairy farms and their characteristics for manure N estimations

		Farm				
		1	2	3	4	5
NAC, Number of Adult Cows	Head	1,000	150	600	1,500	800
BULLS		50	8	65	75	38
HEIFERS	%	20%	0%	100%	0%	50%
RHA, Rolling Herd Average	lbs yr^{-1} cow^{-1}	16,500	13,000	20,075	16,800	21,000
CONFINED	%	62.50%	30.00%	70.00%	40.00%	60.00%
WASTE SYSTEM	code*	1	2	2	2	1
AREA SPRAYFIELDS	ac	90	130	45	240	120
AREA PASTURELAND		440	130**	45	120	250
SPRAYFIELD per COW	ac cow^{-1}	0.09	0.87	0.08	0.16	0.15
PASTURELAND per COW		0.44	0.87	0.08	0.08	0.31
TOTAL AREA per COW		0.53	0.87	0.15	0.24	0.46

*1=separate solids; 2=not separate solids. **Are the same sprayfields

Farm 1 is a medium-large semi-intensive operation with medium productivity of milk. It has shortage of sprayfields, but more abundant pastureland. Its waste system is efficient and has the facilities and the comfort to manage confined animals. Farm 2 is a small grazing system where animals spend more of the time outside; the breed is Jersey or Jersey cross that endures heat stress in summer, but has low milk productivity. This farm has plenty of land for its herd, which serves at the same time as sprayfield and pasture (this is unusual). This farm prefers not to raise heifers; it sells all off-spring and buys replacements.

Farm 3 is a medium-size intensive operation with high milk productivity; all heifers are raised on-farm and animals spend most of the time confined. This farm puts high pressure on the land not only because of the intensity of the operation, but also because of the shortage of land in both sprayfields and pasturelands. Farm 4 is a mixture between intensive and grazing farm, large in size, medium intensive with medium milk productivity, and low time cows spending over concrete. It has abundant sprayfields, but a shortage of pastureland. It does not raise heifers and the waste system does not include solid collection.

Farm 5 is a medium-size intensive system with high milk productivity that keeps cows confined an average time, and seems to have a shortage of sprayfields and pastureland; it raises only half of its heifers and has an advanced waste system that collects solids.

For simplicity, the only variations in waste systems accounted for in Table 5-4 are code 1 (they separate the solids), and code 2 (they do not separate solids). Using values previously presented as a baseline in Table 5-3, it was estimated that with code 1 there is 35.32% N lost and with code 2 there is 28.82% N lost through the manure handling system. Specific farms can and should enter their own specific values.

Usually sprayfields receive liquid manure and the pastureland direct excretions of the dry cows, and young stock, and the milking cows and bulls during non-confined time, but there are a few cases where the fields can receive both as is the case of Farm 2, where the sprayfields are also the pasture fields.

For all farms a "low" protein diet was assumed and water was estimated using the ratio 171.05 gallons maximum amount used by a cow per day in the hottest month, and that water is not recycled. Particular farms should enter their own specific data.

Tables 5-5, 5-6, and 5-7 present the estimated results for these five hypothetical farms. The first glance indicates that there is great variability among farms.

Table 5-5 shows how much manure N the sprayfields receive on a monthly basis according to the characteristics of each of these operations. There is a farm that applies as little as 3 lbs per acre in a month (Farm 2) and a farm that has to apply as much as 136 lbs per acre in a single month (Farm 3). Greater amounts of manure N are sprayed in winter months and lower amounts in summer months, although the amount of variation in seasons also varies according to the characteristics of each farm; some farms have very small variations throughout the year (Farm 2 or Farm 4) while another has greater variations (Farm 3). This difference in seasonal variations is explained by the interaction between natural seasonality of the cow-flow and productivity, and the CT; the lower the CT, the lower the seasonality noticed in the sprayfields because less manure N is going through the waste system. The opposite is also true as in the case of Farms 3 and 5 that have higher seasonality.

Amounts of manure N per acre in a whole year are also highly variable among farms. There is a farm that has to apply more than 1,540 lbs of N per acre in a year (Farm

3), while there is a farm that only requires applying 45 lbs of N per acre in a year (Farm 2). All factors in Table 5-4, except percent of heifers raised and land for pastures, affect these amounts. When a higher land per cow ratio, lower RHA, and lower CT the total N per acre per year will be lower as can be seen in Farm 2 and the opposite for Farm 3. The waste system impacts the final amount of manure N reaching the sprayfields since different amounts of N will be lost; in Table 5-4, waste system 1 loses more N than system 2. Therefore, Farms 2, 3, and 4 would decrease amounts of N in sprayfields if they would implement solid collection in the waste system (change from system 2 to system 1).

Table 5-5. Estimated amounts of manure N to sprayfields in five hypothetical north-Florida dairy farms

		Farm				
		1	2	3	4	5
September	lbs ac^{-1} mo^{-1}	70.22	3.46	119.75	28.08	47.42
October		74.04	3.65	126.08	29.60	49.92
November		73.39	3.62	124.78	29.34	49.41
December		78.53	3.88	133.24	31.39	52.76
January		80.50	3.98	136.41	32.18	54.02
February		75.71	3.74	128.29	30.27	50.81
March		80.73	3.99	136.84	32.27	54.19
April		77.27	3.82	131.09	30.89	51.92
May		78.41	3.87	133.20	31.35	52.76
June		73.24	3.61	124.67	29.28	49.38
July		72.92	3.60	124.34	29.16	49.25
August		71.79	3.54	122.50	28.70	48.51
Total Nitrogen	lbs ac^{-1} yr^{-1}	907	45	1541	363	610
Nitrogen per Cow	lbs cow^{-1} yr^{-1}	82	39	116	58	92

The contribution of each cow to the amount of N applied to sprayfields varies greatly among farms. The model estimates that in Farm 2 the amount of manure N that reaches sprayfields is 39 lbs per cow. This amount is substantially lower than the others and the lowest of all. Farm 2 has the lowest ratio because its RHA is the lowest, reducing the amount of manure N produced for each animal and the confined time of the cows is also the smallest compared with the others (30%). This low rate of N to sprayfield happens even though this farm does not collect solids from the manure.

On the other hand, Farm 3 applies 116 lbs of manure N to sprayfields per each cow. This is substantially higher than the others and the highest of all. Three reasons explain this fact: the high RHA (20,075 lbs cow^{-1} $year^{-1}$, the second highest); the high CT (70%, the highest of all); and the waste system does not collect the solids, so more manure N goes to sprayfields.

Although the NAC and the RHA have the greatest impact on the overall amount of manure N produced, the waste system and the available sprayfields determine how much manure N reaches these fields.

Table 5-6 presents the results of the estimations of the monthly manure N that pastureland would receive in each of the farms. There is also a great difference in the amounts of manure N received among pasture fields.

Table 5-6. Estimated amounts of manure N deposited on pasturelands in five hypothetical north-Florida dairy farms

		Farm				
		1	2	3	4	5
September	lbs ac^{-1} mo^{-1}	18.96	13.41	140.98	140.90	34.62
October		19.44	13.88	145.06	145.60	35.67
November		18.61	13.44	139.88	140.71	34.40
December		19.03	13.96	143.91	145.75	35.47
January		18.78	13.95	142.88	145.46	35.27
February		17.41	12.98	133.27	135.35	32.86
March		18.61	13.86	142.70	144.47	35.13
April		18.05	13.37	138.20	139.56	34.00
May		18.86	13.84	143.44	144.65	35.30
June		18.53	13.38	139.91	140.10	34.35
July		19.45	13.81	145.72	144.88	35.68
August		19.59	13.83	145.93	145.10	35.75
Total Nitrogen	lbs ac^{-1} yr^{-1}	225	164	1702	1713	418
Nitrogen per Cow	lbs cow^{-1} yr^{-1}	99.14	141.87	127.64	137.00	130.78

Exploring Table 5-6, the first conclusion that can be drawn is that these amounts are not small; in fact, the quantity of manure N applied to the fields through direct excretion could surpass those amounts applied on the sprayfields in some cases (Farms 2, 3, and 4). This fact has profound implications because it discovers a source pollution that should be taken into consideration; current major efforts are addressed mostly to sprayfields and waste systems.

Some pastures receive manure N excretions with as little as 13 lbs of N in a month (Farm 2), but others receive excretions with as much as 145 lbs of N in a month (Farms 3 and 4). The quantity of N deposited on pasturelands also has seasonality through the year, but usually different from that of the sprayfields. Higher amounts are expected in summer and fall and lower amounts in winter and spring following the cycle of dry cows and heifers; there would be more cows milking in winter and consequently fewer dry cows on pasture, and more heifers will freshen during fall months, moving them from pastureland to more confined areas. However, as Table 5-6 indicates it varies greatly also because other factors such as the percent of heifers raised on-farm or the confined time of milking cows.

The amount of manure N deposited with the excretion in pasturelands varies from 164 lbs of N in a year (Farm 2) to more than 1,700 lbs of N in a year (Farms 3 and 4). Land area in pastures together with the number of heifers, dry cows, and non-confined time of milking cows and bulls determines these amounts. Additionally, the RHA is important depending on how much time milking cows spend on pasture.

The amount of N per cow that is deposited in pasture fields depends on the RHA; the number of bulls; the percent of heifers raised on-farm; and the CT. The CT is very important since it determines how much time milking cows spend in pastures; e.g., Farm 2, that has the lowest CT of all, presented the lowest manure N per cow in sprayfields, however it shows the highest N deposited per cow in pasture fields.

Table 5-7 presents additional information estimated by the DNFDFM for the five hypothetical farms regarding the manure produced, dry matter intake, and water use.

Table 5-7. Estimated amounts of manure, DMI, and water use in five hypothetical north-Florida dairy farms

		Farm				
		1	2	3	4	5
Total Manure Confined	lbs yr^{-1}	26,333,116	1,663,958	20,889,635	25,570,629	24,397,989
Total Manure Deposited		30,913,417	4,370,231	18,020,830	43,232,565	23,611,177
Total Dry Matter Intake		17,147,309	2,400,529	11,339,436	25,873,975	15,259,717
Water Use	gal yr^{-1}	43,706,188	6,555,930	26,223,723	65,559,310	34,964,950

Table 5-7 summarizes estimations for a whole year. The total manure confined is the wet weight of urine and feces deposited on concrete during the confined time by milking cows and bulls that will reach the waste management system. The manure deposited refers to the amount of feces and urine directly deposited on pasturelands. The total DMI includes all the feedstuff on a dry matter basis for all animals and the water usage is for the confined animals. These estimations are based on livestock characteristics and not on the available land. As in the case of N, estimations of these variables give an idea of the magnitude of variation of these operations regarding the amounts of materials into and out of the system.

5.5 Conclusions

A user-friendly model to accurately estimate manure N production by north-Florida dairy farms has been developed. It is called the Livestock Dynamic

North-Florida Dairy Farm Model (LDNFDFM). The LDNFDFM estimates on a monthly basis the amount of N that reaches the sprayfields and the pastureland on a farm with minimal dataset input required.

Estimations using LDNFDFM were more easily and quickly performed than with the other two models widely used in Florida (Van Horn et al., 2001; NRCS, 2001). Estimations by the LDNFDFM, although relatively close to the others, are believed to be better because they take into account the real dynamics of dairy cows and additionally include seasonality. The LDNFDFM model requires less information than the others since it does not use body weight or dry matter as parameters of estimation.

Comparison of the LDNFDFM with models used in Florida demonstrates that the DNFDFM performs inside the expected ranges but with advantageous characteristics by the inclusion of Florida dairy parameters. This comparison might suggest that previous models either overestimate or underestimate N excretion. Another distinctive characteristic of the LDNFDFM is that this model not only estimates manure N produced by adult cows, but also that produced by young stock and bulls; additionally the estimations not only include amounts of manure N of the waste management system, but also that deposited in pastures.

Using the model, estimations for 5 hypothetical north-Florida farms were performed. Results indicated great variability showing that some fields could receive as little as 3 lbs and as much as 145 lbs of manure N per acre in a month according to seasonality of the year, and that these amounts are independent of being a sprayfield or pastureland. Herd size, milk production, and farm size are critical variables affecting these results. The fact that pasture fields can receive large amounts of manure N, found by simulating these hypothetical farms with the model, has profound implications in policy making and regulations towards decreasing N impacts from dairy farms.

After the simulation of the 5 hypothetical farms, it can be concluded that the main factors that lead the N discharge in the fields in a dairy farm are, in order land area/number of animals; milk productivity or intensity of the farm; characteristics of the waste system; confined time; and interactions among previous factors. The number of bulls and the percentage of heifers raised on-farm have lower impacts.

Farms with more land available per cow (either in pasture or sprayfields) will have less environmental problems because manure N can be distributed over a higher land area, so the amount of N per unit of area decreases. However the commitment of more land to dairy production has an economic cost. It is also clear that farms with higher ratios of productivity (milk per cow) require more feed, which brings more N that cows intake and excrete. Farms with high productivity have more N in the system and carries a higher environmental impact. Farms have to balance the trade-offs between productivity and environmental impacts. Low milk productivity could be a valid option depending on the compliance costs; it will not be surprising that in the future more farms adopt this alternative if they are able to maintain an acceptable profit level.

The waste system and the confined time are closely related since the first determines how much of the confined manure N arrives at the sprayfields, and the latter determines how much manure N pastures receive (plus additions from heifers and dry cows). At the moment, the higher the collection or loss of N from the waste system, the lower the environmental impact. However, this might change in the future when probably every pound of N will have to be accounted, no matter where it goes. The confined time and the environmental impact vary also according to the available land for sprayfields and pastures; in general, if the sprayfield cow/land ratio is higher than the pasture, it would be environmentally favorable to have a high confined time.

User-friendliness of the model was desired and achieved. The DNFDFM works as an Excel® file and only requires the initial conditions of the farm to run. It could be recommended to be introduced and compared with traditional methods by farmers and other stakeholders in the issue of N pollution by dairy farms in the Suwannee River Basin.

CHAPTER 6
FORAGE SYSTEMS IN NORTH FLORIDA DAIRY FARMS FOR RECYCLING N UNDER SEASONAL VARIATION

6.1 Introduction

The presence of N in water is an environmental hazard because it affects human health and ecosystem welfare. The Suwannee River Basin has received much attention in recent years because increased N levels in water bodies. Dairy waste may 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. Evidence indicates that the main way farms have to reduce their total N loads is through forage crop systems that are able to recycle an important part of this N produced on the farm. Improvements in climate or seasonal weather predictions (lead times of 6 to 12 months) can play an important role in devising management strategies that dairy farmers in north-Florida could adopt regarding forage crop systems to pursue economic and ecological sustainability.

Although exporting manure off the farm is an option, few farms are using this practice and only for a small part of their waste. Evidence from interviews indicates that dairy farmers must to deal with their manure inside the farm gate. Manure is applied to fields through spraying systems and/or through direct animal depositions. Amount of N in this manure is usually high compared with normal agronomic applications.   Therefore, efficient crop systems are necessary to uptake as much N as possible and decrease environmental problems. Climatic parameters such as temperature, solar radiation, and rainfall will direct and indirectly affect the crop-soil-environment and interaction with N flow.

A few studies have evaluated the manure N uptake and loss in forage systems of dairy farms. In Georgia, Hubbard et al. (1987) found N concentrations between 10 to 50 mg L^{-1} of NO_3-N at 2.4 m below the soil surface in a forage system of bermudagrass (*Cynodon* spp)-ryegrass (*Lolium multiflorum*) when 530 to 1080 kg ha^{-1} of N in effluents were applied. Johnson et al. (1991) presented data indicating that bermudagrass uptakes between 107 and 130 kg N ha^{-1}, rye (*Secale cereale* L.) between 140 and 250 kg N ha^{-1}, and corn (*Zea mays* L.) between 178 and 237 kg N ha^{-1}, when applied rates of manure N were between 385 and 1,000 kg N ha^{-1}. Vellidis et al. (1993) found N concentrations between 0 and 14 and between 4 and 21 mg L^{-1} in a system of bermudagrass-rye applied with 400 and 800 kg ha^{-1}, respectively. A follow up of this study, reported by Newton et al. (1995), found that N uptake by corn, bermudagrass, and rye were 86, 143, and 91 kg ha^{-1}, respectively with application of 400 kg N ha^{-1}, and 157, 137, and 169 kg ha^{-1}, respectively, with application of 800 kg N ha^{-1}.

For north-Florida conditions, French et al. (1995), presented in Van Horn et al. (1998), found that a crop sequence of perennial peanut (*Arachis glabrata* Benth.) - rye uptakes 430, 470, and 485 kg N ha^{-1} $year^{-1}$ receiving 400, 455, and 500 kg N ha^{-1} $year^{-1}$ from manure effluent, respectively. The rye forage in this system accumulated 4, 4.7, and 4.5 Mg ha^{-1} of dry matter containing 60, 80, and 92 kg of N, respectively.

Woodard et al. (2002) performed an extensive experiment for four years (1996-2000) in a north-Florida dairy with distinct forage systems under different rates of effluent application (500, 690, and 910 kg N $ha^{-1}year^{-1}$). They found for these rates of N, the accumulated dry biomass was 20.5, 20.9, and 21.2 Mg Ha^{-1} for the bermudagrass, 13.4, 12.6, and 12.8 Mg Ha^{-1} for the corn, 9.6, 8.7, 9.4 Mg Ha^{-1}, for the sorghum (*Sorghum bicolor* L.), and 3.4, 3.9, and 4.4 Mg Ha^{-1}, for the rye. The N removal of these forages was 390, 430, and 467 kg N Ha^{-1} for bermudagrass, 148, 152, 166 kg N Ha^{-1} for corn, 111, 111, and 120 kg N Ha^{-1} for sorghum, and 55, 70 and 85 kg N Ha^{-1} for rye. The rye was in both a bermudagrass-rye system and a corn-sorghum-rye system and it performed similarly in both regarding N uptake and biomass accumulation. For this experiment, lysimeters were installed 1.5 m below the surface and measurements were taken every 14 days: in the bermudagrass-rye system, the NO_3-N levels never exceeded 10 mg L^{-1} during the time of the bermudagrass (April-November) but they went above 10, 20 and 30 mg L^{-1} during the time of the rye (December-March). For the corn-sorghum-rye system, the measurements were much higher: they reach levels of 20 to 40 mg L^{-1} during corn growth (April-July), 20 to 60 mg L^{-1} during sorghum growth (August-November), and 30 to 60 mg L^{-1} during rye growth (December-March).

The main aim of the present study was to assess the potential N leaching from forage systems under intensive application of dairy manure in north-Florida. The specific objectives were to estimate

- The capacity of north-Florida forage systems of accumulate biomass and remove N from the soil
- The risk of N leaching under different conditions of
    - Climate
    - Crop systems
    - Soils
    - Manure N applications

6.2 Materials and Methods

The study was conducted on dairy operations of north-Florida in the Suwannee River Basin, considering their most common forage systems, under the different soils conditions, over a period of 43 years (1956-1998), and with a wide range of manure N application rates by using crop simulation models contained in the Decision Support Systems for Agricultural Transfer, DSSAT v.4.0 ® Software (Jones et al., 2003).

6.2.1 Survey, Focus Groups, and Additional Information

A sample of 21 dairy farms (30% of the population) participated in the interviews. This sample was obtained in cooperation with the Suwannee Partnership and the University of Florida Extension offices in the study area. The sample was intended to cover the variability in north-Florida dairy farm systems with respect to forage systems and their management. Interviews were arranged to be conversational in nature without an instrument, but with a guideline of topics. Interviews lasted between one and two hours and on several occasions, a tour of the farm followed. Conversations were recorded, transcribed, and classified. More general information was obtained by eight focus groups conducted with farmers and other stakeholders such as extension agents, technical people, personnel from government and regulatory agencies, private consultants, among others. Interviews and focus groups were conducted during summer and fall 2003. Additional secondary information was obtained from published studies, dairy farm records, and official records.

6.2.2 Location of North-Florida Dairy Farms and Their Soil Series

The study was conducted in dairy operations of Suwannee, Lafayette, Gilchrist, Levy, and Alachua counties in the Suwannee River Basin (21.30 to 30.37 N, and 82.43 to 83.35 W), and included 10 different soil types.

There are 64 dairy farms in the study area: 25 in Lafayette, 19 in Suwannee, 7 in Gilchrist, 7 in Levy, and 6 in Alachua. These were located using the land use survey (1995) of the Suwannee River Water Management District, contained in the Florida Geographic Data Library (1995).

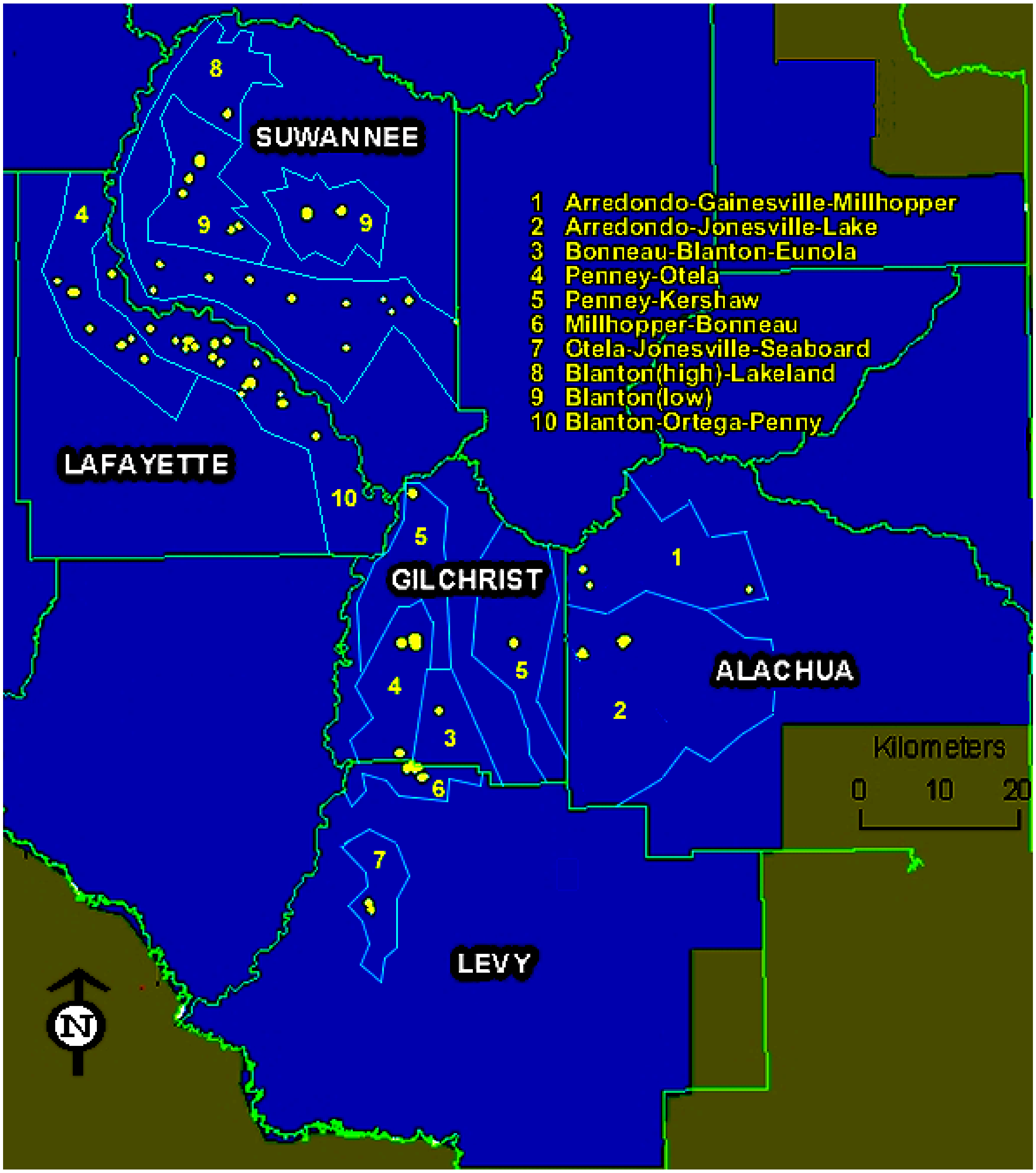


Figure 6-1. Study area, dairy farms, and soil types

The soil series for each of the farms were located overlaying it to the soil series maps from the Soils Survey Geographic Database (SSURGO) from the Natural Resource Conservation Service (2002). Figure 6-1 and Table 6-1 present the soils of the studied dairy farm systems, which were summarized in 10 soil types.

Table 6-1. Soil types, some characteristics, and their sources of information used for the study

Type	Series	County	Drainage[1] Rate	CEC[2] meq 100 g^{-1}	pH[3]	Survey
1	Arredondo-Gainesville-Millhopper	Alachua	0.75	6.0	5.9	Thomas et al., 1985
2	Arredondo-Jonesville-Lake	Alachua	0.65	5.0	6.3	Thomas et al., 1985
3	Bonneau-Blanton-Eunola	Gilchrist	0.80	6.6	5.6	Weatherspoon et al., 1992
4	Penney-Otela	Gilchrist, Lafayette	0.80	3.6	4.9	Weatherspoon et al., 1992
5	Penney-Kershaw	Gilchrist	0.75	3.2	4.7	Weatherspoon et al., 1992
6	Millhopper-Bonneau	Levy	0.85	7.0	5.0	Slabaugh et al., 1996
7	Otela-Jonesville-Seaboard	Levy	0.75	5.5	5.3	Slabaugh et al., 1996
8	Blanton(high)-Lakeland	Suwannee	0.60	2.7	5.1	Houston, 1965
9	Blanton(low)	Suwannee	0.80	7.4	5.3	Houston, 1965
10	Blanton-Ortega-Penny	Lafayette	0.75	5.1	5.3	Weatherspoon et al., 1998

Note: Drainage, CEC, and pH are only for the first soil layer. [1]0.60 (well), 0.75 (somewhat excessive), 0.85 (excessive). [2]Cation Exchange Capacity < 3.0 (extremely low), 3.1-5.0 (very low), 5.1-7.0 (low), 7.1-10.0 (medium). [3] < 5.0 (very strongly acid), 5.1-5.5 (strongly acid), 5.6-6.0 (moderately acid), 6.1-6.5 (slightly acid).

The 10 soil types are summarized in Table 6-1, where there is a brief characterization of each of them regarding drainage, cation exchange capacity, and pH. For more information, there is a reference to the specific soil survey publication. Datasets consisting of several layers of information for each type of soil were collected and organized for the study. These specific data were converted to the format needed by the DSSAT v4.0 system, using SBuild ® software (Uryasev, 2003), where the soil water holding limits were corrected using Saxton et al. (1986).

6.2.3 Climate Information and El Niño Southern Oscillation (ENSO) Phases

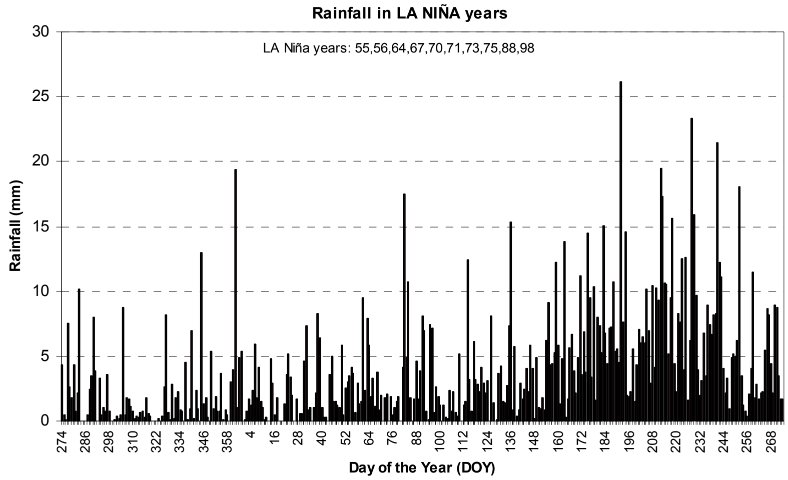
Daily weather information was selected from Levy (29.42 N, 82.82 W), located in the central south part of the Suwannee River Basin, between the years 1956 and 1998 (Mavromatis et al., 2002) to be representative for the study area.

During this time, 11 years were classified as El Niño years, 10 as La Niña years and 23 as neutral years. Each, El Niño, La Niña, or neutral year is defined as beginning in October and running through September of the next calendar year according to the Japan Meteorological Index (JMI) of sea surface temperature (O'Brien et al., 1999).

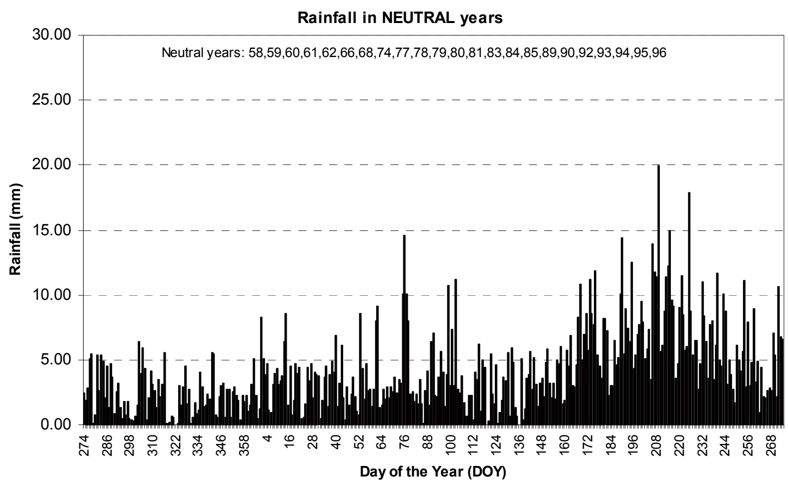
Daily weather information of rainfall, minimum and maximum temperature, and solar radiation between October 1st (day 274 (275 for leap years)) and September 30th (day 273 (274 for leap years) were selected, classified, and organized for the different ENSO years. Figures 6.2 to 6.6 show these daily values for rainfall, temperature, and solar radiation as an indication of the weather information used for the simulation. The DSSAT v4.0 crop models were fed with daily information of these four climatic parameters during the 43 years (1956-1998).

6.2.4 Forage Crop Systems

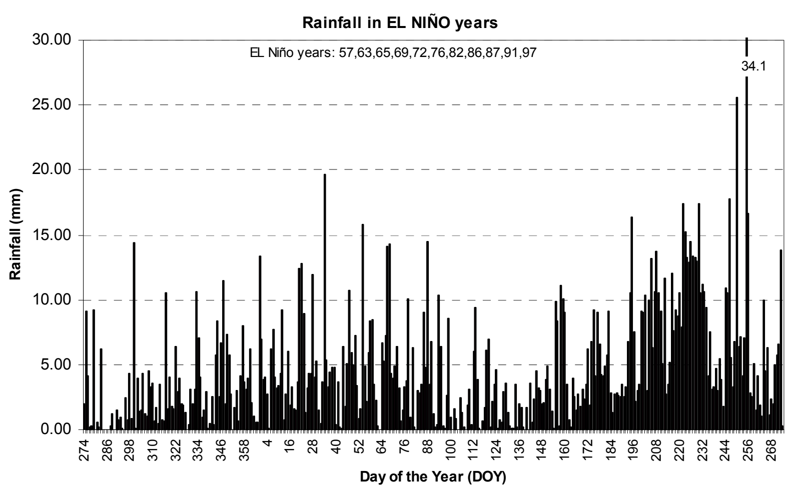
Part of the study was devoted to identify and understand forage systems used in north-Florida dairy farms, including fodder plans, management practices, and sequences. Then, they were calibrated and validated using the DSSAT v4.0.



A



B



C

Figure 6-2. Daily rainfall (1956-1998) in north-Florida for different ENSO phases. A) La Niña; B) Neutral; and C) El Niño years.

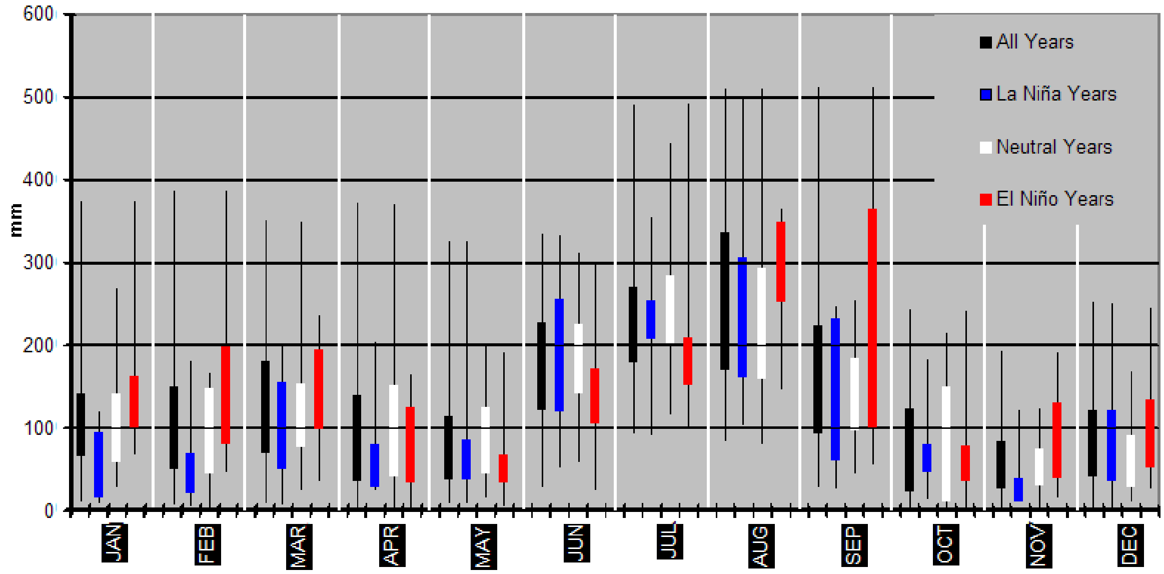


Figure 6-3. Distribution of monthly precipitation (1956-1998) in north-Florida for different ENSO phases

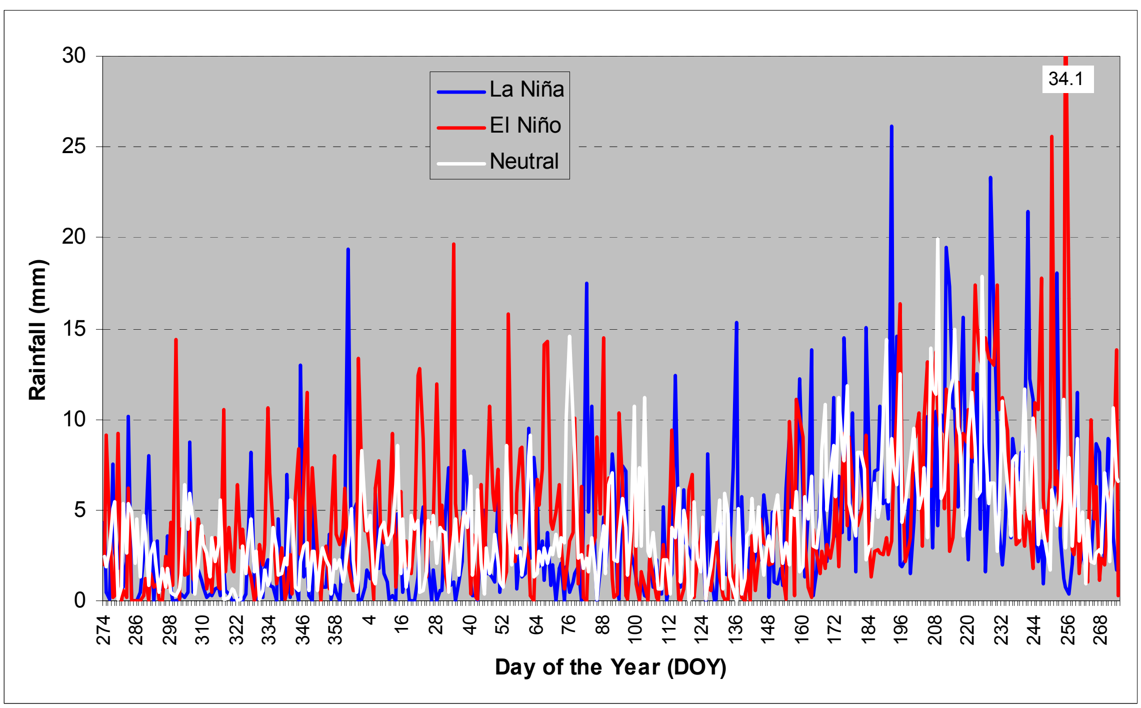


Figure 6-4. Daily precipitation in north-Florida (1956-1998) for different ENSO phases

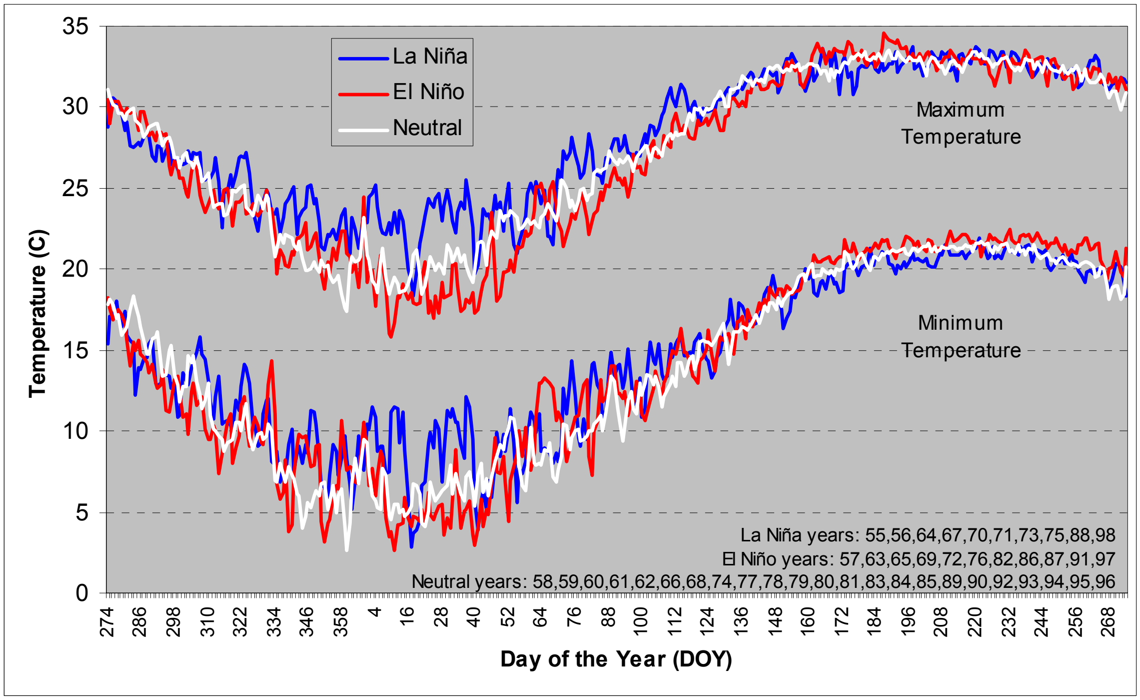


Figure 6-5. Daily temperature (1956-1998) in north-Florida for different ENSO phases

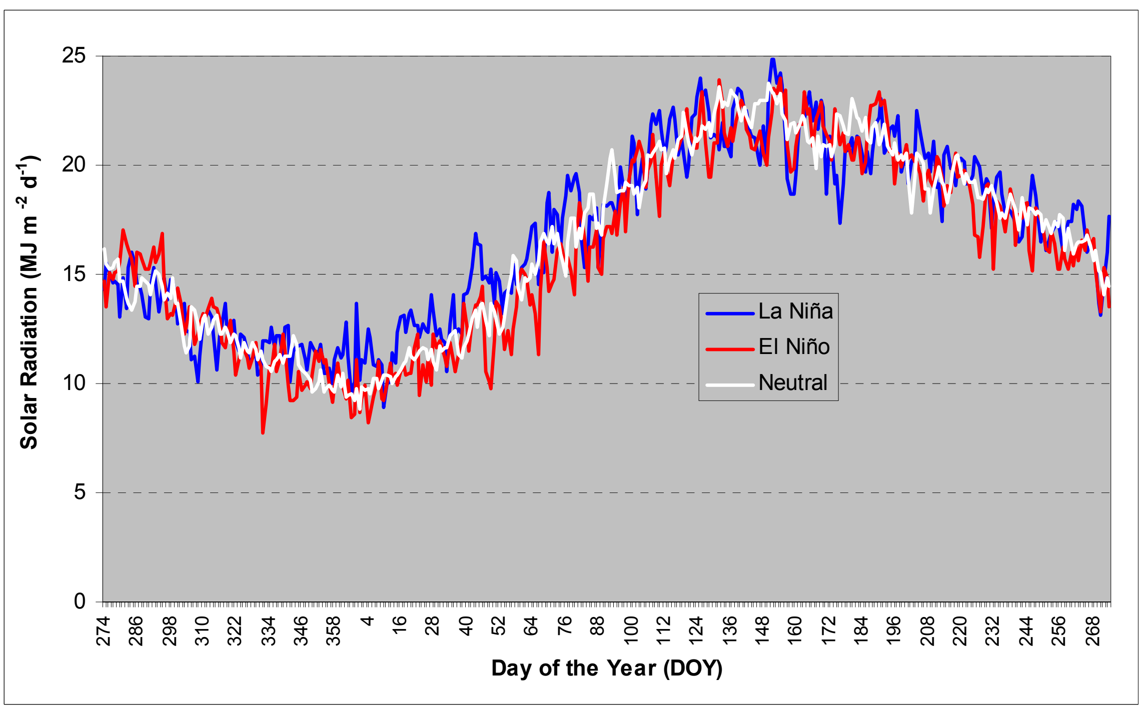


Figure 6-6. Daily solar radiation (1956-1998) in north-Florida for different ENSO phases

6.2.5 Manure N Application

Dairy farm fields receive a highly variable amount of manure N depending on herd size, land available, and waste management system. Simulating dynamic cow flows by integrating real data from seasonality, culling rates, reproduction rates, and milk production of north-Florida dairies, collected by the Dairy Herd Improvement Association (FL-DHIA) summarized by De Vries (2004); and survey information, in a Markov-chain model (Chapter 5), monthly rates of manure N received by fields were estimated for all variety of north-Florida dairy farms. These rates varied between 20 and 160 kg ha^{-1} month^{-1}. Considering that sprayfields usually have two applications in a month, four treatments were arranged at 10, 20, 40, and 80 kg ha^{-1} application^{-1} in the DSSAT v4.0 system.

6.2.6. Crop Simulations

Forage crop simulations were performed using adapted crop models in the Decision Support System for Agricultural Transfer, DSSAT v4.0 (Jones et al., 2003). These crop models are dynamic process models that simulate crop growth and yield in response to management, climate, and soil conditions. They include light interception, photosynthesis, N uptake, soil water balance, evapotranspiration, respiration, leaf area extension, growth of component parts, root growth, senescence, N mobilization, and crop development processes. For the soil C and N components, the Century model (Parton et al., 1979) implemented in the DSSAT by Gijsman et al. (2002) was used. This model estimates soil N balances that include soil and surface organic matter, inorganic N, additions and removals of N, and all the processes that include the N cycle in the soil, such as decomposition, mineralization, N leaching, etc.

Bahiagrass (*Paspalum notatum*) and bermudagrass (Rymph, 2004) are the only forage crops developed for the DSSAT system, therefore, part of the study consisted in adapting, calibrating, and validating crop models based on the closest existing models. For corn forage, maize was utilized; for forage sorghum, grain sorghum; for pearl millet (*Pennisetum glaucum*), grain millet; and for winter forage small grains, wheat (*Triticum aestivum*). These models were utilized after altering their cultivar coefficients. Calibration and validation against local, actual and current studies followed as well as a sensitivity analysis of the N leaching. These procedures are described in detail in the results section.

Forage systems were arranged to mimic dairy farm systems in three growing seasons: spring-summer, summer-fall, and winter. All potential forage combinations were run for four N effluent ranges, ten types of soils found in the study area, and for 43 years of daily weather data (1956-1998). Residual organic matter from one crop to the next one was accounted for as well as other management choices that are common in these systems such as extra irrigation and harvests.

6.2.7 Analyses

Daily cumulative N leached (kg ha^{-1}) and biomass (kg ha^{-1}) outputs from the simulations were compiled in monthly rates for the span of the study period (1956-1998). All months were classified according to ENSO phases and results were summarized by the factors incorporated in the simulations: 12 months x 3 ENSO phases x 4 Manure N applications x 10 soil types x 11 forage combinations.

6.3 Results and Discussion

6.3.1 Forage Crop Systems in North-Florida Dairies

Forage crop systems in north-Florida dairies can be summarized by seasons of the year. There are three marked seasons in the north-Florida forage calendar. Spring-summer: from late March or early April to mid July; summer-fall: from late July or early August to early or mid November; and fall-winter: from late November or early December to mid March (Figure 6-7).

6.3.1.1 Spring-summer crops

Three crops were reported during this season in dairy farm fields: corn, bermudagrass, and bahiagrass. Sorghum or pearl millet could also be an option in this season, but were not reported. Corn is planted for silage and always as a part of a sequence of crops. Bermudagrass and bahiagrass are used for either hay, haylage, or grazing and they are also usually part of a sequence of crops. It is possible to over plant bermudagrass or bahiagrass with corn in this season. One to three cuttings are expected for the grasses during this season (two are usual), if they are not grazed.

MAR – JUL (APR, MAY, JUN)	JUL – NOV (AUG, SEP, OCT)	NOV – MAR (DEC, JAN, FEB)
SPRING - SUMMER	SUMMER - FALL	FALL - WINTER
CORN	SORGHUM	RYE
BERMUDA GRASS	MILLET	OATS
BAHIA GRASS	CORN	WHEAT
SORGHUM*	BERMUDA GRASS	RYEGRASS
MILLET*	BAHIA GRASS	CLOVER**
	PERENNIAL PEANUT* **	

Figure 6-7. Forage systems and their seasonality in north-Florida dairy farms. * Not found in the interviews, but they are possible. ** Not common and not simulated with DSSAT.

6.3.1.2 Summer-fall crops

There are more options to grow during summer-fall. Sorghum and millet are very common, although continuation of grasses from the previous season is also common. Some farmers also grow corn for silage in this season or let the bermudagrass or bahiagrass re-grow, if they were over-planted in spring-summer. Another option, mentioned by only one farmer, is the re-growth of perennial peanut forage during this season. Sorghum, millet, perennial peanut, and the grasses can be used either for hay or haylage or for grazing. One to three cuttings will be expected for the grasses and one to two cuttings for the sorghum and millet if they are not grazed.

6.3.1.3 Fall-winter crops

Winter forages are common in the crop sequences of dairy farms in north-Florida. They are usually small grains or ryegrass; small grains often used are rye, oats (*Avena sativa*) or wheat. Although bermudagrass and bahiagrass are perennial, they are dormant during this season, where they can be over-seeded or multi-cropped with other species. If there are perennial grasses already established in the field, these winter crops are usually non-till over seeded. Small grains are used for hay or haylage, ryegrass is preferred for silage. Winter small grains could be cut one to four times (two cuts are usual), if they are not grazed. Clover (*Trifolium* spp.) was also mentioned as an option by one farmer, intercropped with several other grasses.

6.3.1.4 Sequences of forages

If bermudagrass or bahiagrass is established and allowed to re-grow in the spring-summer, they will continue growing in the summer-fall season, and no other crops will be possible on the same field until fall-winter season. However, if corn is grown in spring-summer over-planted on one of those grasses, the grass will be allowed to re-grow in the summer-fall season.

If corn, sorghum, or millet is planted in spring-summer, any summer-fall crop (from Figure 6-7) will be possible to follow. In fall-winter any small grain or ryegrass could follow any summer-fall crop.

If perennial grasses are not established, the most common sequence of forages is silage corn in spring-summer followed by sorghum or millet in the summer-fall, and any small grain or ryegrass in the fall-winter. If grasses are established, a very common sequence is grass-grass-small grain or ryegrass, for the same seasons. Bermudagrass is much more common than bahiagrass and they both are much more common than perennial peanut.

Rye, oats, and wheat are very similar forages and farmers use them indistinctly. Ryegrass was indicated as having better-quality forage, but requires more care and time. It is very common to mix these winter forages in the fields.

Farmers try to have a crop in the field at all times, with brief windows between the growing seasons. The regulatory agencies strongly recommend this practice in order to ameliorate the risk of N leaching.

6.3.1.5 Harvest and processing

With the exception of corn, all other forages have the option of being grazed directly by the animals. All forages can be cut and processed as hay, haylage, or silage. Hay consists of drying directly in the field. Haylage is an intermediate process of silage performed directly in the field by wrapping up bales with plastic. The silage is a more elaborate process that usually takes place in specially designed facilities. Any forage could follow any of these processes after cutting, but corn and ryegrass are much appreciated for silage and the bermudagrass and bahiagrass are usually intended for hay.

6.3.2 Calibration and Validation of DSSAT Crop Models

Models must be calibrated and validated using real data; biophysical models such as crop simulation models contained in the DSSAT v4.0 must be tested to make sure that they represent real plant behavior under specific environmental conditions. Pertinent and trustworthy information from different sources was collected for this purpose. Previous studies, farm records, and survey information were used as baseline information to adjust and compare behavior of these forages on north-Florida dairy farms.

Especially designed experiments for this purpose contain the ideal information against which these models can be calibrated and validated. Thanks to very recent studies (Rymph, 2004), the DSSAT v 4.0 has two forage crops adjusted for Florida conditions, the bermudagrass and the bahiagrass. However, experimental information is not available for the other forage crops; indeed, there are no genotypic experimental coefficients available for them. Fortunately, close relatives for most of these forages exist: for silage corn, grain maize; for forage sorghum, grain sorghum; for pearl millet, millet; for winter forages, wheat.

Since the main objective in this study was to assess potential N leaching, biomass accumulation (that determines the N uptake) was used as the driver in the calibration and validation processes. Because the main interest in these crops is their potential use as forages, the cultivar coefficients are not as important and therefore they could be manipulated to emulate a desired behavior (G. Hoogenboom, pers. comm.). And, even when some used crop species are not forages *per se*, biomass and N uptake are equivalent when species produce or do not produce grain. Consequently, models can be simulated ignoring whether or not they would be producing grain (K. Boote, pers. comm.). The most important data sources used for calibration and validation are listed in Table 6-2.

6.3.2.1 Forage sorghum

Woodard et al. (2002) found that forage sorghum between early August and early November will produce between 7.3 and 11.1 Mg ha^{-1} of dry matter and will uptake between 99 and 150 kg N ha^{-1}, under strong N applications of manure effluents.

Environmental conditions of the actual experiment were emulated with the DSSAT v4.0. Soil data of the series Kershaw for Gilchrist County were obtained from the Soil Survey Geographic Database (SSURGO) from USDA, NRCS.

Table 6-2. Information sources for calibration and validation of forage crops in north-Florida dairy farm systems

Study/Source	Location	Weather	Soil Series	Observations
Woodard et al. (2002)	North-Florida Holsteins Farm, Inc. Bell. 29.73 N, 82.85 W	1996-1998	Kershaw	Several forages: corn, sorghum, rye. Manure effluent applied in rates of 500, 690, and 910 kg N ha^{-1} $year^{-1}$
Fontaneli et al. (2000) (2001)	Forage Field Evaluation Laboratory. Gainesville. 29.08 N, 82.42 W	1996-1997	Sparr	Cool season forages: comparing winter multi-crops. Warm season forages: comparing three varieties of millet and two varieties of sorghum
Wright et al. (1993)	North-Florida Research and Education Center. Quincy. 30.40 N, 84.27 W	1992	Norfolk	Millet and sorghum. Different treatments and purposes
Johnson et al.	Tifton, GA. 31.43 N, 83.89 W	Before 1991	Tifton	Corn and rye with different rates of Manure effluent applied
Survey north-Florida dairy farms	Suwannee River Basin	Several years	Several types	Not always precise information, but real and trustworthy

Daily weather data of Levy (29.42 N, 82.82 W) compiled by Mavromatis et al. (2002) were used for the study. Manure effluent was set up to be applied as described in the study: two applications every month containing 21, 29, or 38 kg N ha^{-1} each one, for a total in a year of 500, 690, and 910 kg N ha^{-1}. The sorghum crop received 6 applications with a total of 132, 174, and 228 kg N ha^{-1}. As described in the study, in addition to the water in the liquid manure applied, extra irrigations were realized, so the crop would have most of the water requirements with some minimal stresses.

A new cultivar was created, the forage sorghum, by changing some cultivar coefficients. The final cultivar had the coefficients detailed in Table 6-3. With these coefficients, the validation comparison was realized between the simulated and the experimental data as seen in Figure 6-8. Figure 6-8 shows the comparison between simulated versus observed data. Overall values are inside the expected ranges and they follow the same pattern as the observed data.

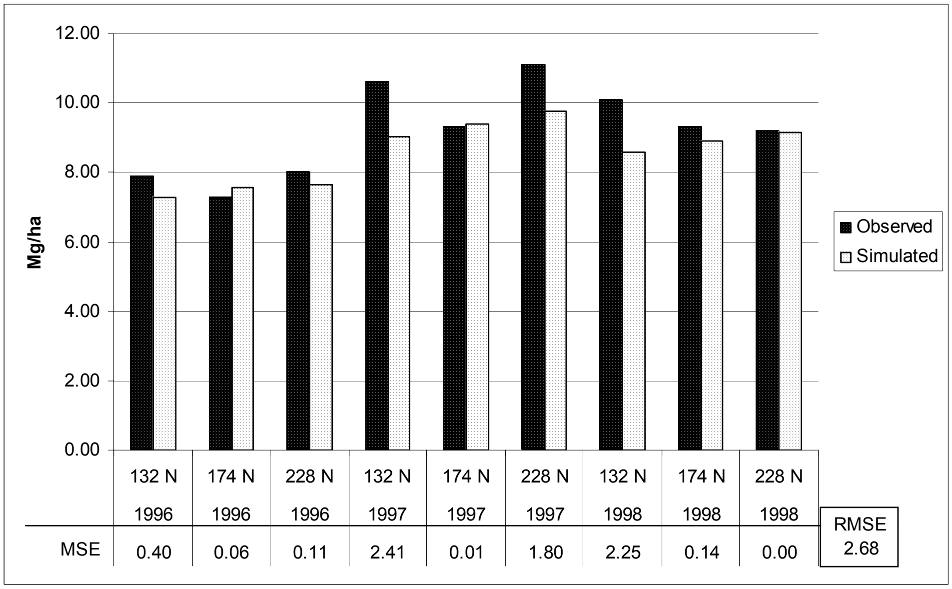


Figure 6-8. Forage sorghum: Observed and simulated biomass production, Bell, 1996-1998. Individual mean square error (MES) and overall Root Mean Square Error (RMSE)

6.3.2.2 Pearl millet

Fontaneli et al. (2001) presented results of a study carried out at the Forage Evaluation Field Laboratory (24 Km NE of Gainesville, 29.08 N, 82.42 W), where three cultivars of pearl millet and two of sorghum were tested at different planting dates. The experiment realized during spring-summer-fall of 1996 and 1997 revealed that no significant differences exist between millet and sorghum regarding biomass accumulation. Millet would be a higher producer, but very slightly. Also, in both sorghum and millet, the planting date greatly affected the biomass accumulation, which varied between less than 5 Mg ha^{-1} to nearly 8 Mg ha^{-1}. Also, Chambliss (1997) suggests that millet and sorghum would be very similar forage crops under Florida conditions. Under this premises, sorghum data could be used to validate millet considering the lack of detailed experimental information for this forage.

With similar information on environmental conditions of sorghum, a new cultivar was created, the forage millet, by changing some coefficients. The final cultivar had the coefficients shown in Table 6-3. Additionally, the conversion of solar radiation (in the species file) was set at 0.42, which was originally 0.50, in order to diminish a higher than expected growth. Using these coefficients, the validation comparison was realized between the simulated and the experimental data and results can be seen in Figure 6-9.

Table 6-3. Coefficients values and coefficients definitions of modified crops in DSSAT

Forage	P1	P1V	P1D	P2	P20	P2R	P5	G1	G2	G3	PHINT
sorghum	500.0				10.5	90.0	540.0	5.0	6.0		44.0
millet	600.0				10.0	90.0	540.0	5.0	6.0		44.0
Corn	200.0			0.52			940.0		620.0	8.5	38.9
winter forage		47.0	64.0				360.0	28.0	25.0	1.3	80.0

P1: Thermal time from seedling emergence to the end of the juvenile phase (expressed in degree days above a base temperature (10 ^{o}C sorghum, 8 ^{o}C millet and corn) during which the plant is not responsive to changes in photoperiod.

P1V: Relative amount that development is slowed for each day of unfulfilled vernalization, assuming that 50 days of vernalization is sufficient for all cultivars

P1D: Relative amount that development is slowed when plants are grown in a photoperiod 1 hour shorter than the optimum (which is considered to be 20 hours).

P2: Extent to which development (expressed as days) is delayed for each hour increase in photoperiod above the longest photoperiod at which development proceeds at a maximum rate (which is considered to be 12.5 hours).

P20: Critical photoperiod or the longest day length (in hours) at which development occurs at a maximum rate. At values higher than P20, the rate of development is reduced.

P2R: Extent to which basic development leading to panicle initiation (expressed in degree days) is delayed for each hour increase in photoperiod above P20.

P5: Thermal time (degree days above a base temperature (10 ^{o}C sorghum, 8 ^{o}C millet and corn, 1 ^{o}C winter forages) from beginning of grain filling (3-4 days after flowering) to physiological maturity.

G1: Scaler for relative leaf size (sorghum and millet); Kernel number per unit weight of stem (less leaf blades and sheaths) plus spike at anthesis (winter forages)

G2:Scaler for partitioning of assimilates to the panicle (sorghum, millet, corn); Kernel filling rate under optimum conditions (winter forages)

G3: Kernel filling rate during the linear grain filling stage and under optimum conditions (corn); Non-stressed dry weight of a single stem (excluding leaf blades and sheaths) and spike when elongation ceases (winter forages)

PHINT: Phylochron interval; the interval in thermal time (degree days) between successive leaf tip appearances

Forage millet was also tested using another set of information from Wright et al. (1993) of a study realized in Quincy, Florida (30.40 N, 84.27 W) during 1992 on soils of the series Norfolk. An experiment in DSSAT v4.0 to try to mimic the experimental conditions was set up. Even when this experiment was done outside of the boundaries of the study (soils are very different), a more general comparison could be achieved providing more support for the previous validation. Experimental data (with a variety of treatments) showed a range of millet production of biomass under these conditions between 12.5 and 14.4 Mg ha^{-1}. Figures 6-9 and 6-10 show the results of the observations and simulations. Overall values are inside the expected ranges and they follow the same pattern as the observed data.

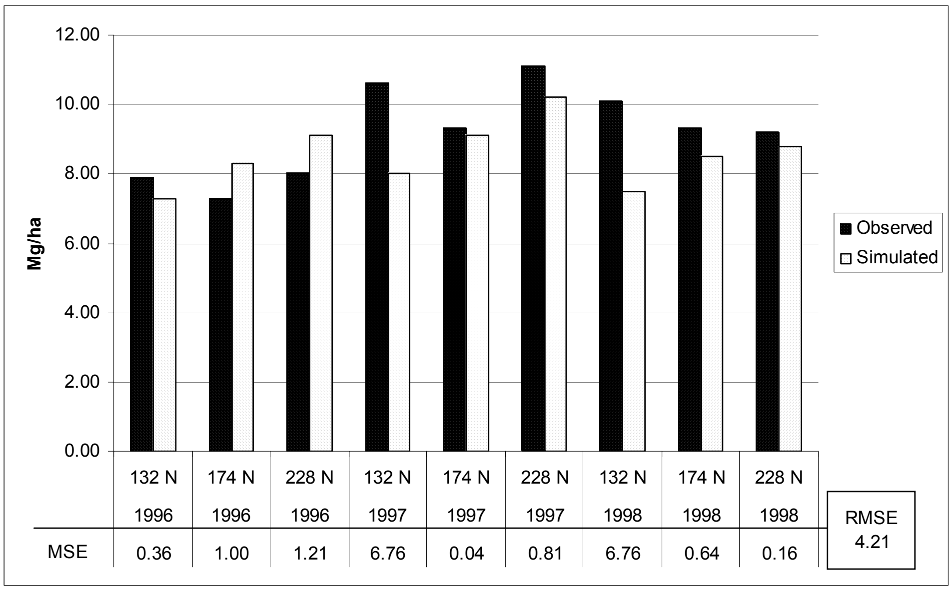


Figure 6-9. Forage millet: Observed and simulated biomass production, Bell, 1996-1998. Individual mean square error (MES) and overall Root Mean Square Error (RMSE)

6.3.2.3 Silage corn

Woodard et al. (2002) found that corn forage grown between early April and mid July will produce between 10.8 and 15.2 Mg ha^{-1} of dry matter and will uptake between 119 and 200 kg N ha^{-1}, under strong N applications of manure effluents.

Environmental conditions of the actual experiment were emulated as in the case of forage sorghum and millet. Manure effluent was set up to be applied as described in the study: the corn crop received 7 applications with a total of 147, 203, and 266 kg N ha^{-1}.

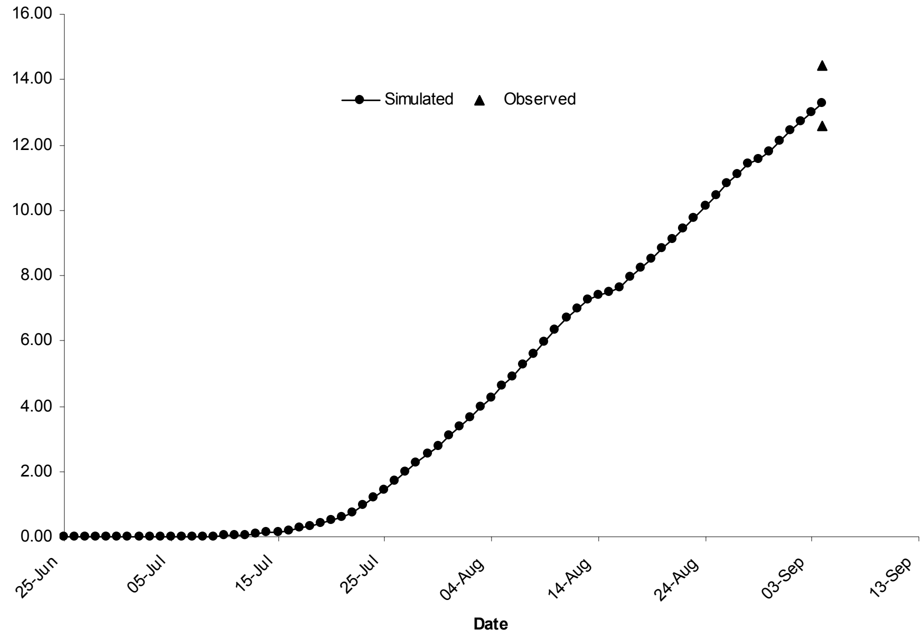


Figure 6-10. Forage millet: Observed and simulated biomass production, Quincy 1992

A new cultivar was created, the silage corn, on which the calibration was performed. The final cultivar had the coefficients summarized in Table 6-3. Using these coefficients, the validation comparison was realized between the simulated and the experimental data as can be seen in Figure 6-11. Overall values are inside the expected ranges and follow the same pattern.

6.3.2.4 Winter forages

Farmers refer to winter forages as a group of forages that include the small grains and ryegrass. Small grains are commonly wheat, rye, and oats; rye is the most common. It is usual that farmers mix these crops in winter with ryegrass. Using information provided during the interviews these forages can be simulated as a single crop. DSSAT v4.0 has the wheat coefficients, which were used as the baseline to simulate winter forages.

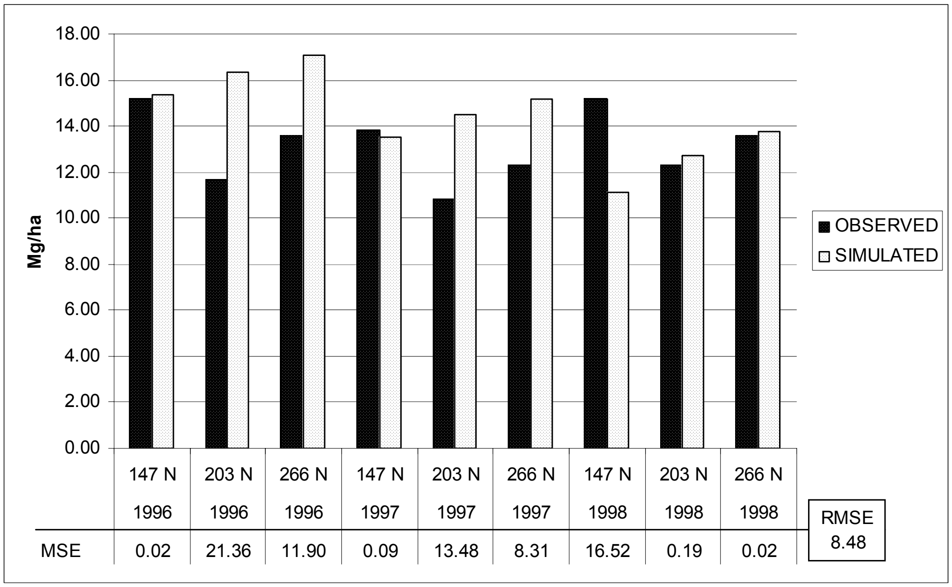


Figure 6-11. Silage corn: Observed and simulated biomass production, Bell, 1996-1998. Individual mean square error (MES) and overall Root Mean Square Error (RMSE)

Woodard et al. (2002) found that rye forage produced between late November and mid March will produce between 2.7 and 5.0 Mg ha^{-1} of dry matter and will uptake between 46 and 89 kg N ha^{-1}, under strong N applications of manure effluents.

Environmental conditions of the actual experiment were emulated with the DSSAT v4.0 as in previous cases. Manure effluent was set up to be applied as described in the study; the small grain forages received 7 applications with a total of 147, 203, and 266 kg N ha^{-1}. Biomass production was compared to the years 1996/97 and 1997/98.

A new cultivar was created, the winter forage, upon which the calibration was performed. The final cultivar had coefficients that are shown in Table 6-3.

Using these coefficients, the validation comparison was realized between the simulated and the experimental data. Figure 6-12 shows the results of such a comparison. Overall values are inside the expected ranges and follow the same pattern as the observed data.

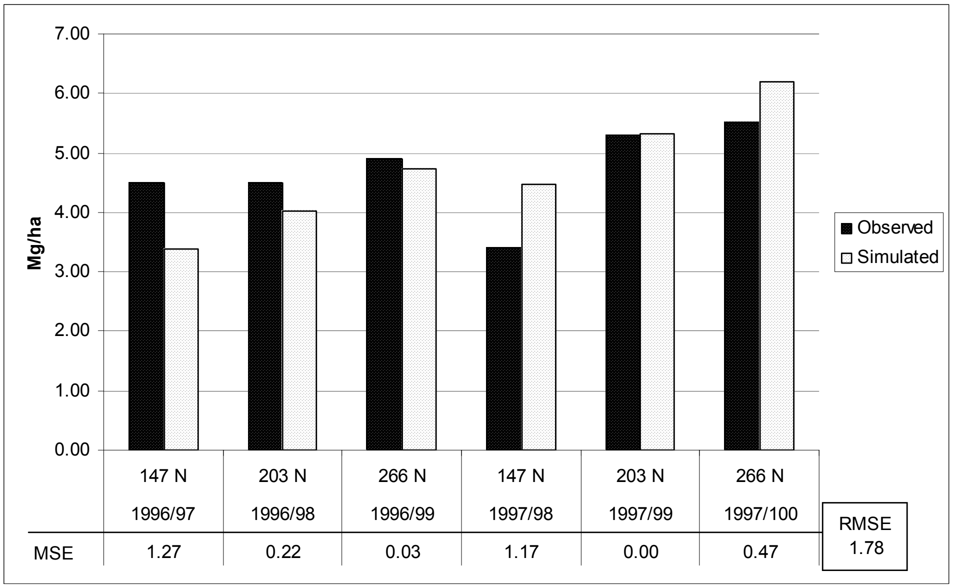


Figure 6-12. Winter forages: Observed and simulated biomass production, Bell 1997-1998. Individual mean square error (MES) and overall Root Mean Square Error (RMSE)

6.3.3 Sensitivity Analysis of Forage Crops to Manure N Application

A sensitivity analysis of biomass accumulation, N uptake, and N leaching was conducted in which extreme values of manure N were used on the crops to be used for this study. Six rates of manure N were tested in all crops 0, 10, 20, 40, 60, 80, and 100 kg per application (2 applications per month), or 0, 240, 480, 960, 1440, 1920, and 2400 kg year^{-1}. Irrigation was arranged as usual in dairy farms and it was tested for 1996/1997 (a Neutral climatic year where results from previous calibration and validation are known) and for Kershaw soils as in the Woodard et al. (2002) experiment.

Corn was planted on April 4th and harvested on July 16th, and received 7 manure N applications. Sorghum was planted on August 14th and harvested on November 13th 1996. During this period the crop received 6 manure N applications.

Winter forage was planted on December 3rd and harvested on March 11th 1997. During this time the crop received 7 manure N applications. Millet was planted on August

14th and harvested on November 13th 1997 and received 6 manure N applications. Bahiagrass and bermudagrass were grown from March 30th to November 16th 1996 and received 22 manure N applications.

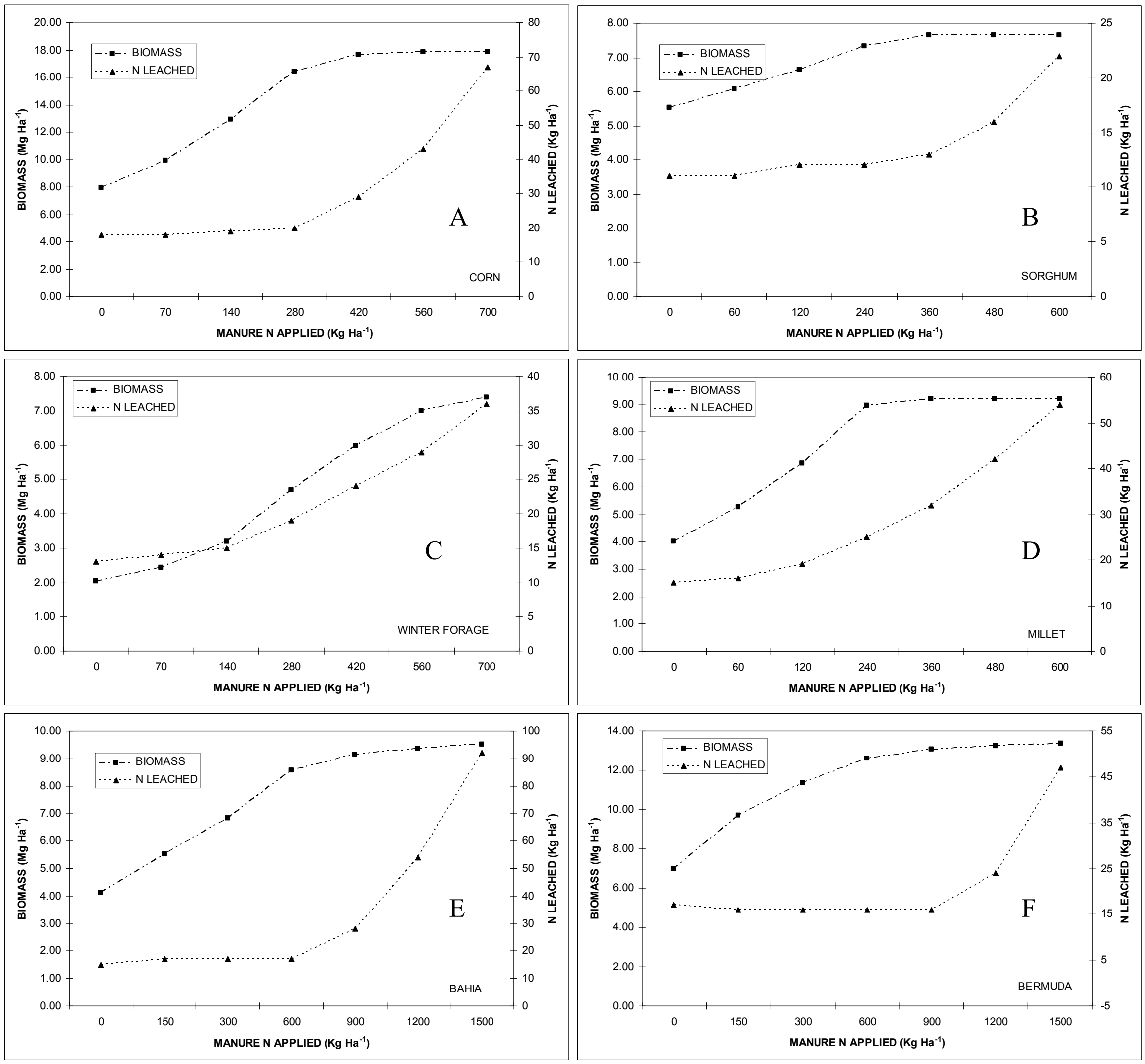


Figure 6-13. Sensitivity response of N leaching and biomass accumulation to different rates of manure N applied for simulations in a Kershaw soil series during the season 1996/1997. A) corn; B) sorghum; C) winter forage; D) millet; E) bahiagrass; and F) bermudagrass.

As expected, biomass accumulation increases with manure N application, but at a decreasing rate as it reaches a maximum. There is no noticeable effect of toxicity with the high amounts of N. According to the parameters of the soil there is some organic matter that would provide some N at the beginning, that is why in the zero N application a low but not extremely low biomass and uptake are expected, similarly to the N leached. N leaching increased faster with higher manure N application, consistent for all crops.

6.3.4 Variability by ENSO Phases

N leaching increased and biomass accumulation decreased from La Niña years to Neutral and to El Niño years. Lowest N leaching (highest biomass accumulation) was always observed in La Niña years and highest N leaching (lowest biomass accumulation) was always observed in El Niño years. This fact was consistent for different type of soils, for different forage rotations, and for different manure N applications.

As an example, a trade-off of N leaching vs. biomass accumulation for two forage systems, two type of soils, and four manure N applications is shown in Figure 6-14. Figure 6-14 shows, for different ENSO phases, a similar increasing trend for both N leaching and biomass accumulation, responding to the increase of manure N application. At the beginning, this N leaching trend was smooth and slow, but it jumped up abruptly when the manure N changed from 40 to 80 kg ha^{-1} mo^{-1}. Something similar, although less marked happened with the biomass accumulation change from these manure N levels. Different from the sensitivity analysis, it is deduced from these graphs that biomass accumulation had not yet reached a peak with this maximum manure N application.

Notice that graphs in Figure 6-14 have different scales for the N leaching in order to show the trend, even though substantial differences in N leaching existed between the soil types and the forage systems. Differences between graph A) and B) are attributed exclusively to the type of soils and differences between graphs A) and C) are exclusively because forage system.

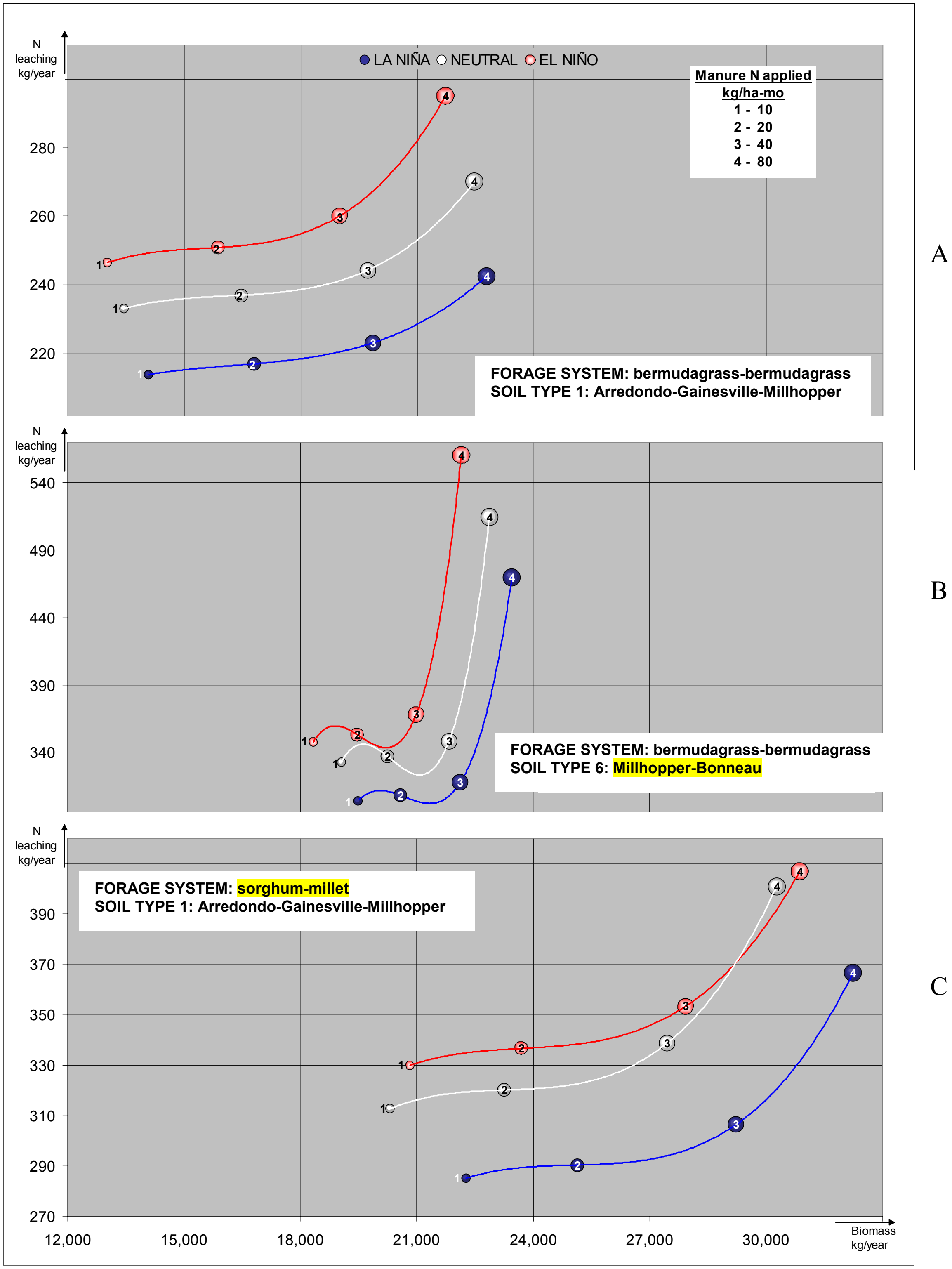


Figure 6-14. Nitrogen leaching vs. biomass accumulation for different ENSO phases under two forage systems consisting of bermudagrass and millet-sorghum, four manure N applications (10, 20, 40, and 80 kg ha^{-1} mo^{-1}), and two type of soils (Arredondo-Gainesville-Millhopper and Millhopper-Bonneau)

The soil type 6 (Millhopper-Bonneau) showed substantially higher N leaching than the soil type 1 (Arredondo-Gainesville-Millhopper). It would be expected that soil type 6 has lower biomass accumulation because more N is being leached and consequently not up-taken by the crops, however higher biomass accumulation was also observed in soil type 6. It seems that low retentive and shallow soils such as soil type 6 provide better forage growth conditions (under these conditions of high nutrients) together with a higher risk of N leaching.

A forage system consisting of bermudagrass-bermudagrass leaches substantially less N than sorghum-millet, but sorghum-millet accumulates substantially higher biomass amounts. The rate of N leaching increasing for Neutral years is distinctive from the other two phases when sorghum-millet rotation is present; this is more marked between 40 and 80 kg ha^{-1} mo^{-1}. Nevertheless, the pattern of highest N leaching during El Niño years and lowest during La Niña years persists.

Notice also that the magnitude of change between manure N application treatments in soils type 6, compared with soils type 1 and in rotation bermudagrass-bermudagrass, compared with rotation sorghum-millet varies considerably, indicating that there is interaction among ENSO phases, manure N application, soil types and forage rotations.

6.3.4.1 Nitrogen leaching in different ENSO phases

Substantially higher (~10%) N leaching (kg ha^{-1} year^{-1}) was predicted for El Niño (357.25) than for La Niña years (322.29). For Neutral years expected N leaching was between La Niña and El Niño years (342.90), very close to the overall average (341.84), Table 6-4. Winter months, especially January and February, are critical because the N leached in these two months represent more than 50% of the total N leached in a year. Significantly ($p<0.05$) higher N leaching (Coefficient of Variability, CV) was predicted in

January for El Niño years 127.35 kg ha^{-1} (21%) when compared to either Neutral 108.9 kg ha^{-1} (30%) or La Niña years 83.19 kg ha^{-1}(35%) and also significant ($p<0.05$) differences were predicted when comparing La Niña with Neutral years in this month. For February, more N leaching (CV) was expected for La Niña years 84.22 (9%) than El Niño years 71.6 (20%), with significant differences ($p<0.05$). Even though no more significant differences were found in other months, there are substantial differences among ENSO years and different months that can be appreciated in Figure 6-15.

Figure 6-15 shows the relative variation with respect to the average of different ENSO phases: El Niño phase presented more overall variability through the year and maximum N leaching in the months of December, January, August, September, and November. The Neutral phase presented maximum N leach amounts during the months of April, May, June, and October; and for La Niña phases more N leach was expected in the months of February, March, and July.

The highest N leaching in a month was matched with specific years in order to explain the driving factors. The three highest rates in January in El Niño years (187, 152, and 140 kg ha^{-1} $year^{-1}$) were found to happen in the years 1964, 1987, and 1970, when the Japan Meteorological Index (JMI) (Center for Ocean-Atmospheric Prediction Studies, 2003) indicated ocean temperature of 0.7, 1.0, and 0.8°C, respectively. For Neutral years, the three highest rates were 173, 158, and 156 kg ha^{-1} $year^{-1}$ in the years 1979, 1991, and 1994 with JMI of 0.0, 0.4, and 0.2. In La Niña years the highest amounts were substantially lower (108, 107, and 107 kg ha^{-1} $year^{-1}$) and they happened in 1965, 1972, and 1971, with the JMI of -0.8, -0.7, and -1.11. An attempt to correlate these JMI indexes with the N leached failed and corroborates what previously was found: that there is no significant relationship of these indexes either with biomass accumulation or N leaching under the study parameters. The same happened when comparing the highest JMI, for example 2.7 or 3.1 for El Niño years that indicated N leaching less than the highest amounts (86 and 117 kg ha^{-1} year^{-1}).

Table 6-4. Nitrogen leaching (kg ha^{-1}) and ENSO phases, when all other factors are averaged

	All Years		La Niña		Neutral		El Niño	
	N Leach	CV	N Leach	CV	N Leach	CV	N Leach	CV
Dec	10.59	98%	13.15	93%	7.69	80%	15.64	127%
Jan	108.42	32%	83.19*	35%	108.90*	30%	127.35*	21%
Feb	78.57	24%	84.22*	9%	79.94*	29%	71.60*	20%
Mar	20.86	49%	23.54	56%	20.55	42%	19.28	45%
Apr	5.81	97%	4.90	78%	6.42	71%	5.45	70%
May	12.18	73%		103%	12.94	59%	10.61	72%
Jun	23.22	43%	22.01	45%	25.13	38%	20.69	50%
Jul	16.65	44%	18.42	33%	17.09	48%	14.33	37%
Aug	17.05	40%	16.99	40%	15.65	38%	19.71	36%
Sep	21.22	39%	19.34	44%	20.33	34%	24.50	39%
Oct	20.27	33%	19.02	35%	20.79	36%	20.35	21%
Nov	7.00	59%	5.11	42%	7.47	58%	7.75	62%
Year	341.84		322.29		342.90		357.25	

* Significant differences (p<0.05). CV is coefficient of variation.

It was found, as suspected, that N leaching is highly related to precipitation associated with climatic ENSO phases: for most of the months the highest precipitation by ENSO phase presented the highest N leached (Figure 6-3), however it does not happen for February, March, and June. For example, the mean rainfall for January in the study area was 104 mm, and varied for El Niño years (148 mm), for Neutral years (111 mm), and for La Niña years (54 mm) explaining the variation in N leached. Also, matching the highest N leaching with rainfall, we found that the N leached will be highly related to the total amount of rainfall and to the occurrence of extreme rainfall events.

For the highest El Niño events the rainfall amounts were 315, 194, and 140 mm; for the highest Neutral years, these were 269, 242, and 239 mm; and for the highest La Niña years these were 118, 101, 70 mm, respectively, These rainfall amounts were substantially higher than normal, and in the cases when this not happened, as in the third highest El Niño and third highest La Niña, extreme rainfall events occurred which had high amounts of rainfall concentrated in small time periods (e.g., rainfall >20 mm in a day). For February and March, higher leaching in El Niño years would be expected because considerably more precipitation is observed, but more N leaching was predicted for La Niña years. Possible causes would point to the rainfall distribution, other climatic factors such as temperature and solar radiation, and soil N dynamics; during February and March, in La Niña years, the precipitation patterns indicate that the rainfall events were intense (although not as much as El Niño) and infrequent.   This could cause the water in the soil to be highly variable (more than in El Niño and Neutral years) because there are drought and flooding periods (different from other years when water is permanent) making the system more unstable and consequently more prone to N leaching. Other possible causes are the higher temperatures and higher solar radiation observed during these months for La Niña phases; and even though both of these factors will induce higher plant growth rates and consequently higher N uptake by plants, it seems that they may increase even more the decomposition and mineralization processes of the N inducing its leaching. Additionally, the dynamics of N in the soil would influence this behavior, meaning that the high amount of N leached in January in El Niño years would leave less N prone to leach the following months and that the relatively lower amount leached in La Niña years during January, leaves more N prone to leach in February. In June, when more N leaching would be expected for La Niña years, substantially more N leaching is predicted for Neutral, followed of El Niño years and the only possible explanation is the rainfall distribution and intensity of the events, because there are no apparent differences in temperature and solar radiation. Effectively, in Neutral years there are very intense events, just days before and during the month of June.

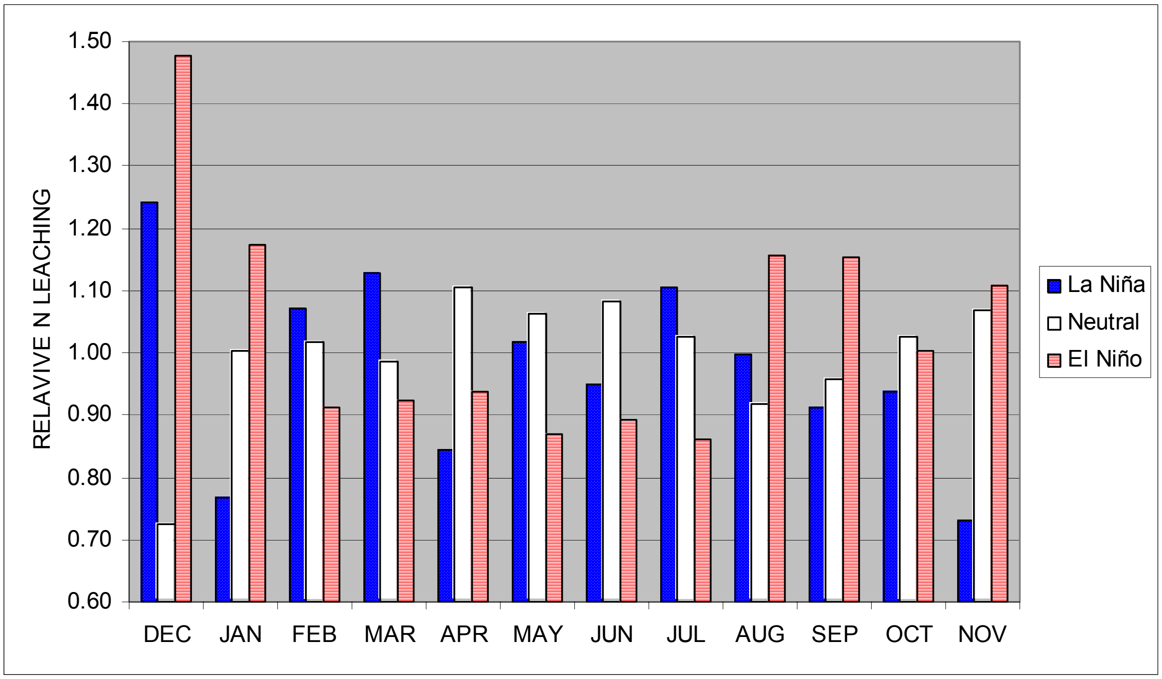


Figure 6-15. Nitrogen leaching vs. ENSO phases relative to absolute averages, when all other factors are averaged

In order to analyze the interactions among N leaching, month of the year and ENSO phase, cumulative probabilities were estimated and plotted (Figure 6-16). In Figure 6-16, the lines are cumulative probabilities of N leaching for the ENSO phases; the Y-axis represents the percent or probability of occurrence.

If for example, we would like to know the chance that there will be at most 50 kg ha^{-1} N leached in January, 50 kg ha^{-1} in February, and 20 kg ha^{-1} in all the other months, we would find that: having as little as 50 kg of N leached per ha is very unlikely in the months of January and February; indeed only 25% of the time in La Niña and only 5% of the time in January in Neutral years it would occur. This goal would be reached for February only

10% of the time in El Niño and Neutral phases, respectively. There is no chance for El Niño in January and for La Niña in February that the leaching be less than 50 kg ha^{-1}.

For April, August, September, and November the N leaching would always be lower than 20 kg ha^{-1} independently of the ENSO phase, however for the remaining months the chances would vary depending on climatic conditions.

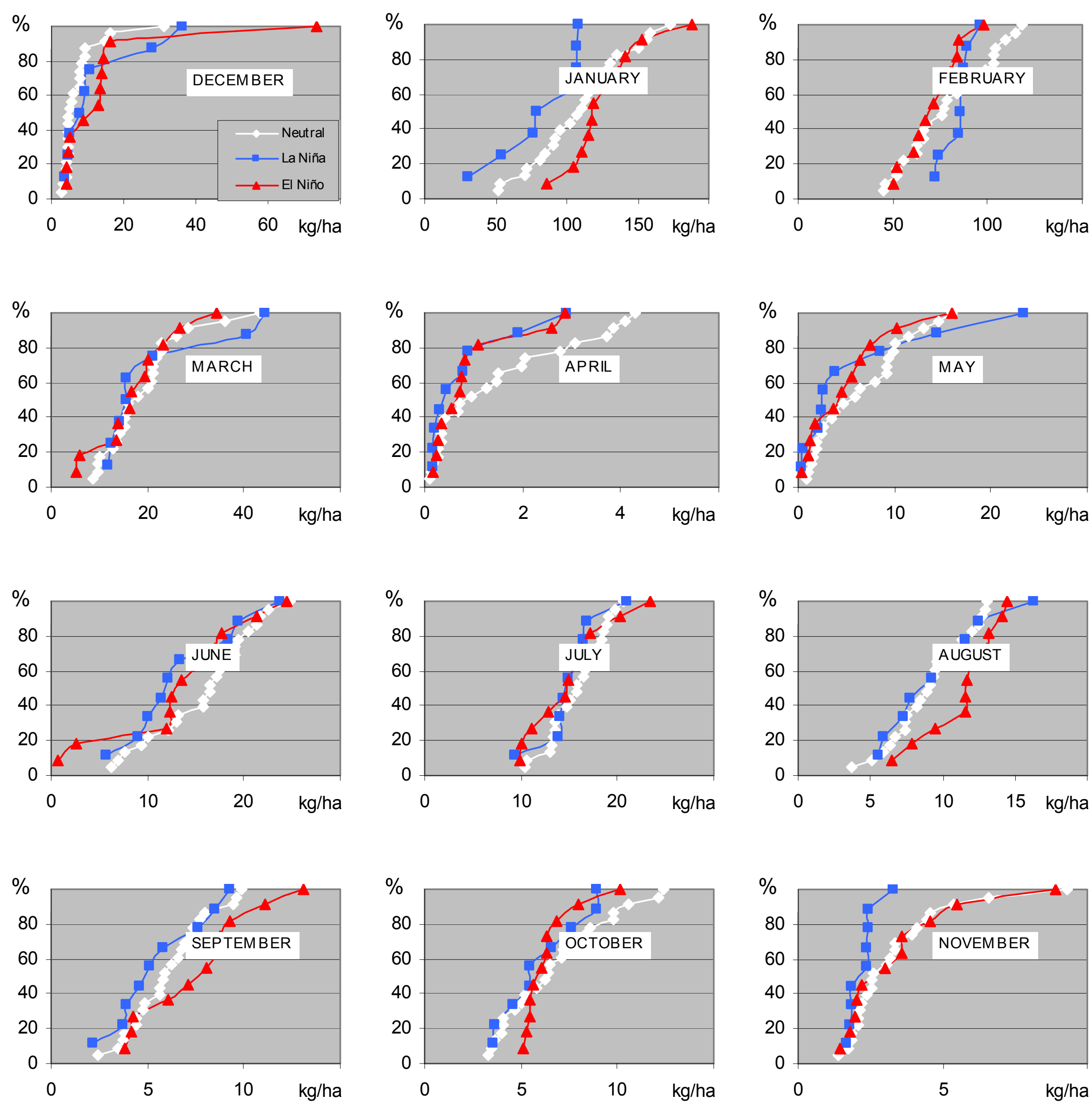


Figure 6-16. Probability distribution of N leaching by ENSO phases, when all other factors are averaged

In December, there is very little chance that the leaching exceeds 20 kg; in La Niña years there would be an 18% chance, in El Niño years a 10% chance, and in Neutral years less than 5%. Similarly for March, the probabilities of having more than 20 kg leached would be 50%, 40%, and 30% for Neutral, La Niña, and El Niño years, respectively.

Another way to analyze the interaction among N leaching, month of the year and ENSO phase is through exploring monthly N leaching distributions for El Niño, Neutral, and La Niña years (Figure 6-17). First, for most of the months the distributions were skewed to either the left or the right, or they were far from being normal, with the exception of June and July. For Neutral years, it was consistent to observe, in all months, that its distribution was sparse throughout all the values and it was close to be a normal distribution, meaning that almost any value can be seen in Neutral phases. For December, for any ENSO phase, highest will be the chance that N leaching were between the ranges 3 to 17.1 kg ha^{-1}, however there was a chance that this would be higher than 24 kg ha^{-1}; and it would be about 25% for La Niña years, 10% for El Niño years, and 5% for Neutral years. In January where highest amounts of leaching are expected for all phases, in La Niña years the leaching would be at most 112.3 kg ha^{-1}with a 50% chance of being even lower than 81.9. For neutral years the distribution indicates that most of the time the amount leached would be between 112.3 and 142.6 kg ha^{-1} and for El Niño years it would have more than 70% chance to be above 142.6 kg ha^{-1}.

For February, another high N leaching month, in La Niña years there would be more than 81.5 3 kg ha^{-1} and a chance of more than 70% that this would be even 99.7 kg ha^{-1}of N leaching or higher. For El Niño years there is a chance of more than 25% that the leaching would be lower than 63.3 kg ha^{-1} but about another 25% of chance that it would be 99.7 kg ha^{-1} or higher. Neutral ENSO phase for February presents the sparsest distribution; the leaching could be much lower, but it could also be also much higher than La Niña or El Niño years.

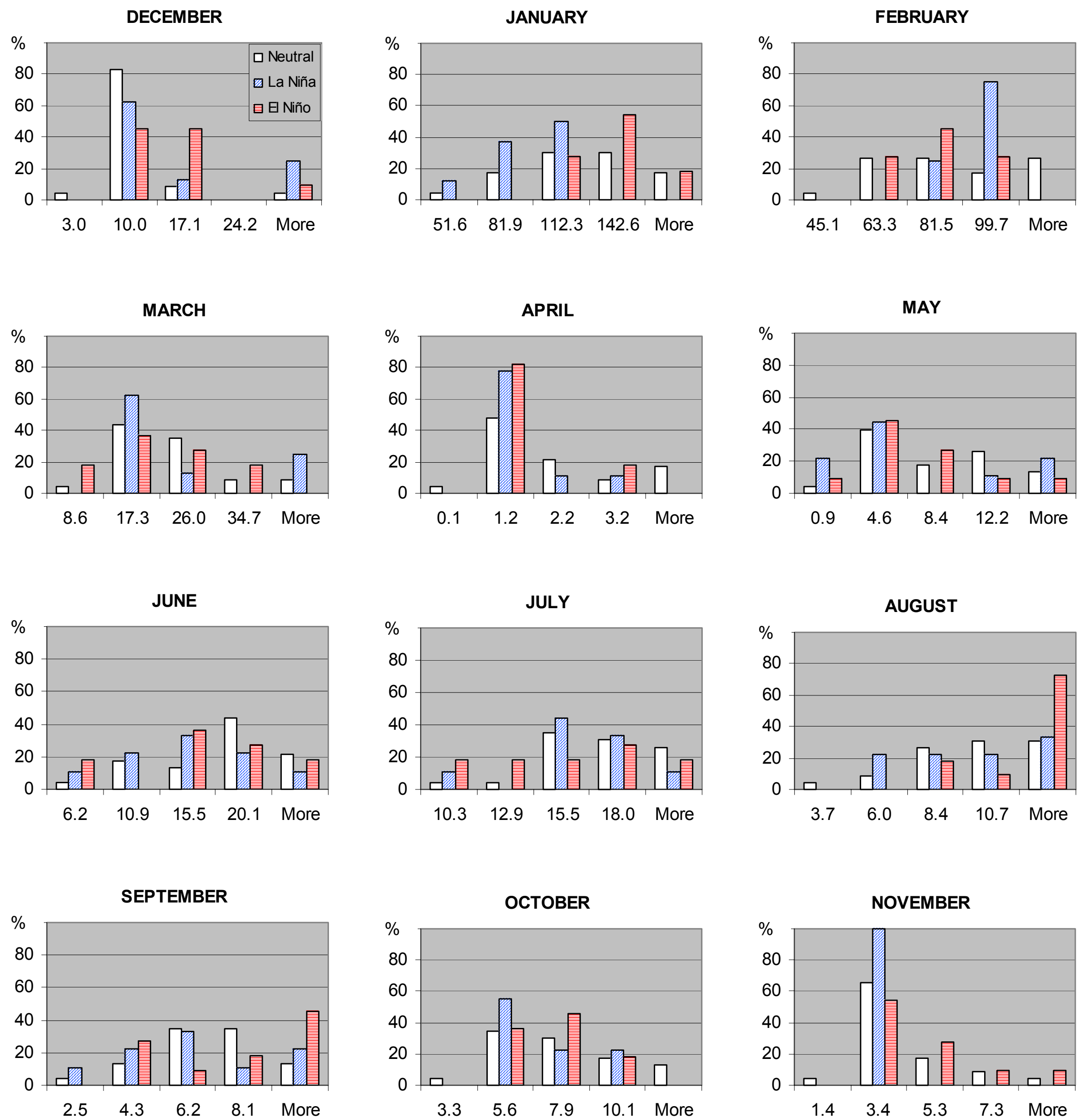


Figure 6-17. Frequency distribution of N leaching and month of the year by ENSO phase, when all other factors are averaged

6.3.4.2 Biomass in different ENSO phases

Biomass accumulation by forage systems changes by season and crop. The highest accumulations were in spring-summer months (April-July), followed by the summer-fall months (August-November). While in spring, summer and fall a variety of forages were possible, in winter only small grains (rye-ryegrass and relatives) are possible. The biomass accumulation (CV) varied from 86 kg ha^{-1} (32%) in December to 4,908 kg ha^{-1} (13%) in June. Biomass accumulation (CV) was higher for La Niña years and lower during El Niño years compared to Neutral, Table 6-5.

Table 6-5. Biomass (kg ha^{-1}) and ENSO phases, when all other factors are averaged

	All Years		La Niña		Neutral		El Niño	
	Biomass	CV	Biomass	CV	Biomass	CV	Biomass	CV
Dec	86	32%	102	30%	77	28%	92	41%
Jan	1,367	17%	1,563*	13%	1,319*	14%	1,301*	22%
Feb	2,292	10%	2,343*	11%	2,346*	7%	2,151*	9%
Mar	1,439	28%	1,329*	23%	1,561*	30%	1,297*	14%
Apr	959	35%	1,094	28%	938	32%	883	27%
May	4,546	12%	4,691	7%	4,487	16%	4,533	7%
Jun	4,908	13%	4,997	9%	4,818	19%	4,997	9%
Jul	3,232	13%	3,280	9%	3,173	18%	3,300	8%
Aug	1,649	27%	1,660	16%	1,654	20%	1,631	28%
Sep	2,784	11%	2,821	10%	2,811	10%	2,704	12%
Oct	3,127	12%	3,211	15%	3,060	11%	3,180	9%
Nov	811	49%	833	63%	754	51%	899	44%
Year	27,202		27,924		26,999		26,968	

Higher biomass (kg ha^{-1} year^{-1}) was predicted for La Niña years (27,924) than for Neutral (26,999) or El Niño years (26,968), Table 6-5. Most of the months consequently were predicted to have higher biomass accumulation (CV) in La Niña years, however for February and March the prediction indicates that they would be slighter higher in Neutral years, 2346 (7%), and 1561 (30%). Similarly for June, the accumulation (CV) would be close for La Niña and El Niño years 4,997 (9%), and in July it would be slightly higher for El Niño years, 3,300 (8%), Figure 6-18. This indicates that the accumulation is sensitive to the ENSO phases but not in the same way as it is with the N leaching. Overall, the crops did not respond to higher rainfall with higher yields; indeed higher biomass accumulation was seen with low or medium rainfall patterns for winter (La Niña and Neutral), for spring-summer (La Niña and El Niño), and also for summer-fall (La Niña).

Temperature and radiation also affected the accumulation of biomass. In La Niña years there are consistently higher temperatures and more radiation in the last months and in the first months of a year (fall-winter) coinciding with the higher accumulation rates.

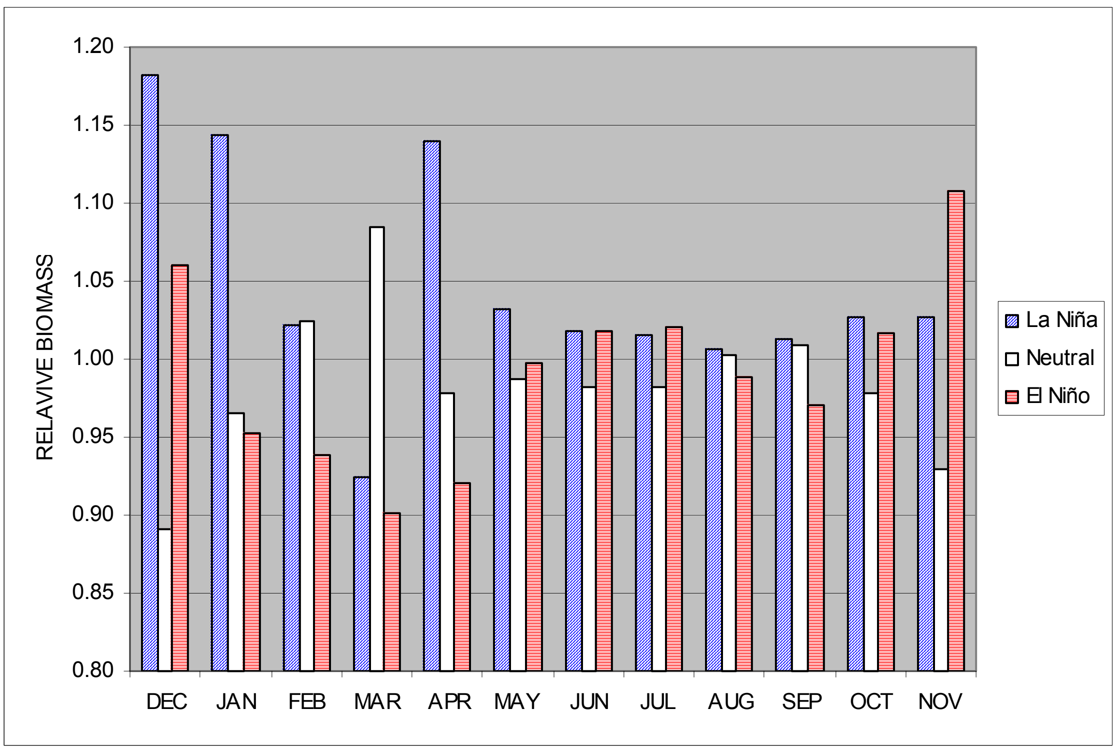


Figure 6-18. Biomass accumulation vs. ENSO phases relative to absolute averages, when all other factors are averaged

Biomass accumulation in Neutral and El Niño years was significantly ($p<0.05$) lower than La Niña in January, El Niño events were significantly lower ($p<0.05$) than Neutral and La Niña years in February and March, respectively, and El Niño events were significantly lower ($p<0.05$) than Neutral years in March.

6.3.5 Variability by Crop Sequences

Crop sequences performed substantially different regarding N leaching and biomass accumulation, Figure 6-19. For example, forage system number 11 (bermudagrass-bermudagrass-winter forage) consistently showed the lowest N leaching rate, but low biomass accumulation. The system bahiagrass-bahiagrass-winter forage showed the lowest biomass accumulation, independently of the ENSO phase and the amount of manure N application rate.

Rotations consisting of sorghum-millet and millet-sorghum presented the highest N leaching rates with medium biomass accumulation. Rotations that included corn-corn and corn-millet showed the highest rates of biomass accumulation with medium levels of N leaching. And rotations of corn-millet and sorghum-corn showed a medium N leaching together with a medium biomass accumulation. When corn was followed by bermudagrass and/or bahiagrass, the N leaching was low and the biomass accumulation was medium.

As in previous cases, it was consistent that higher N leaching (lower biomass accumulation) occurred in El Niño years and lower N leaching (higher biomass accumulation) in La Niña years.

By comparing the two graphs in Figure 6-19, the effect of higher N application (40 to 80 kg ha^{-1} mo^{-1}) can be observed. The measurements moved to the upper-right, indicating that with higher N applications, higher N leaching is expected together with higher biomass accumulation.

Three facts deserve mention when comparing graphs A) and B) in Figure 6-19. The bahiagrass-bahiagrass sequence seemed to change drastically with the N application change, showing a higher vulnerability to N leaching under high pressure of N applications; this rotation was one of the lowest N leaching with 40 kg ha^{-1} mo^{-1} and it became the highest with an application of 80 kg^{-1} ha^{-1}. The bermudagrass-bermudagrass rotation was the most resilient of all to N leaching under higher N applications and the most preventive for N leaching; even though all the other rotations (except bahiagrass-bahiagrass) increased proportionally from Graph A) to B), the bermudagrass rotation increased its N leaching but considerably less than the others. And, the rotation millet-corn responded more than the others with respect to biomass accumulation becoming the highest

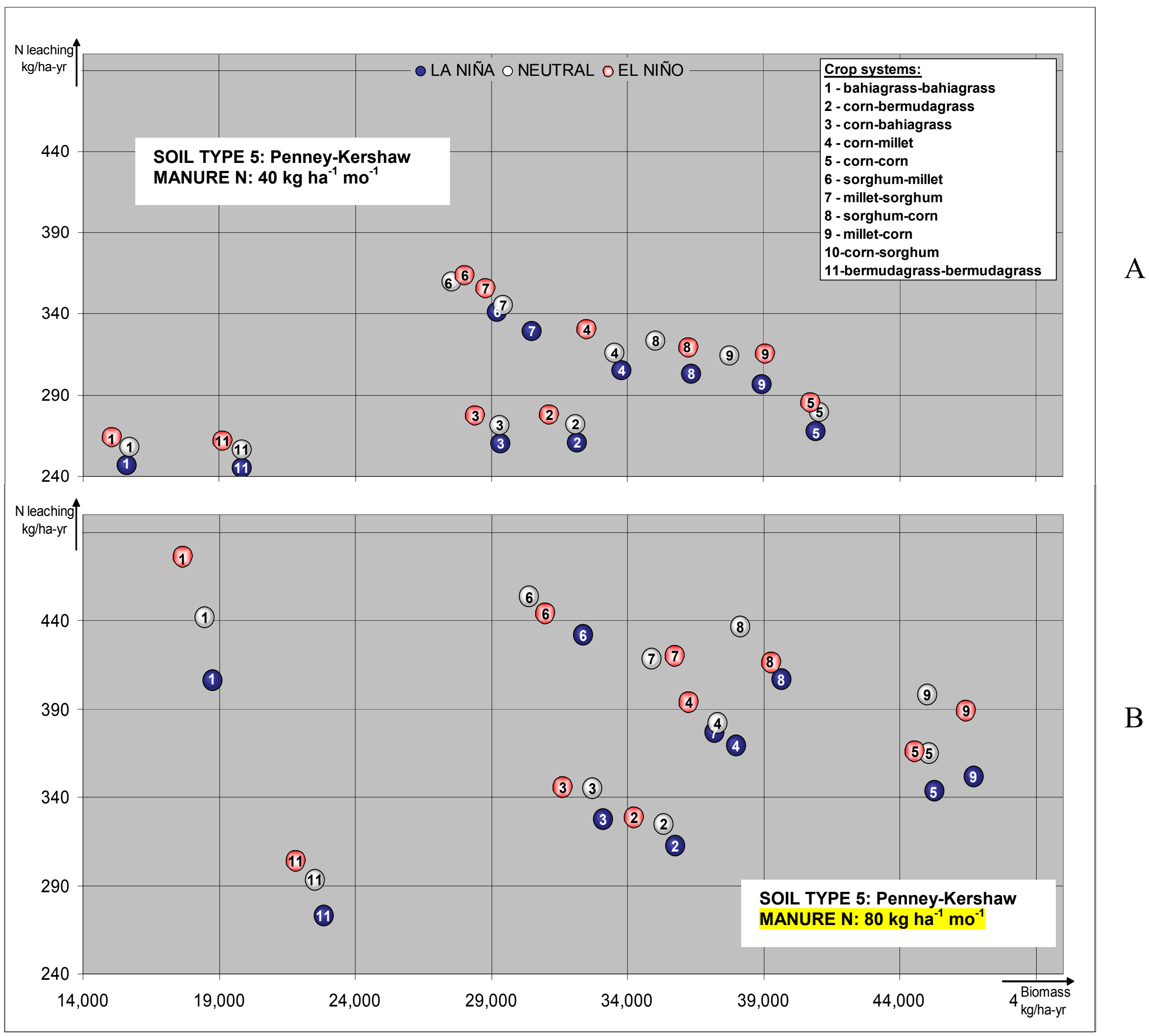


Figure 6-19. Nitrogen leaching vs. biomass accumulation for different forage systems under different ENSO phases (La Niña, Neutral, and El Niño), two manure N applications (40 and 80 kg ha^{-1} mo^{-1}), and soils of type Penney-Kershaw

in biomass accumulation after the higher manure N application. It seemed that the millet accumulation rate increases faster than the corn with higher N applications.

Additionally, the magnitude of the changes (the spatial positions) of the measurements between graphs in Figure 6-19 indicates high interactions among ENSO phases, crop rotations, and N application rates.

6.3.5.1 Nitrogen leaching and crop systems

Overall N leaching (kg ha^{-1}) in an entire year varied from 281 (bermudagrass-bermudagrass) to 397 (sorghum-millet), Table 6-6.

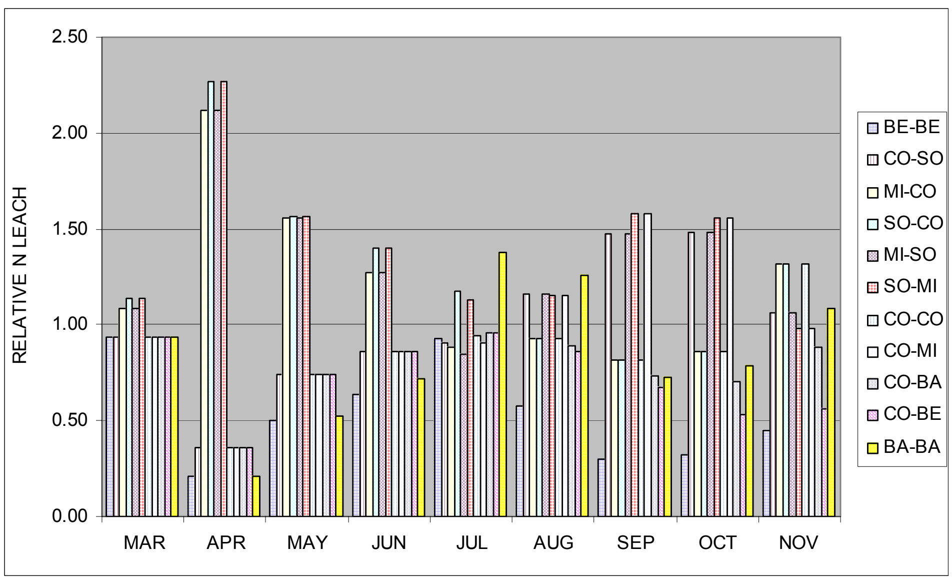


Figure 6-20. Nitrogen leaching vs. crop sequences relative to absolute averages, when all other factors are averaged. Note: abbreviations are two first letters of rotations in Table 6-6.

N leaching was predicted to be low when the rotation starts in spring with bermudagrass or corn, followed in the summer by bermudagrass, corn or bahiagrass; it was medium if it started with bahiagrass or corn and if they were followed by either bahiagrass, sorghum or millet; and it was high if the sequence started with millet or sorghum and continued with corn, sorghum, or millet (Figure 6-20).

Table 6-6. Nitrogen leaching (kg ha^{-1}) and crop sequences, when all other factors are averaged

	bermudagrass bermudagrass		corn sorghum		millet corn		sorghum corn		millet sorghum		sorghum millet	
	N Leach	CV	N Leach	CV	N Leach	CV	N Leach	CV	N Leach	CV	N Leach	CV
Mar	19.44	51%	19.57	52%	22.59	45%	23.77	43%	22.59	45%	23.77	43%
Apr	1.21	146%	2.10	114%	12.30	50%	13.16	51%	12.30	50%	13.16	51%
May	6.13	91%	9.06	77%	18.99	59%	19.10	60%	18.99	59%	19.10	60%
Jun	14.77	42%	19.94	41%	29.57	45%	32.51	46%	29.57	45%	32.51	46%
Jul	15.50	22%	15.06	42%	14.69	60%	19.52	52%	14.04	63%	18.87	54%
Aug	9.83	30%	19.76	42%	15.85	43%	15.85	43%	19.76	42%	19.68	42%
Sep	6.43	39%	31.31	43%	17.35	36%	17.35	36%	31.31	43%	33.55	42%
Oct	6.52	35%	29.98	30%	17.44	37%	17.44	37%	29.98	30%	31.57	29%
Nov	3.12	57%	7.42	71%	9.20	55%	9.20	55%	7.42	71%	6.86	62%
Year	281		352		356		365		384		397	

Table 6-6. Continued

	corn corn		corn millet		corn bahiagrass		corn bermudagrass		bahiagrass bahiagrass	
	N Leach	CV	N Leach	CV	N Leach	CV	N Leach	CV	N Leach	CV
Mar	19.57	52%	19.57	52%	19.57	52%	19.57	52%	19.44	51%
Apr	2.10	114%	2.10	114%	2.10	114%	2.10	114%	1.23	146%
May	9.06	77%	9.06	77%	9.06	77%	9.06	77%	6.42	93%
Jun	19.94	41%	19.94	41%	19.94	41%	19.94	41%	16.74	45%
Jul	15.71	41%	15.06	42%	15.94	41%	15.93	41%	22.88	26%
Aug	15.85	43%	19.68	42%	15.13	38%	14.69	38%	21.50	33%
Sep	17.35	36%	33.55	42%	15.64	37%	14.23	35%	15.42	41%
Oct	17.44	37%	31.57	29%	14.24	33%	10.82	30%	15.91	34%
Nov	9.20	55%	6.86	62%	6.17	53%	3.93	51%	7.59	56%
Year	324		355		315		308		325	

6.3.5.2 Biomass and crop systems

Overall biomass accumulation (kg ha^{-1} year^{-1}) varied from 14,061 kg ha^{-1} for bahiagrass-bahiagrass to 39,099 kg ha^{-1} for the corn-corn system. Also on the high side were the sorghum and millet crops and on the low side bermudagrass, Table 6-7.

All crops performed better in the spring- summer, when higher accumulation was predicted, June being the single month with the highest biomass accumulated. On a monthly basis, kg ha^{-1} (CV), the corn substantially outperformed all the others, reaching an accumulation of 6,700 kg ha^{-1} (10%) in June or 5,873 kg ha^{-1} (7%) in September. Millet followed the corn, which could accumulate up to 4,996 kg ha^{-1} (20%) in the month of June or 4,690 kg ha^{-1} (20%) in September. A little lower was the sorghum with 4599 kg ha^{-1} (22%) accumulated in June or 3,529 kg ha^{-1} (7%) in September. After those crops, bermudagrass and bahiagrass followed.

Table 6-7. Biomass (kg ha^{-1}) and crop sequences, when all other factors are averaged

	Bermudagrass Bermudagrass		Corn Sorghum		Millet Corn		Sorghum Corn		Millet Sorghum		Sorghum Millet	
	Bio-mass	CV	Bio-mass	CV	Bio-mass	CV	Bio-mass	CV	Bio-mass	CV	Bio-mass	CV
Mar	1,435	27%	1,435	27%	1,437	29%	1,447	29%	1,437	29%	1,447	29%
Apr	2,078	19%	349	33%	1,441	30%	925	33%	1,441	30%	925	33%
May	3,159	10%	6,450	7%	4,788	19%	3,061	18%	4,788	19%	3,061	18%
Jun	2,129	6%	6,700	10%	4,996	20%	4,599	22%	4,996	20%	4,599	22%
Jul	1,966	6%	3,214	7%	3,565	20%	3,514	19%	3,509	20%	3,458	19%
Aug	1,641	7%	111	73%	5,002	8%	5,005	8%	111	26%	33	92%
Sep	1,116	15%	3,058	6%	5,809	8%	5,873	9%	3,058	7%	2,685	22%
Oct	775	18%	3,529	7%	4,803	10%	4,919	15%	3,529	12%	4,690	20%
Nov	229	34%	1,112	26%	540	87%	582	87%	1,112	55%	1,471	51%
Year	18,274		29,703		36,125		33,669		27,726		26,114	

Table 6-7. Continued

	Corn Corn		Corn Millet		Corn Bahiagrass		Corn Bermudagrass		Bahiagrass Bahiagrass	
	Bio-mass	CV	Bio-mass	CV	Bio-mass	CV	Bio-mass	CV	Bio-mass	CV
Mar	1,435	27%	1,435	27%	1,435	27%	1,435	27%	1,435	27%
Apr	349	33%	349	33%	349	33%	349	33%	1,419	24%
May	6,450	7%	6,450	7%	6,450	7%	6,450	7%	2,304	9%
Jun	6,700	10%	6,700	10%	6,700	10%	6,700	10%	1,280	7%
Jul	4,042	10%	3,214	11%	4,042	10%	4,487	9%	1,139	6%
Aug	5,005	8%	30	59%	2,078	7%	3,084	8%	1,014	5%
Sep	5,873	9%	2,621	17%	1,065	8%	1,793	8%	868	10%
Oct	4,919	15%	4,574	11%	844	9%	1,404	8%	663	15%
Nov	582	87%	1,430	46%	288	19%	481	17%	195	30%
Year	39,099		30,547		26,994		29,927		14,061	

Even though bermudagrass and bahiagrass were in the lower end of biomass accumulation, when they were associated with corn in the spring-summer season, they could accumulate amounts close to or above the overall average. Another distinction about bahiagrass and bermudagrass was that they maintain a smoother rate of accumulation throughout their growing months. This was different from the other crops that present more variability during the growth season.

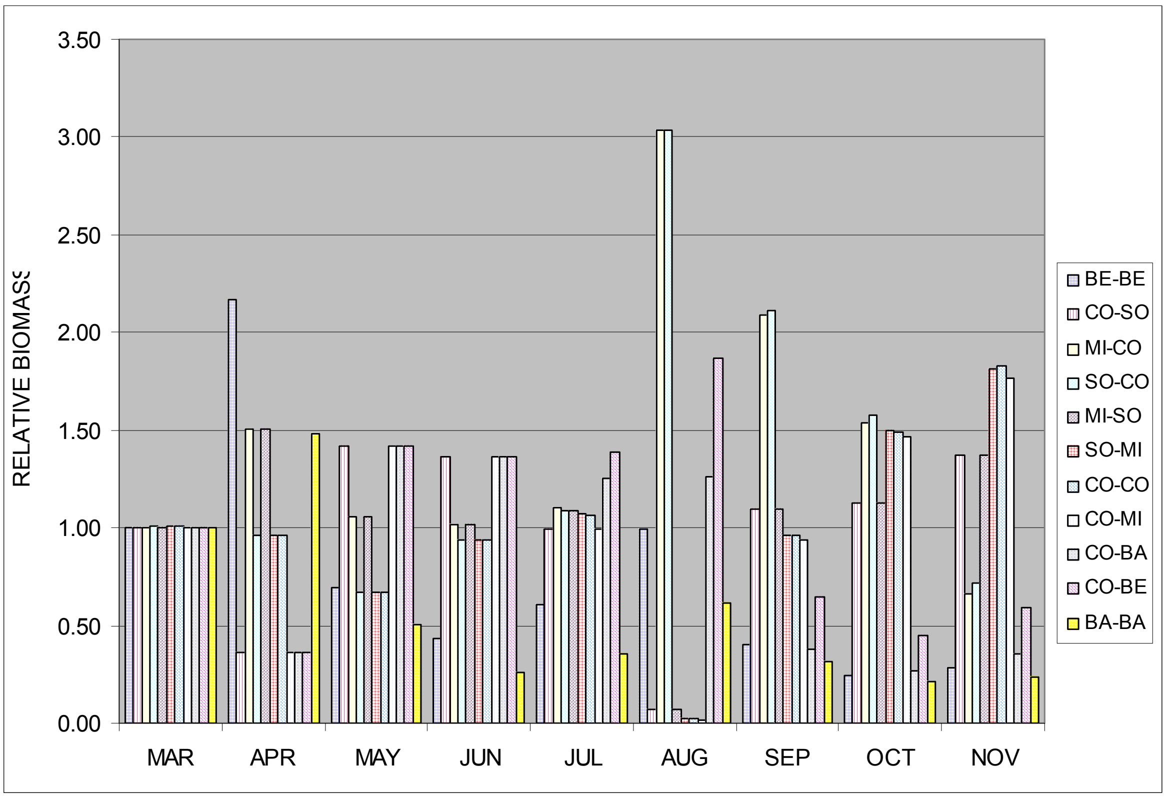


Figure 6-21. Biomass accumulation vs. crop sequences relative to absolute averages, when all other factors are averaged. Note: abbreviations are two first letters of rotations in Table 6-7.

During May June and July corn performed much better than the others; during August, September, and October millet and sorghum accumulated better than the others, together with corn.

6.3.6 Variability by Soil Types

In Figure 6-22 it is possible to explore the variability among soil types regarding N leaching and biomass accumulation under different ENSO phases, two manure N application ratios and with a crop rotation consisting of corn-sorghum. Evidently, the crops in soil type 2 (Arredondo-Jonesville-Lake) leach the least N with a medium biomass accumulation rate and crops in soil type 6 (Millhopper-Bonneau) leach the most N and at the same time accumulate the most biomass. Also, consistently, crops in soil type 4 (Penney-Otela) and soils 10 (Blanton-Ortega-Penny) leach and accumulate medium levels.

Crops in soil 3 (Bonneau-Blanton-Eunola), followed by soil type 9 (Blanton (low)) had the lowest biomass accumulation rates with a medium-high level of N leaching.

As in previous cases, consistently less N leaching and more biomass accumulation were found in El Niño ENSO phases and the opposite in La Niña years.

It is important to notice that the N leaching in soil type 6 is substantially higher than the others together with higher rates of biomass accumulation. These soils have the highest drainage rate and it may be the main reason for these differences, as was previously discussed.

Comparing the two graphs A) and B) in Figure 6-22, it can be observed that not much difference is found in N leaching between the two different rates of manure N applied (20 and 40 kg ha^{-1} mo^{-1}), but the difference is marked in the biomass accumulation, indicating that the crops are still up-taking extra amounts of manure N applied.

Additionally, the higher amounts of organic matter because of higher manure N applications can help prevent N leaching; this potential explanation would not hold, however, for the case of even higher manure N applications, where much higher N leaching was noticed (Figure 6-22).

It can be also observed, by comparing the graphs, that the relative spatial positions of the measurements changes because the interactions of soils, ENSO phases, and manure N application as can be seen, for example, by the biomass accumulation for soils 6, 4, 10, 9, 8, 5, 4 and 3 in Neutral years, which is lower than the El Niño years for manure N application of 20 kg ha^{-1} mo^{-1}, compared to the higher application of 40 kg ha^{-1} mo^{-1}.

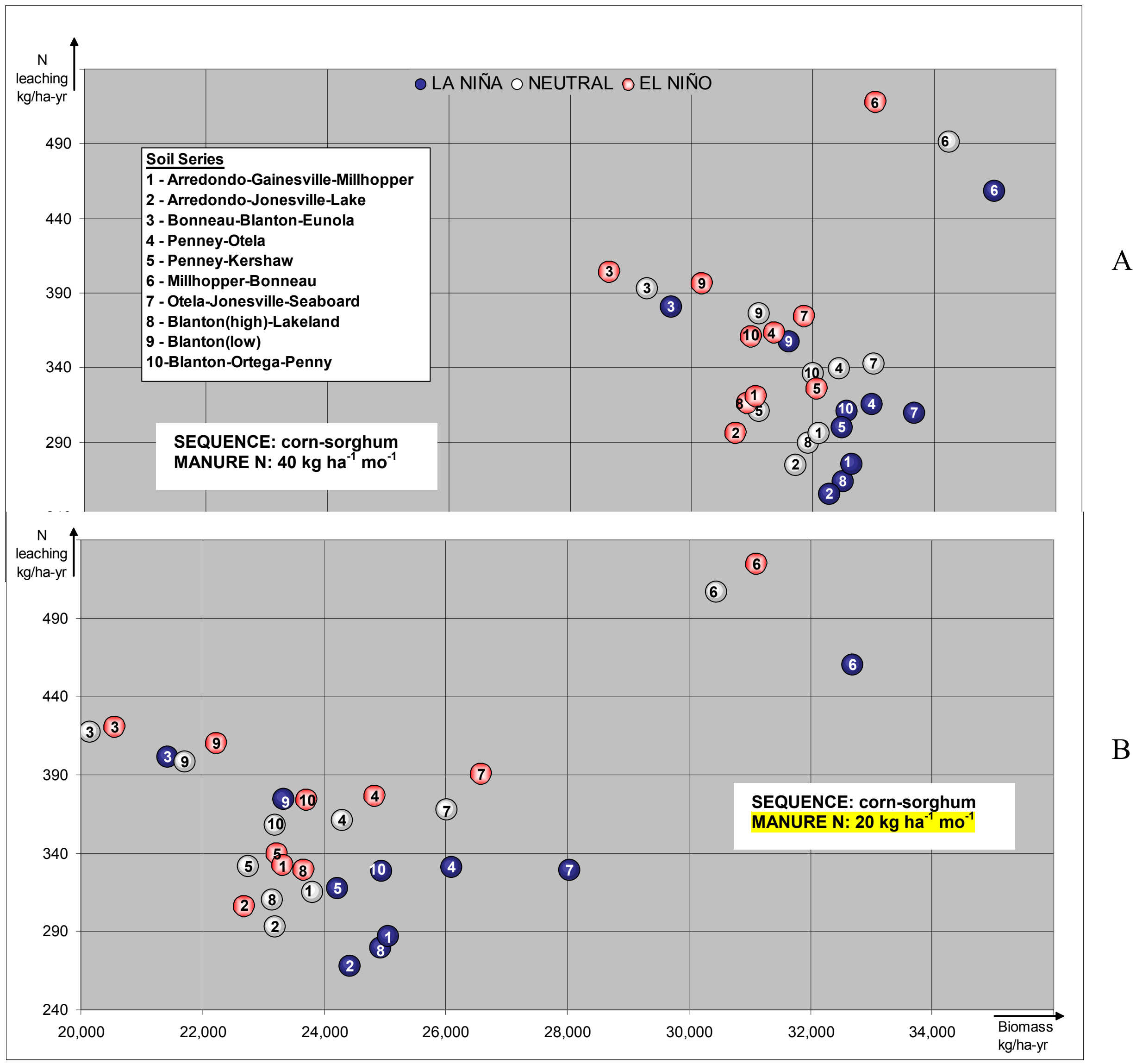


Figure 6-22. Nitrogen leaching vs. biomass accumulation for different soil types under different ENSO phases (La Niña, Neutral, and El Niño), two manure N applications (40 and 20 kg ha^{-1} mo^{-1}), and forage system consisting of corn-sorghum-winter forage

6.3.6.1 Nitrogen leaching and soil types

N leaching, besides the amount of manure N deposited, depends on the permeability, the water holding capacity, the exchange capacity, the temperature, and the pH of the soil. N leaching is favored when soil conditions present nitrates (NO_3^-), the N compound more readily leached, and low water holding capacity. Nitrates (NO_3^-) are more likely to occur in soils with low exchange capacity, moderate or high temperature, and higher pH. Overall, north-Florida soils are highly vulnerable with respect to N leaching because they are very sandy and present low exchange capacity. The pH is an important factor. The pH of these soils varies from slightly acid to very strongly acid. The slightly acid soils are more prone to N leach than the very strongly acids (Table 6-1). Strongly acid or very strongly acid soils (pH $\leq$ 5.5) tend to lose less N because much of the N is converted to ammonium, NH_4^+, which can be adsorbed and stabilized by the exchange complex of the soil. However, soils with higher pH (moderately or slightly acid, pH > 5.5) tend to lose more N because the N can be converted to either ammonia (NH_3) or to nitrate (NO_3^-). While NH_3 volatilizes to the air and is not a direct threat to water, NO_3^- is easily leached when soils have low water holding capacity.

Additionally, soil temperatures in north-Florida are warm enough to not stop or decrease considerably the processes of mineralization or nitrification of the waste N sources that conduce N leaching.

Overall, yearly N leaching (kg ha^{-1} year^{-1}) presented substantial variation for the different soil types found in North-Florida; it ranged from 272 kg ha^{-1} for soils type 2 to 480 kg ha^{-1} for soils type 6, Table 6-8. This fact can be mostly attributed to the drainage that is the lowest for soil 2 and the highest for soil 6 (Table 6-1). Exploring more in depth the N leaching and soils, it can be seen that, comparing soils with the same drainage rate (soils 1, 5, 7 and 10 with 0.75 drainage and soils 3, 4, and 9 with drainage 0.80, Table 6-1), more N leaching occurred on those soils with lower cation exchange capacity and/or in those with higher pH, as would be expected.

The months with the lowest rates of N leaching, December and April, are those with the maximum variability. As in previous discussions, January and February presented the highest rates of N leaching independently of the soil type.

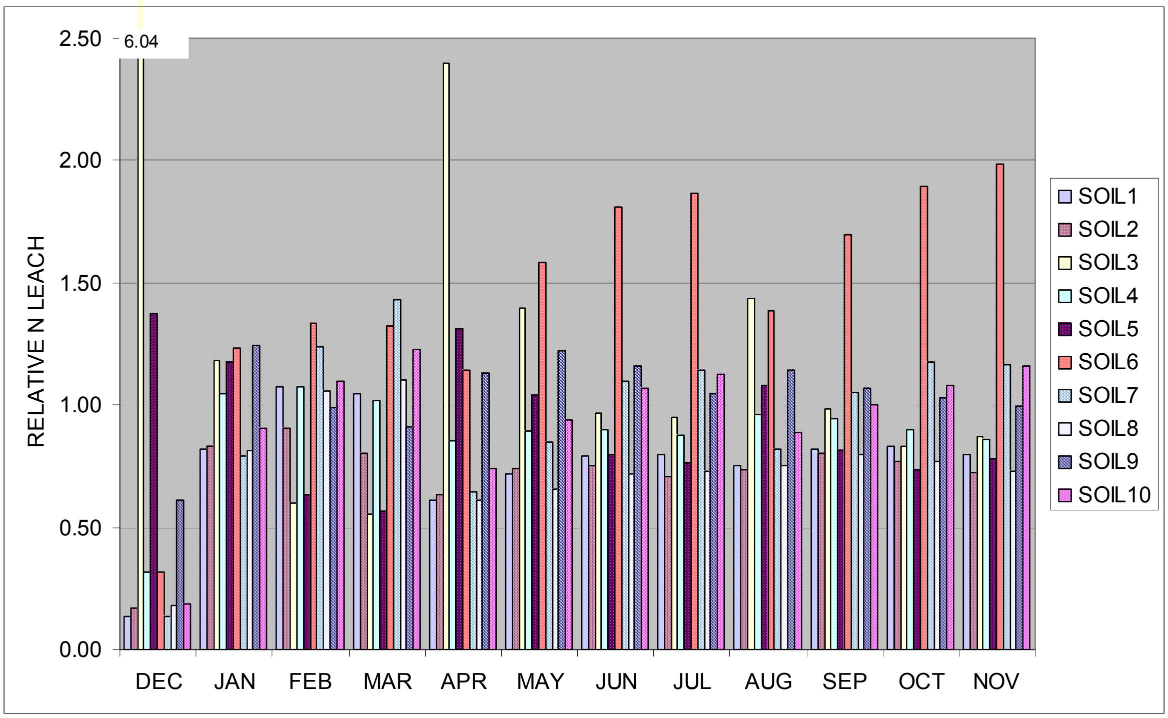


Figure 6-23. Nitrogen leaching vs. soil types relative to absolute averages, when all other factors are averaged. Note: Soil numbers refer to soil types defined in Table 6-1.

When crops are initiating their cycle they heavily use nutrients and therefore, there is less available N for leaching. Soil type 3 is an exception that showed a high N leaching rate even during the starting months, probably because of a very poor retentive soil system along with a low depth profile. There was quite a variation among soils in the other months, but N leaching was the highest during winter in February and March, followed by September and October and next for June and July.

Table 6-8. Nitrogen leaching (kg ha^{-1}) and soil types, when all other factors are averaged

	Soil1		Soil2		Soil 3		Soil 4		Soil5	
	N Leach	CV	N Leach	CV	N Leach	CV	N Leach	CV	N Leach	CV
Dec	1.46	489%	1.82	460%	63.98	43%	3.33	370%	14.57	171%
Jan	89.04	43%	90.05	37%	128.08	18%	113.35	34%	127.26	20%
Feb	84.33	25%	70.94	26%	47.14	28%	84.46	25%	49.57	33%
Mar	21.82	54%	16.70	56%	11.57	44%	21.20	52%	11.80	49%
Apr	3.53	121%	3.68	118%	13.93	45%	4.96	110%	7.60	78%
May	8.73	80%	9.04	79%	16.99	43%	10.87	76%	12.68	49%
Jun	18.37	43%	17.42	44%	22.42	42%	20.85	44%	18.51	39%
Jul	13.26	45%	11.82	47%	15.85	45%	14.63	47%	12.70	49%
Aug	12.82	45%	12.51	45%	24.52	29%	16.36	42%	18.42	30%
Sep	17.45	40%	17.08	40%	20.91	38%	20.00	42%	17.27	35%
Oct	16.84	33%	15.61	34%	16.83	38%	18.24	36%	14.94	35%
Nov	5.59	61%	5.05	62%	6.09	65%	6.02	65%	5.46	59%
Year	293		272		388		334		311	

Table 6-8. Continued

	Soil6		Soil7		Soil8		Soil9		Soil10	
	N Leach	CV	N Leach	CV	N Leach	CV	N Leach	CV	N Leach	CV
Dec	3.37	403%	1.43	494%	1.90	436%	6.45	280%	2.00	380%
Jan	133.46	33%	86.08	47%	88.15	42%	135.04	26%	97.85	37%
Feb	105.05	23%	97.17	21%	83.02	23%	77.71	29%	86.32	22%
Mar	27.56	48%	29.83	46%	23.04	50%	19.05	52%	25.55	50%
Apr	6.63	121%	3.76	171%	3.56	139%	6.58	97%	4.29	130%
May	19.33	77%	10.31	91%	8.02	88%	14.86	60%	11.43	77%
Jun	42.04	43%	25.46	44%	16.74	48%	26.86	39%	24.78	42%
Jul	31.05	45%	19.07	43%	12.11	48%	17.41	43%	18.71	41%
Aug	23.62	43%	14.02	50%	12.84	47%	19.45	36%	15.12	43%
Sep	36.03	41%	22.39	43%	16.88	44%	22.64	37%	21.25	38%
Oct	38.40	33%	23.88	33%	15.62	36%	20.86	32%	21.89	30%
Nov	13.90	60%	8.16	58%	5.11	65%	6.98	58%	8.11	58%
Year	480		342		287		374		337	

Note: Soil numbers refer to soil types defined in Table 6-1.

Monthly variation of N leaching in different soil types (Figure 6-23) showed that with exception of December, April, and August, soil 6 would leach the highest. It is interesting to notice that there was a temporal variation for different soil types and N leaching as is the case of soil 3 that presented the third highest N leaching rate in January (128.08 kg ha^{-1}), but it also presented the lowest N leaching rate in February (47.14 kg ha^{-1}). The possible explanation lies in the dynamic of the soils meaning that a high amount of leaching in January would leave less N available for leach in February or vice versa.

With the exception of soil 3 that evidently is an outlier, and soil 6 in November, the variation of the mean regarding leaching went from 90% above and below depending of the crops and the season of the year. For the months with more than 10 kg ha^{-1} mo^{-1} leached (Table 6-8) there was quite a variation for different soils. Soil 1 was consistently below the average of leaching for all the months except February and March, soil 2 was always 10 to 80 % below the average, and soil 4 was most of the time between 0 and 10 % below the average.

6.3.6.2 Biomass and soil types

Overall biomass accumulation (kg ha^{-1} $year^{-1}$) varied from 24,441 for soils type 3 to 31,297 for soils type 6. Greater biomass accumulation was predicted with soils of type 6 and 7 and less biomass accumulation was observed with soils of type 3 and 9 (Table 6-9).

Apparently, the high permeability and low water holding capacity besides promoting higher N leaching also promotes better plant growth and development under the conditions of spray fields in north-Florida dairy farm systems with these high nutrient applications. For example, for soils of type 6 that leached the most, the biomass accumulation was also the highest: for soils of type 2 that had the lowest N leaching, the biomass accumulation was the third lowest (Figure 6-24).

In winter, during February and March soil 6 showed the highest accumulation and soil 3 the lowest. Also during spring-summer soil 6 yielded the most and soil 3 the least. During summer-fall there was less variation among soils.

Table 6-9. Biomass (kg ha^{-1}) and soil types, when all other factors are averaged

	Soil1		Soil2		Soil3		Soil4		Soil5	
	N Leach	CV	N Leach	CV	N Leach	CV	N Leach	CV	N Leach	CV
Dec	86	31%	86	31%	86	30%	86	31%	86	31%
Jan	1,369	17%	1,313	17%	1,242	15%	1,381	17%	1,441	17%
Feb	2,227	10%	2,138	10%	1,987	10%	2,308	10%	2,389	10%
Mar	1,401	30%	1,372	29%	1,313	30%	1,449	29%	1,452	31%
Apr	977	39%	960	38%	868	34%	973	39%	934	36%
May	4,575	11%	4,459	12%	3,875	10%	4,667	11%	4,353	11%
Jun	4,842	12%	4,801	13%	4,358	12%	5,017	12%	4,711	12%
Jul	3,202	12%	3,170	12%	2,946	12%	3,306	12%	3,111	12%
Aug	1,657	31%	1,623	31%	1,532	29%	1,684	31%	1,599	29%
Sep	2,778	11%	2,726	11%	2,560	10%	2,855	11%	2,706	10%
Oct	3,083	12%	3,043	13%	2,901	12%	3,194	13%	3,020	12%
Nov	796	46%	791	46%	773	46%	821	46%	787	46%
Year	26,992		26,481		24,441		27,741		26,589	

Table 6-9. Continued

	Soil6		Soil7		Soil8		Soil9		Soil10	
	N Leach	CV	N Leach	CV	N Leach	CV	N Leach	CV	N Leach	CV
Dec	85	31%	86	31%	86	31%	86	31%	86	31%
Jan	1,505	20%	1,410	18%	1,336	17%	1,282	16%	1,327	17%
Feb	3,007	9%	2,464	10%	2,202	10%	2,034	10%	2,188	10%
Mar	1,799	24%	1,545	27%	1,406	29%	1,346	29%	1,396	29%
Apr	1,005	42%	988	40%	954	38%	942	37%	961	39%
May	5,308	12%	4,857	12%	4,494	11%	4,282	11%	4,544	12%
Jun	5,649	12%	5,243	12%	4,865	12%	4,655	13%	4,873	13%
Jul	3,602	12%	3,424	12%	3,213	12%	3,092	12%	3,217	12%
Aug	1,810	35%	1,729	32%	1,631	30%	1,585	30%	1,645	32%
Sep	3,115	12%	2,941	11%	2,759	11%	2,650	11%	2,768	11%
Oct	3,534	13%	3,318	13%	3,088	12%	2,955	13%	3,089	13%
Nov	879	48%	846	47%	802	46%	782	46%	801	46%
Year	31,297		28,850		26,835		25,689		26,895	

Note: Soil numbers refer to soil types defined in Table 6-1.

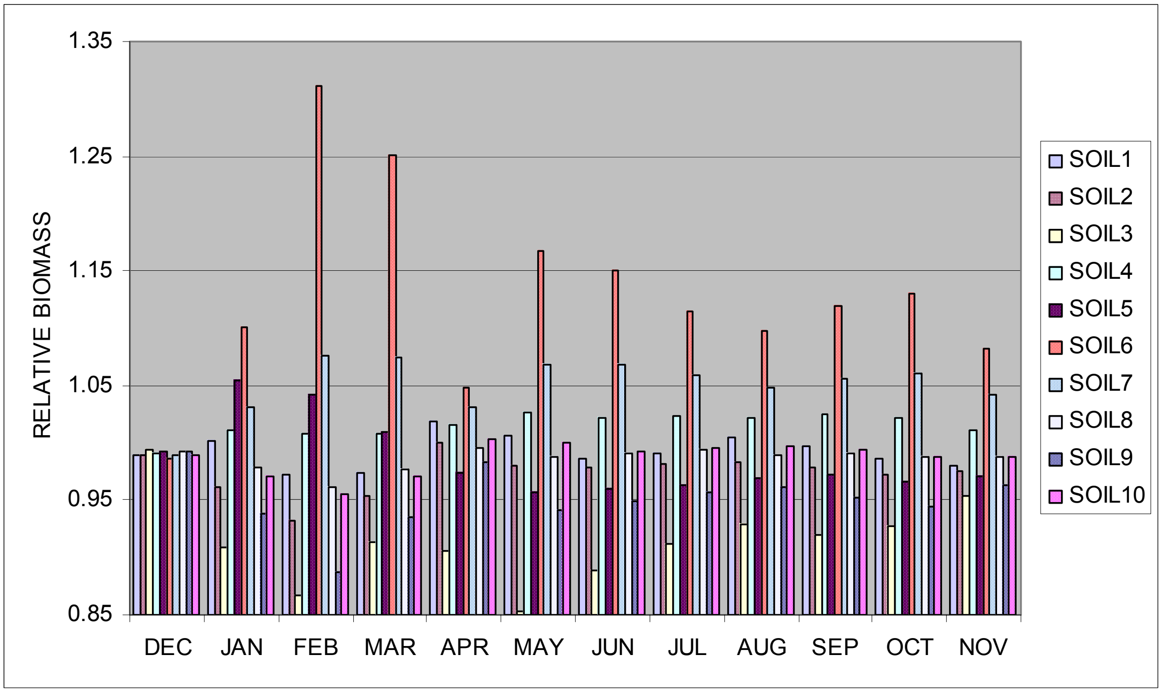


Figure 6-24. Nitrogen leaching vs. soil types relative to absolute averages, when all other factors are averaged. Note: Soil numbers refer to soil types defined in Table 6-1.

6.4 Conclusions

North-Florida dairy farm systems use 11 possible crop/pasture sequences for a year in three main crop seasons (spring-summer, summer-fall, and winter). The most common winter forages (WF) are the small grains such as rye, oats, wheat, or ryegrass. The sequences are bermudagrass-bermudagrass-WF; corn-sorghum-WF; millet-corn-WF; sorghum-corn-WF; millet-sorghum-WF; sorghum-millet-WF; corn-corn-WF; corn-millet-WF; corn-bahiagrass-WF; corn-bermudagrass-WF; and bahiagrass-bahiagrass-WF.

Although only bermudagrass and bahiagrass have currently available models, all of the above crop/pasture sequences are possible to simulate using the DSSAT v4.0 by adapting crop coefficients from closely related crops: silage corn from maize, forage sorghum from grain sorghum, pearl millet from millet, and winter forages from wheat and calibrating and validating them against experimental data. This study found crop coefficients to represent north-Florida forage crops.

A sensitivity analysis of N leaching and biomass accumulation of the north-Florida forage systems to extreme effluent manure N application (0 to 200 kg N month^{-1}) indicated that the rate of N leaching will increase while the rate of biomass accumulation will decrease to zero when the rates of N applied with the manure increase. When the application is approximately 120 kg N month^{-1} the biomass accumulation reaches a maximum and the leaching of N increases at a higher rate.

Higher (lower) N leaching (biomass accumulation) is predicted for El Niño years than Neutral years or La Niña years, attributed mostly to the number and intensity of rainfall events. An attempt to relate the leaching with the Japan Meteorological Index, used to predict the El Niño Southern Oscillation phases, showed little correlation. Winter in general, and specifically January and February are the critical months for N leaching when more than 50% of annual N leaching is predicted. This is the same time that low biomass accumulation is noticed.

Biomass accumulation is the highest for corn, millet, and sorghum, followed by bermudagrass and bahiagrass. However, higher stability and consequently less variability is noticed in the systems when they include either of the perennials (bermudagrass or bahiagrass). The best forage systems to prevent N leaching are those that start in spring-summer with bermudagrass or corn; have bermudagrass, bahiagrass or corn in summer; and finish with winter forages. The systems that leach the most are those that include millet and/or sorghum. Bahiagrass could also leach high N in conditions of high manure N application.

There is great variability in the interaction of soil types and months of the year regarding N leaching and biomass accumulation. Water holding capacity, pH and permeability of soils are believed to hold most of the causes for these differences. Soils with very low permeability and higher pH will facilitate the leaching of N, which also will vary throughout the year, and at the same it will determine higher biomass accumulation. There is more biomass accumulation for soils with higher N leaching rates because in these intense systems there will be little stress because lack of N, other nutrients, and/or water because these fields have irrigation systems that deliver the manure effluent and artificial irrigation as needed.

The use of crop simulations were critical in recognizing trends, interactions, and identifying absolute values of N leaching and biomass accumulation under different conditions of climate, manure N applications, soil types, and forage systems. It would be impossible to design and conduct a real experiment of these magnitudes.

CHAPTER 7
AN INTEGRATED SIMULATION MODEL TO ASSESS ECONOMIC AND ECOLOGIC IMPACTS OF NORTH FLORIDA DAIRY FARM SYSTEMS

7.1 Introduction

Environmental concerns for dairy systems, N leaching specifically, for north-Florida are recognized as the most important factors for successful business in the future (Staples et al., 1997; Fraisse et al., 1996; Van Horn et al., 1998). Because the increasing concern regarding N levels in the Suwannee River Basin, north-Florida dairy farms are being more closely scrutinized by regulatory agencies (Twatchtmann, 1990), and effective tools to estimate point-source pollution of specific operations as well as potential ways to mitigate the problem inside the farm gate is an imperative need.

The complexity of dairy farms in north-Florida justifies the creation of a whole-farm model, integrating several modeling approaches, in order to better analyze these systems (Herrero, 2000). Participatory and interdisciplinary methodologies can be pursued along with model creation, calibration, and validation in order to have better acceptance by final users (Geurtz and Joldersma, 2001).

The objective of this paper is to describe the EXCEL-based Dynamic North-Florida Dairy Farm Model (DNFDFM). The DNFDFM is a simple event-controlled, dynamic model coupled to crop and optimization models created to assess N leaching from north-Florida dairy farm systems and the economic impacts of reducing it. The model responds to specific environmental (climate and soils) and managerial characteristics of dairies (total number of cows, milk production, crop rotations, waste system, etc.) and can be used to study the economic and ecologic sustainability of these systems. The driver of the DNFDFM is a dynamic adaptation of the framework “balance” and/or “budgeting” of nutrients in dairy farms, commonly used in Florida (Van Horn et al. (1991, 1994, 1998, 2001) and NRCS (2001) (Chapters 1 and 5). The DNFDFM incorporates Markov-chain probabilistic simulations of cow-flows (Chapter 5), crop simulation models (Jones et al., 2003) (Chapter 6) for historical climatic years for El Niño Southern Oscillation (O’Brien, 1999) (Chapter 6), automated linear programming optimization of managerial options (Hazell and Norton, 1986), participatory modeling (Geurtz and Joldersma, 2001) (Chapter 4), and user-friendliness.

7.2 Materials and Methods

7.2.1 Conceptual Model

Most dairies in Florida manage animals under semi-intensive or intensive systems and are essentially businesses producing milk: decisions are based on profit maximization and operation regulations (Adams, 1998). North-Florida dairies are business enterprises and have full access to credit opportunities, information, and new technologies (Adams, 1998). Additionally, dairy farms, which produce both livestock and crops, are composed of interconnected units; any part of which is affected by and affects the behavior of other parts, including human management decisions and strategies (Adams, 1998).

Since a whole-dairy-farm encompasses environmental, economic, and bio-physical components, its analysis is best served by a systems approach that accounts for the interactions of these components, and that can trace the consequences of an intervention through the entire system (Kelly, 1995). While systems can be conceptualized at any of many scale levels, a systems approach defines a specific scale of interest and an appropriate boundary of analysis; analysis in the systems approach is marked by recognition of the whole system and the interactions within that system rather than looking only at a system component (Kelly, 1995). A systems approach employs specific techniques and tools, such as rapid appraisal, pattern analysis, diagrams, and modeling, often in a multidisciplinary fashion, to identify system boundaries and recognize component interactions (Kelly, 1995).

In order to assess what would happen with the whole dairy operation and what would happen specifically with nitrate flow under different climate-management scenarios, models of these realities were set up (Thornley and Johnson, 1990). Models allow foreseeing results when temporal or material conditions make it impractical to develop field experiments. The successful planning of an animal waste management system requires the ability to simulate the impact of waste production, storage, treatment, and utilization on the water resources; it must address overall nutrient management for the operation (Fraisse et al., 1996).

The systems approach used is Farming Systems Research and Extension (FSRE) as described by Hildebrand (1990). The “farm household” in livelihood systems analyses is replaced by “farm management” (Hazell and Norton, 1986) for commercial or industrial farm dimensions such as north-Florida dairy farms. The farming system is composed of an arrangement of subsystem components that function as units. These subsystems include biophysical, environmental, and economic components as well as relationships of the dairy operation to climate variability. These agroecosystems, as described by Powers and McSorley (2000), include the populations and communities in relationship with the abiotic factors organized in ecosystems.

The Van Horn et al. (1991, 1994, 1998, 2001), NRCS (2001), and Lanyon (1994) approaches were adjusted, modified, and used for keeping track of dynamic N movement in all system components. Van Horn et al. (1998) mentioned the quantitative information needed on nutrient flow through all segments of the system. They list the following critical research questions:

- How much of individual nutrients are excreted by dairy cows?
- How does the manure management system affect nutrient flow and nutrient recoveries for fertilizer use?
- What is the potential nutrient removal by plants?
- How can a manure nutrient budget be developed?
- What steps help to document environmental accountability?

Agronomic measures of nutrient balance and tracking of inputs and outputs for various farm management units can provide the quantitative basis for management to better allocate manure to fields, to modify dairy rations, or to develop alternatives to on-farm manure application (Lanyon, 1994). For instance, identifying where pollutants are being directly discharged and taking measures to reduce these discharges are more easily accomplished than controlling the indirect sources or “non-point” source pollutants (Environmental Literacy Council, 2002). Indeed, historically, scientists have been able to track single, or "point" sources of pollution, but tracking multiple, or “non-point” sources has been difficult (Ondersteijn, 2002).

Crop models (Jones et al., 2003, Jones et al. 1998) are process-based dynamic simulation models that allow translating biophysical and environmental conditions into agricultural outcomes (Philips et al., 1998). Crop models can be used to estimate monthly biomass accumulation and N leaching by a number of crop and/or pasture sequences under different climatic conditions, depending on soil conditions, manure applications, and other managerial choices.

Linear programming models (LP) are optimization models that can devise alternative management choices that maximize (minimize) an objective function according to a set of restrictions (Hazell and Norton, 1986). LP models have been widely used in analysis of farming systems, beginning about the time of the Heady and Candler book in 1958.

Different simulation methods were needed to represent accurately the north-Florida dairy crop and livestock systems, and test management strategies that yield the most desired outcomes. Complex systems demand the study of interactions among processes acting on multiple scales, and consequently new and innovative approaches are needed to deal with these problems, coupling advances in dynamical theory, stochastic processes, and statistics (Levin, 1991).

7.2.2 Computer Implementation

The model, Dynamic North-Florida Dairy Farm Model (DNFDFM) was developed in Excel ® using embedded Visual Basic ® in order to produce a user-friendly final product for farmers, Extension services, and regulatory agencies.

The crop models were previously run by using the Decision Support System for Agricultural Transfer, DSSAT v4.0 (Jones et al., 2003) and the results were implemented to be reproduced in the DNFDFM in Excel. The optimization component is automatically set up and solved taking advantage of the solver tool that ships with Excel.

7.2.3 Analysis of Synthesized Dairies in North-Florida

The model was run for 3 synthesized farms; synthesized farms were created using real data. Because of the sensitivity of the topic, "synthesized" farms have been created as examples for small, medium, and large operations. These synthesized farms combine many real characteristics of dairies in the study area without pointing out any specific farm information for which the DNFDFM can be run to perform relevant analyses. Outputs of simulating these farms are presented in the results sections. Statistical, optimizations, and other analyses of results are presented in the next chapter (Chapter 8).

7.3 Model Description

7.3.1 Overall Characteristics

The Dynamic North-Florida Dairy Farm Model (DNFDFM) is an integrated, whole-dairy-farm simulation that links decision making with biophysical, environmental, and economic processes. The main objective of the DNFDFM is to predict monthly N leaching and profit in response to environmental (climate and soils) and managerial characteristics of farms (livestock management, waste management, and crops management). The DNFDFM can be used to study the economic and ecologic sustainability of these systems, as well as to diagnose sources of problems and search for feasible alternative management practices.

The simulation approach includes a dynamic event-controlled simulation model connected to crop models and to optimization models. The driver, that has the livestock and waste modules, follows a dynamic adaptation of the budgeting framework of tracking the flow of N through the entire system along with production and additional economic variables, according to a pre-defined set of management and climatic conditions. Crop models assess the N recycled by plants and the amount of N leached according to management, genetic, soil, and climatic specific conditions. The optimization model consists of a linear programming model that either minimizes N leaching or maximizes profit for specific farm conditions. The DNFDFM incorporates Markov-chain probabilistic simulation of cow-flows and crop simulation for historical climatic years (El Niño Southern Oscillation), automated optimization of managerial options, participatory modeling, and user-friendliness.

7.3.2 Components

The main components of the DNFDFM are displayed in Figure 7-1. The livestock model simulates the cow-flow and manure N excretion. The waste model receives inputs from the livestock model and simulates the manure N flow through the waste handling system.

The crop models receive inputs from the waste model to simulate N leaching and biomass accumulation in the crop fields. The livestock, waste, and crop models run in parallel dynamically in monthly steps. Each one of them is a function of a set of management practices.

Crop models are additionally sensitive to climate conditions and soil characteristics. The outputs of crop simulations are measured in monthly estimations of overall N leaching and biomass accumulation in a dairy farm. An economic component goes across the livestock, waste, and crop models to estimate monthly overall profit.

The optimizer is a linear programming model that solves a matrix built with outputs of several simulations. The optimizer changes management scenarios and controls multiples simulation runs. The optimizer that is an automated tool that triggers the linear programming modeling, minimizes N leaching or maximizes profit under a set of restrictions.

Suggested management strategies by the optimizer can be compared with feasible farm practices in consultation with the farm manager to find the feasible adjustments in each particular case in an iterative process of changing input managements and re-run the simulation.

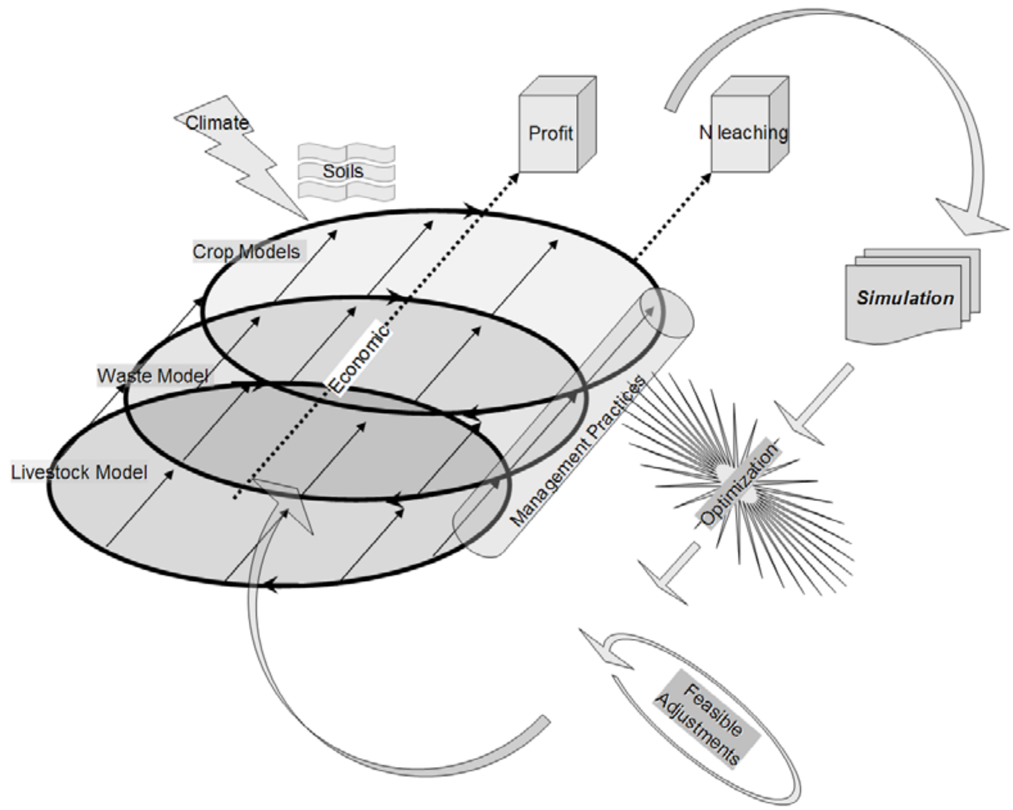


Figure 7-1. Representation of the dynamic north-Florida dairy farm model

Following are the specifics of each one of the DNFDFM components regarding model creation and implementation. For more details other chapters can be also reviewed. Chapter 1 deals with overall characteristics of models, the north-Florida dairy farm characteristics, and the conceptual theory in the modeling. Chapter 5 describes in detail the parameterizations of the livestock and waste models. Chapter 6 is comprehensive in the simulation of forage systems using crop models.

7.3.3 The Livestock Model

The livestock model simulates the cow-flow (C_{ijk}); milk production (Mk); water consumed (Wc); manure excreted in concentrated areas (Mc), in pasture (Mp), and in the waste system (Mw); and N excreted in concentrated areas (Nc), in pasture (Np), and in the waste system (Nw) (Figure 7-2). Additionally, the livestock model estimates the dry matter intake (DMI) and the N inputted in the feed (Nf). Required inputs as initial conditions are: total adult cows (TAC), total number of bulls (TNB), percent of heifers raised (PHR), rolling herd average (RHA), percent of seasonality (POS), amount of crude protein (ACP), percent of confined time (PCT), time spend in concentrated areas (TCA), maximum water usage (MWU), and the amount of water recycled (Rc).

In Table 7-1, *i* is the months in milk after delivery (1-18) for adult cows or the months of age after birth (1-32) for heifers; *j* is the pregnancy months (0-9); *k* is the lactation cycle (0-9), and *m* is the month of the year.

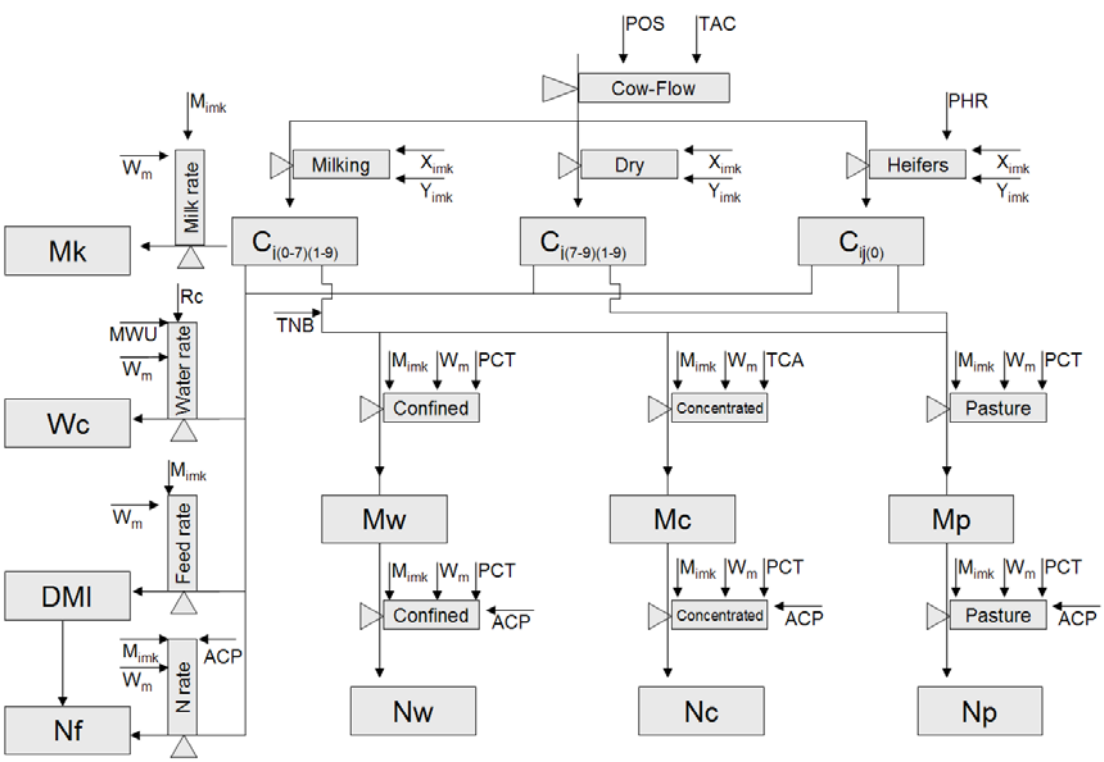


Figure 7-2. Representation of the livestock model

X_{imk}, Y_{imk}, and M_{imk} represent three dimensional matrices that include the parameterization of the culling rates, reproduction rates, and the milk production rates, respectively, according to north-Florida dairy farms conditions (De Vries, 2004). A fourth dimension common to these matrices is the seasonality level. This seasonality level goes between 0% (minimum variation of milk production throughout the year) and 100% (maximum variation of milk production in seasons of the year). By default the seasonality level is 100% because that is the way most north-Florida dairy farms operate. Milk production M_{imk} is additionally adjusted to match the inputted RHA, after the model starts to run.

Equation [7-1] simulates the cows that do not become pregnant, while equation [7-2] represents cows that become pregnant in a determined month. Equation [7-3] updates cows that were already pregnant and Equation [7-4] deals with cows that are freshening (having calves) and entering a superior lactation cycle. Every month there are cows that are involuntary culled X_{imk}, but additionally, if cows are not pregnant after 12 months in milk or heifers are not pregnant when 24 months of age, they are voluntarily culled. Milking cows are adult cows that produce milk, including cows of first lactation or higher and between 0 and 7 months pregnant, Equation [7-5]; dry cows are adult cows of first lactation or higher, between 8 and 9 months pregnant, Equation [7-6]. Heifers are young livestock that include all animals in lactation 0 plus the female off-spring that are 50% of all born. The number of heifers is adjusted by the PHR, Equation [7-7].

Milk production is estimated by the productivity rates of milking cow groups, M_{imk}, and the number of cows at each stage of productivity. Milk production is adjusted by the

Table 7-1. State variables and monthly update of the livestock model

Name	State Variable	Units	t+1	#
Cow category	C_{ijk}	Heads	$\left(C_{(i+1)jk}\right)\left(X_{imk}\right)\left(1-Y_{imk}\right)$	[7-1]
			$\left(C_{(i+1)(j+1)k}\right)\left(X_{imk}\right)\left(Y_{imk}\right)$	[7-2]
			$\left(C_{(i+1)(j+1)k}\right)\left(X_{imk}\right)\forall_{j\geq 1}$	[7-3]
			$\left(\sum_{i=11}^{32} C_{i9(k+1)}\right)\left(X_{imk}\right)\forall_{j=9}$	[7-4]
Milking cows	$C_{i(0-7)(1-9)}$	Heads	$\sum_{k=1}^{9}\sum_{j=0}^{7}\sum_{i=1}^{18} C_{ijk}$	[7-5]
Dry cows	$C_{i(7-9)(1-9)}$	Heads	$\sum_{k=1}^{9}\sum_{j=8}^{9}\sum_{i=1}^{18} C_{ijk}$	[7-6]
Heifers	$C_{ij(0)}$	Heads	$\left(\sum_{j=0}^{9}\sum_{i=1}^{32} C_{ij0}\right)\left(PHR\right)+\left(\left(\sum_{i=11}^{32} C_{i9(k+1)}\right)\left(X_{imk}\right)\forall_{j=9}\right)/2$	[7-7]
Milk	Mk	lbs month^{-1}	$\left(\sum_{k=1}^{9}\sum_{j=0}^{7}\sum_{i=1}^{18} C_{ijk}.M_{imk}\right)\left(W_m\right)$	[7-8]
Water consumption	Wc	Gallons month^{-1}	$\left(\sum_{k=1}^{9}\sum_{j=1}^{7}\sum_{i=1}^{18} C_{ijk}\right)\left(MWU\right)\left(RW_m\right)\left(Rc\right)\left(W_m\right)$	[7-9]
Dry matter intake	DMI	lbs month^{-1}	$DMI_M + DMI_D + DMI_H + DMI_B$	[7-10]
N inputted in feed	Nf	lbs month^{-1}	$Nf_M + Nf_D + Nf_H + Nf_B$	[7-11]
Manure waste system	Mw	lbs month^{-1}	$(M_M + M_B)(PCT_m)$	[7-12]
Manure conc. areas	Mc	lbs month^{-1}	$(M_M + M_B)(1-PCT_m)(TCA)$	[7-13]
Manure pasture	Mp	lbs month^{-1}	$(M_M + M_B)(1-PCT_m)(1-TCA)+M_H+M_D$	[7-14]
Nitrogen waste system	Nw	lbs month^{-1}	$(N_M + N_B)(PCT_m)$	[7-15]
Nitrogen conc. areas	Nc	lbs month^{-1}	$(N_M + N_B)(1-PCT_m)(TCA)$	[7-16]
Nitrogen pasture	Np	lbs month^{-1}	$(N_M + N_B)(1-PCT_m)(1-TCA)+N_H+N_D$	[7-17]

number of days in each month of the year W_m, including a differentiation between regular and leap years, Equation [7-8].

The livestock model requires a time for self adjustment, in which it runs in the background to find a steady state of the cow-flow and the objective inputted RHA.

Equation [7-9] estimates the monthly water usage based on the number of milking cows, the MWU, the ratio of monthly usage, RW_m, and the amount of water recycled, Rc. This is adjusted to the number of days in each month, W_m.

The dry matter intake is the sum of the independent DMI of the milking cows ($_M$), the dry cows ($_D$), the heifers ($_H$), and the bulls ($_B$) as noted in Equation [7-10]. The specifics can be seen in equations [7-17] through [7-20] in Table 7-2. Functions in Table 7-2 use book values parameterized for north-Florida conditions.

The partition of the manure in different parts of the farm is estimated using Equation [7-12] for manure that goes through the waste system, Equation [7-13] for manure deposited in concentrated areas, and Equation [7-14] for manure deposited in pastures.

Table 7-2. Dry matter intake estimations

Variable	Units	t+1	#
DMI_M	lbs month^{-1}	$\sum_{k=1}^{9}\sum_{j=0}^{7}\sum_{i=1}^{18}\left(25.2+.16(M_{imk})+3.3^{-3}(M_{imk})^2-2^{-5}(M_{imk})^3\right)(C_{ijk})(W_m)$	[7-17]
DMI_D		$\sum_{k=1}^{9}\sum_{j=8}^{9}\sum_{k=1}^{9}(25.2)(C_{ijk})(W_m)$	[7-18]
DMI_H		$\left(\sum_{j=0}^{9}\sum_{i=1}^{32}(2.7+i(0.70))(C_{ij0})\right)(PHR)(W_m)$	[7-19]
DMI_B		$(25.2)(B)(W_m)$	[7-20]

Notice that manure from milking cows and bulls ($_{M,\ B}$) can be deposited in any of these compartments, however manure from heifers and dry cows ($_{H,\ D}$) is only deposited in pastures.

The PCT can be constant across months or can be inputted as a function of the month of the year (PCT_m). The functions of waste excretion by different group of cows can be observed in Equations [7-21] through [7-24] in Table 7-3, which are based on book values and milk production levels.

Table 7-3. Manure excretion estimations

Variable	Units	t+1	#
M_M	lbs month^{-1}	$\left(\sum_{k=1}^{9}\sum_{j=0}^{7}\sum_{i=1}^{18}\left(98.75+1.37(M_{imk})+.05(M_{imk})^2-3^{-3}(M_{imk})^3\right)(C_{ijk})(W_m)\right)$	[7-21]
M_D		$\left(\sum_{k=1}^{9}\sum_{j=8}^{9}\sum_{i=1}^{18}(80)(C_{ijk})(W_m)\right)$	[7-22]
M_H		$\left(\left(\sum_{j=0}^{9}\sum_{i=1}^{32}(76.5+i(3.4))(C_{ij0})\right)(PHR)(W_m)\right)$	[7-23]
M_B		$(80)(B)(W_m)$	[7-24]

The excretion of N in different parts of the farm is estimated using Equations [7-15] through [7-17] in Table 7-1 and the specifics are detailed in Equations [7-25] through [7-28] in Table 7-4. The partition of N excreted that goes to the waste system is expressed in Equation [7-15], the N excreted that goes to the concentrated areas is shown in Equation [7-16], and the N excreted in pastures is accounted for by Equation [7-17]. Following the same pathway as the manure, N manure from milking cows and bulls ($_{M,\ B}$) can be deposited in any of these compartments, however N manure from heifers and dry cows ($_{H,\ D}$) is only deposited in pastures. Functions shown in Equations [7-25], [7-26], [7-27], and [7-28] are based on book values for Florida and parameterizations of N excreted based on milk production.

The N inputted in the feed, Equation [7-11], is estimated similarly as the sum of specific functions of animal groups represented in equations [7-25] to [7-28] in Table 7-4, but in this case each one divided by the constant of undigested N in feed of 0.67 (Van Horn et al., 1998).

Table 7-4. Nitrogen excretion estimations

Variable	Units	t+1	#
N_M		$\left(\sum_{k=1}^{9}\sum_{j=0}^{7}\sum_{i=1}^{18}\left(.36+2.4^{-3}(M_{imk})+6^{-5}(M_{imk})^2-3^{-7}(M_{imk})^3\right)\left(C_{ijk}\right)\left(W_m\right)\right)$	[7-25]
N_D		$\left(\sum_{k=1}^{9}\sum_{j=8}^{9}\sum_{i=1}^{18}(.36)\left(C_{ijk}\right)\left(W_m\right)\right)$	[7-26]
	lbs month^{-1}		
N_H		$\left(\left(\sum_{j=0}^{9}\sum_{i=1}^{32}\left(2.8^{-2}+i(1.2^{-2})\right)\left(C_{ij0}\right)\right)(PHR)\left(W_m\right)\right)$	[7-27]
N_B		$(.364)(B)(W_m)$	[7-28]

Additionally, the N inputted in feed (Nf), Equation [7-11] and the N excreted by the animals (Nw, Nc, Nw), Equations [7-15], [7-16], and [7-17] are corrected by a factor of the amount of crude protein in the diet “low” (13.9370%) or “high” (15.0342%) according to NRC standards by Equation [7-29] and Equation [7-30].

$$N_M = N_M + N_M\,(\text{ACP-13.9370})(.0956) \qquad [7\text{-}29]$$

$$N_D = N_D + N_D\,(\text{ ACP-13.9370})(.0956) \qquad [7\text{-}30]$$

7.3.4 The Waste Model

The waste model follows the flow of the manure N in the concentrated areas, the pasture, and the waste system after its excretion and before its utilization. Essentially, the waste model balances the manure N that reaches the crop fields after loss in different parts of the system: volatilization before flushing (VBF), solids collected (SC), volatilization in lagoon (VL), volatilization in storage pond (VP), sedimentation in sludge (SS), volatilization during irrigation (VI), and volatilization in the soil after being applied (VS). These are percentage rates required as initial conditions to be inputted before running the model.

Table 7-5. Nitrogen through waste system estimations

Variable	Units	t+1	#
Mw_f	lbs month^{-1}	$Mw \bullet SC \bullet SS$	[7-31]
Nw_f		$Mw \bullet VBF \bullet SC \bullet VL \bullet VP \bullet SS \bullet VI \bullet VS$	[7-32]
Mc_f		Mc	[7-33]
Nc_f		$Nc \bullet VS$	[7-34]
Mp_f		Mp	[7-35]
Np_f		$Np \bullet VS$	[7-36]

In Table 7-5, Equations [7-31] through [7-36] estimate the manure and manure N at the final point of utilization (*f*) for the waste system, the concentrated area, and the pastures. This model estimates the manure and manure N movement in successive steps and results in the model can be explored at any of the points of this continuous flow. Notice that the amount of manure for concentrated areas and pasture remains the same as that estimated in the livestock model.

7.3.5 The Crop Models

The crop models from the Decision Support Systems for Agricultural Transfer (DSSAT v4.0, Jones et al., 2003) use daily weather information of temperature, irradiation, and precipitation along with soil characteristics, manure effluent applied, and other management choices to estimate monthly biomass accumulation and N leaching for specific crop sequences that are common in north-Florida dairy farm systems. Dynamic, process-based crop simulation models quantify interactions between environmental physical conditions of soils and climate, genetic physiological conditions of crops, and management conditions (Boote et al., 1996) and they are being widely used to experiment with in situations when limitations of time, space, or finances do not allow a field experiment.

Crop models simulate light interception, leaf-level photosynthesis, N uptake, soil water balance, evapotranspiration, respiration, leaf area growth, growth of component parts, root growth, senescence, N mobilization, carbohydrate dynamics, and crop development processes. For the soil component, the Century model (Parton et al., 1979) implemented in the DSSAT by Gijsman et al. (2002) was used, which estimates soil N balances that include soil and surface organic matter, inorganic N, additions and removals of N, and all the processes that include the N cycle in the soil such as decomposition, mineralization, N leaching, or denitrification.

Specific data for each of the soil types were converted to the DSSAT v4.0 system using SBuild ® software (Uryasev, 2003), where the drained upper limit values were corrected using Saxton et al., (1986).

Forage crops were adapted, calibrated, and validated for north-Florida dairy farm conditions and all potential forage combinations were run for all N effluent ranges, 10 types of soils found in the study area (Table 7-6), and for 43 years of daily weather data (1956-1998). Residual organic matter from one crop to the next was accounted for as well as other management choices that are common in these systems such as extra irrigation and harvests.

Daily cumulative N leached (lbs acre^{-1}) and biomass (lbs acre^{-1}) outputs from the simulations were compiled in monthly rates for the span of the study period (1956-1998). All months were classified according to ENSO phases and the main factors incorporated in the simulations (Figure 7-3).

Table 7-6. Codification of ENSO phases, soil types, and forage systems from crop models

	e, ENSO phase
1	La Niña
2	Neutral
3	El Niño

	s, Soil Types
1	Arredondo-Gainesville-Millhopper
2	Arredondo-Jonesville-Lake
3	Bonneau-Blanton-Eunola
4	Penney-Otela
5	Penney-Kershaw
6	Millhopper-Bonneau
7	Otela-Jonesville-Seaboard
8	Blanton(high)-Lakeland
9	Blanton(low)-
10	Blanton-Ortega-Penny

	f, Forage Systems	
1	Bermudagrass	Bermudagrass
2	Corn	Sorghum
3	Millet	Corn
4	Sorghum	Corn
5	Millet	Sorghum
6	Sorghum	Millet
7	Corn	Corn
8	Corn	Millet
9	Corn	Bahiagrass
10	Corn	Bermudagrass
11	Bahiagrass	Bahiagrass

In order to couple the crop models with the livestock and waste models two matrices were created with outputs of the crop models, one for N leaching (Nl_{mesfn}) and the other for biomass accumulation (Ba_{mesfn}) (lbs acre^{-1} month^{-1}).

Each of these matrices has 5 dimensions: month of the year *m*, ENSO phase *e*, soil type *s*, forage system *f*, and manure N applied *n*. The values for *e*, *s*, and *f* are inputs (that the user enters according to his/her own farm conditions) while *m* and *n* are estimated (calculated by the by the simulation).

Coefficients of the N leaching (Nl_{mesfn}) and for biomass accumulation (Ba_{mesfn}) (lbs acre^{-1} month^{-1}) are coded according to Table 7-6 and Table 7-7.

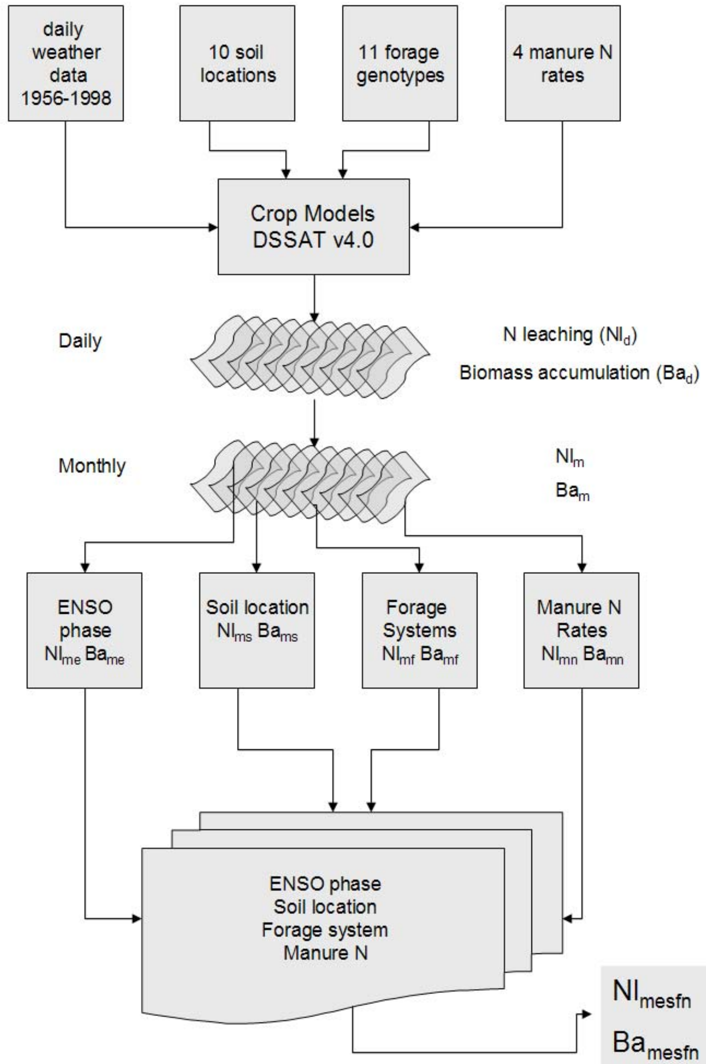


Figure 7-3. Data management of simulation of crop models

Estimations of N leaching (Nl) and biomass accumulation (Ba) are summarized in Equations [7-37] and [7-38]. Nl and Ba at the farm level are the sum of Nl or Ba in the pasture fields t plus the Nl or Ba in the sprayfields q. To estimate these in each pasture or spray field with a determined forage system f, a coefficient from the matrix Nl_{mesfn} or Ba_{mesfn} is obtained according to m, e, s, f, and n and multiplied by the area of the field, PFa_t, SFa_q, respectively.

N leaching	Nl	lbs month^{-1} farm^{-1}	$\sum_{f=1}^{F}\sum_{t=1}^{T}(Nl_{mesfn})(PFa_t)+\sum_{f=1}^{F}\sum_{q=1}^{Q}(Nl_{mesfn})(SFa_q)$	[7-37]
Biomass accumulation	Ba	lbs month^{-1} farm^{-1}	$\sum_{f=1}^{F}\sum_{t=1}^{T}(Ba_{mesfn})(PFa_t)+\sum_{f=1}^{F}\sum_{q=1}^{Q}(Ba_{mesfn})(SFa_q)$	[7-38]

For the pasture fields, a correction is performed based on the fact that these fields receive direct deposits of manure and they are not irrigated. By using local knowledge and farm registers in the area, it was estimated that the N leaching is reduced 25% and biomass accumulation 40% in pasture fields, compared to sprayfields.

The parameter *n* that represents the manure N applied to the fields that is estimated by the waste model does not necessarily match the amounts used in the experiments that were run with the crop models contained in the matrices Nl_{mesfn} and Ba_{mesfn}. They are interpolated between the points in which the crop models were run Na_n, which are coded as *n* in Table 7-7.

Equation [7-39] represents a general interpolation to find the Nl in sprayfields, which can be modified to perform the same estimations for pastures replacing Nw_f with Np_f or for Ba replacing Nl with Ba.

Table 7-7. Nitrogen applied estimated by the waste model and N applied in crop models

Nw_f or Np_f	n	Na_n
< 8.9218	1	0
8.9218-17.8436	2	8.9218
17.8436-35.6872	3	17.8436
35.6872-71.3743	4	35.6872
$\geq$ 71.3743	5	71.3743

$$\left(Nl_{mesfn}\bullet Nw_f+Na_n\bullet Nl_{mesf(n+1)}-Nw_f\bullet Nl_{mesf(n+1)}-Na_{n+1}\right)/\left(\left\langle Na_n-Nw_f\right\rangle-\left\langle Na_{n+1}-Nw_f\right\rangle\right) \quad [7\text{-}39]$$

7.3.6 The Economic Module

This module estimates the overall profit $\prod$ (US\$ month^{-1}) of the simulated farm, based on a profitability ratio of milk productivity. Table 7-8 defines the variables involved in the calculations, all of them are inputs. The profit is estimated as the difference between the revenues less the expenses, Equation [7-40].

Equations [7-41] and [7-42] that calculate the R and E include the value of the biomass (*Ba*) and N (*Nl*) as a revenue and an expense, respectively.

Table 7-8. Definition of variables in economic module (US$ cwt^{-1} milk^{-1})

Revenues	*R*
Cow Sales	*Rc*
Heifer Sales	*Rh*
Gain on purchased livestock	*Rg*
Crop sales	*Rf*
Other revenues	*Ro*
Expenses	*E*
Personnel	*Ep*
Feed purchased	*Es*
Milk marketing	*Em*
Crop expenses	*Ef*
Other expenses	*Eo*
Other Inputs	
Milk price	*Mp*
N value	*Nv* (US$ cwt^{-1})
Crop value	*Cv* (US$ cwt^{-1})

$$\prod = R - E \qquad [7\text{-}40]$$

$$R = Mk \bullet Mp + Rc + Rh + Rg + Rf + Ro + Cv \bullet Ba \qquad [7\text{-}41]$$

$$E = Ep + Ef + Es + Em + Ef + Eo + Nv \bullet Nl \qquad [7\text{-}42]$$

The value of the milk sold as revenue is expressed as the multiplication of the milk produced Mk by its market price Mp. More than 90% of the revenue on north-Florida dairy farms comes from the milk sold; therefore the model is highly sensitive to this factor. The model can run with a *fixed* milk price $\overset{o}{Mp}$ inputted or by using a *stochastic* milk price $\overset{f}{Mp}$ that is estimated by a stochastic milk price generator included with the economic module. The stochastic function $\overset{f}{Mp}$ resembles the distribution found in monthly prices of milk in the last 10 years in north-Florida, which can be seen in Table 7-9.

The stochastic price function generates a random number r $(0 < r < 1)$ which together with the month of the year is used to predict the stochastic price $\overset{f}{Mp}$ as shown in Equation [7-43].

Table 7-9. Monthly milk prices distribution in north-Florida as cumulative probability (US\$ cwt^{-1} $milk^{-1}$)

Cumulative Probability	Jan	Feb	Mar	Apr	May	Jun		Aug	Sep	Oct	Nov	Dec
0.10	14.80	14.40	14.40	14.10	14.50	15.10	14.80	14.70	14.70	14.40	14.80	13.50
	14.90	14.80	14.80	14.30	15.10	15.20		15.10	15.10	14.90	15.70	14.70
0.30	15.20	14.90	14.80	15.00	15.30	15.40	15.00	15.40	15.20	15.20	16.00	16.00
0.40	16.30	15.60	15.70	15.00	15.30	15.70		15.60	15.30	15.50	16.00	16.20
0.50	16.40	15.90	15.80	15.60	15.40	15.80	15.70	15.60	16.10	16.10	16.20	16.20
0.60	16.50	16.20	16.30	15.60	15.50	15.80		16.20	16.70	17.30	18.00	16.40
0.70	16.70	16.30	16.50	16.20	16.20	15.80	16.10	16.30	17.90	19.30	18.70	16.60
0.80	17.00	16.90	16.60	16.30	16.50	16.80		18.30	19.40	19.80	20.00	17.90
0.90	17.40	17.70	17.30	17.00	16.70	17.40	18.30	18.90	19.80	20.20	20.10	18.90
1.00	20.30	20.30	19.30	17.00	17.70	18.40		19.00	20.00	20.30	20.70	21.30

Source: Prepared with data from Florida Agricultural Statistics Service, 2003.

$$\overset{f}{Mp} = Mp_{rm} \qquad [7\text{-}43]$$

7.3.7 The Optimization Module

The optimization process is conceptualized in Figure 7-4 and starts by selecting management options that a dairy farm potentially could change. The next step defines the levels of each management practice to be tested. A further task combines all levels of any management practice with all levels of all management practices, forming the scenarios.

The simulation module is run for each of these scenarios and monthly results of profit and N leaching are organized in a matrix and then optimized for different ENSO phases using a linear programming model.

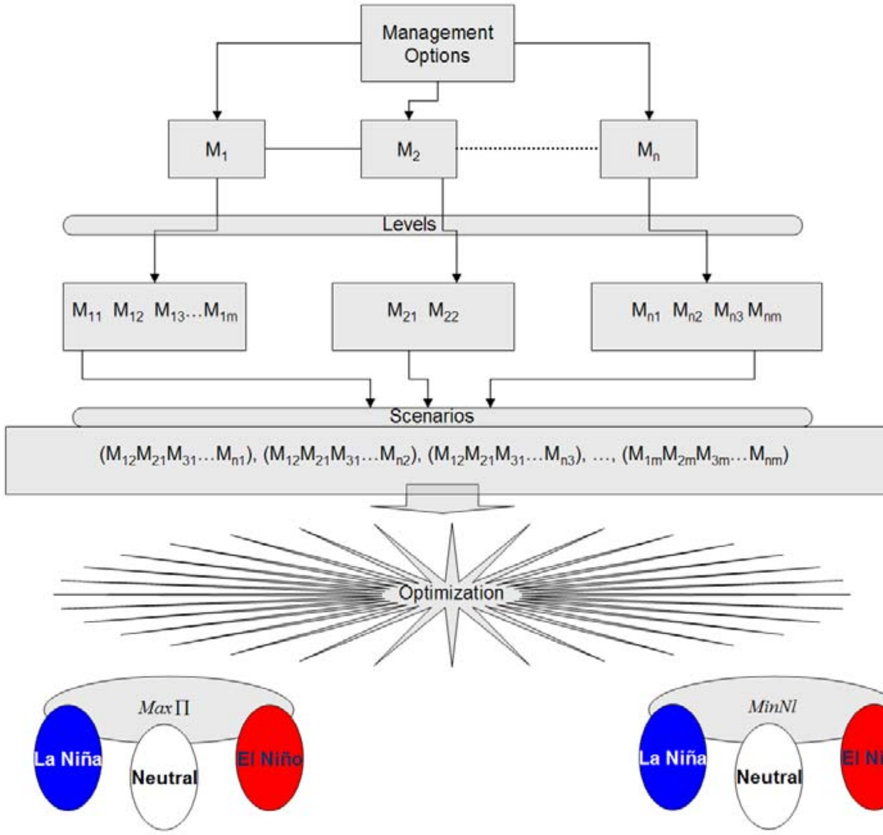


Figure 7-4. The process of optimization

The optimization module is a mathematical linear programming model that maximizes profit ($\prod$) or minimizes N leaching (Nl) of multiple scenario simulation runs s under restrictions of at most average Nl or at least average $\prod$, respectively, as seen in following Equations [7-44], [7-45] and [7-46].

$$\max,\min(\prod, Nl) = \sum_{s=1}^{S}\sum_{m=1}^{12} C_{ms} \bullet X_{ms} \quad [7\text{-}44]$$

$$\text{subject to } \sum_{m=1}^{12} X_{ms} \bullet A_{ms} \le \overline{Nl}\,, \quad \sum_{m=1}^{12} X_{ms} \bullet A_{ms} \ge \overline{\prod} \quad [7\text{-}45]$$

$$\text{and } X_{ms} \ge 0 \quad [7\text{-}46]$$

C_{ms} is the profit or the N leaching per unit of activity X_{ms} , in a month m and in a scenario s. A_{ms} are the technical coefficients obtained by the simulation of multiple scenarios. $\overline{Nl}$

and $\overline{\prod}$ are the average of all scenarios selected in the optimization process. Optimization is repeated independently for each ENSO phase: La Niña, Neutral, and El Niño years, so results and suggested practices are a function of predicted climate conditions.

The final results of the optimization process are maximum levels of profit or minimum levels of N leaching at the farm level together with the combination of scenarios suggested as management practices that the farm could implement in order to decrease N leaching and/or increase profit, under different climate forecast conditions.

7.3.8 The Feasible Adjustments Component

The feasible adjustments refer to the feasible practices a dairy farm could implement pursuing an objective (i.e., decrease N leaching). It is a user-friendly concept of taking advantage of the simulation and the optimization components of the DNFDFM. It is not automated and requires interaction with the farmer or farm manager.

After the optimization module proposes a set of management practices to minimize N leaching with a defined level of profitability, the farmer can decide which practices and their levels it would be possible to implement.

The DNFDFM simulation module is then run again, several times as needed, to find an environmental/profitable level for a farm that is superior to the current situation, by implementing only those practices that are feasible in the eyes of the farmer.

7.4 User Friendly Implementation

7.4.1 General Characteristics

The model was developed in Excel ® using embedded Visual Basic ® in order to produce a user-friendly final product for farmers, extension services, and regulatory agencies. Users only need to open a file of Excel and the model is ready to work.

Excel ® software is one of the most widely used computer programs. The DNFDFM[2] takes advantage of this fact and delivers an application that will be easier to adopt for final users as an Excel file (*xls* extension). The DNFDFM does not change any of the normal capabilities of a normal Excel software; it only locks the codes and some cell contents in order to protect the application from unintended changes, but leaves intact all the other Excel capabilities, so the users can utilize the Excel as usual when they want to make spreadsheet calculations, printouts, or take any other action along with the model.

The main components of the DNFDFM simulation package are the livestock module, the waste management handling system, the location control, the crop controls, the climate controls, the economic components, and the optimization module. For user-friendliness all modules and their connections are graphically represented in the starting spreadsheet of Excel (Figure 7-5). A button inserted in this spreadsheet triggers a user-friendly menu that guides the user through the use of the application.

This menu first appears showing a tab called "start" with a message welcoming the user to the system, briefly explaining the purpose of the application, and suggesting the help file be read before starting the runs. This welcoming tab also gives the contact information to obtain support and the date that will be used for the printouts. Both, the welcome page and the start spreadsheet have a button to trigger the help file.

The user-friendly menu (Figure 7-6) has eight tabs (top) and a common section (bottom). Besides the welcoming start tab, there are tabs for: livestock, N, soil, crop, climate, economics, and optimize; in each of which the user can navigate for reviewing,

[2] The model can be downloaded by clicking in the link: DNFDFM.xls (3.44 MB). It requires at least Windows XP and Office XP.

inputting and/or selecting specific data. The common section consists of a drop-box menu, buttons of view selection, and a button called run. The drop-box menu allows the user quickly to customize *small, medium, or large farms* to represent a typical north-Florida farm of any of these sizes; and the view buttons allow the user select between seeing graphs or numbers in real time of simulation. These global options are useful for analysis purposes when several runs are intended as is the case of optimizations, but also are useful to use as templates to begin the specific customization of each farm. The run button triggers a simulation run of the DNFDFM.

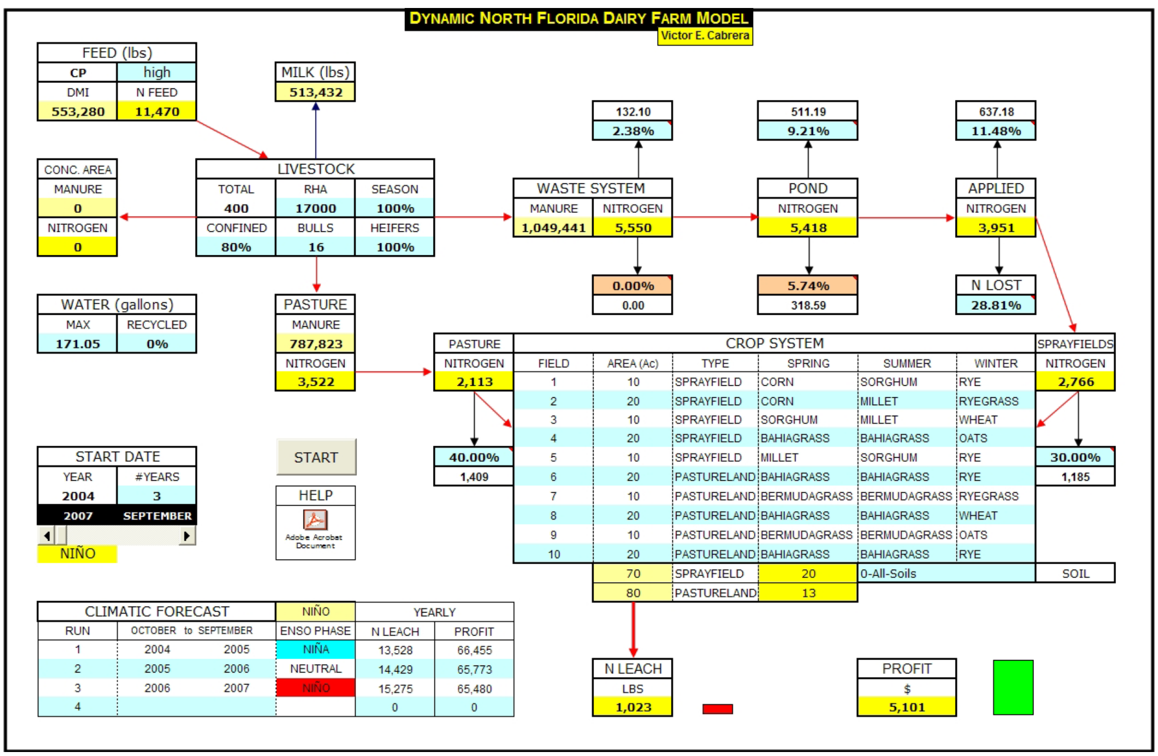


Figure 7-5. Main screen of the computer implementation of The Dynamic North-Florida Dairy Farm Model (DNFDFM)

The livestock tab deals with the cow-flow and milk production variables; the N tab is about the waste management system and water usage; the soil tab deals with the farm location and the type of soils; the crop section defines all the farm fields, their size and their crop sequences.

The climate module allow the user define the number of years of simulation together with the climatic years (El Niño, La Niña, or Neutral climatic years, according to ENSO); the economic section allows the user to personalize the revenues and expenses for specific farms; and the optimization tab can be used to define and trigger the optimization task.

Figure 7-6. The start message menu control

For all modules, there are default values to start with as a help to the user for introducing information. Additionally, there are other buttons, figures, check boxes and other objects to help the user fill in customized information.

After the initial information is inputted, the user can hit the run button and the model will start simulating; a time lag will proceed to let the model self adjust and then the results will be seen in real time by numbers and/or graphs changing in the screen. After running, the user can review the results by moving a scrollbar changing the timeline of the run. Also the user can review the database generated from the results.

7.4.2 The Livestock Module

The livestock model could represent the dynamics of the cows and the seasonality of milk production and manure N of a north-Florida dairy farm very well by only inputting the total number of adults cows and the rolling herd average; however for more customization and for other estimations the user can input other layers of information such as the total number of bulls, the percent of heifers raised on the farm, the percent of seasonality, the amount of crude protein in diet, the percent of confined time, and the percent of time milking cows spend in concentrated areas (Figure 7-7). For the confined time, there is an additional button that allows the user to enter monthly variations of confined time if desired.

The livestock module communicates directly with the feed component to retrieve information about the dry matter intake and the protein amounts and moves its outputs to the modules that handle the waste in the concentrated areas, the pasture fields, and the waste management system.

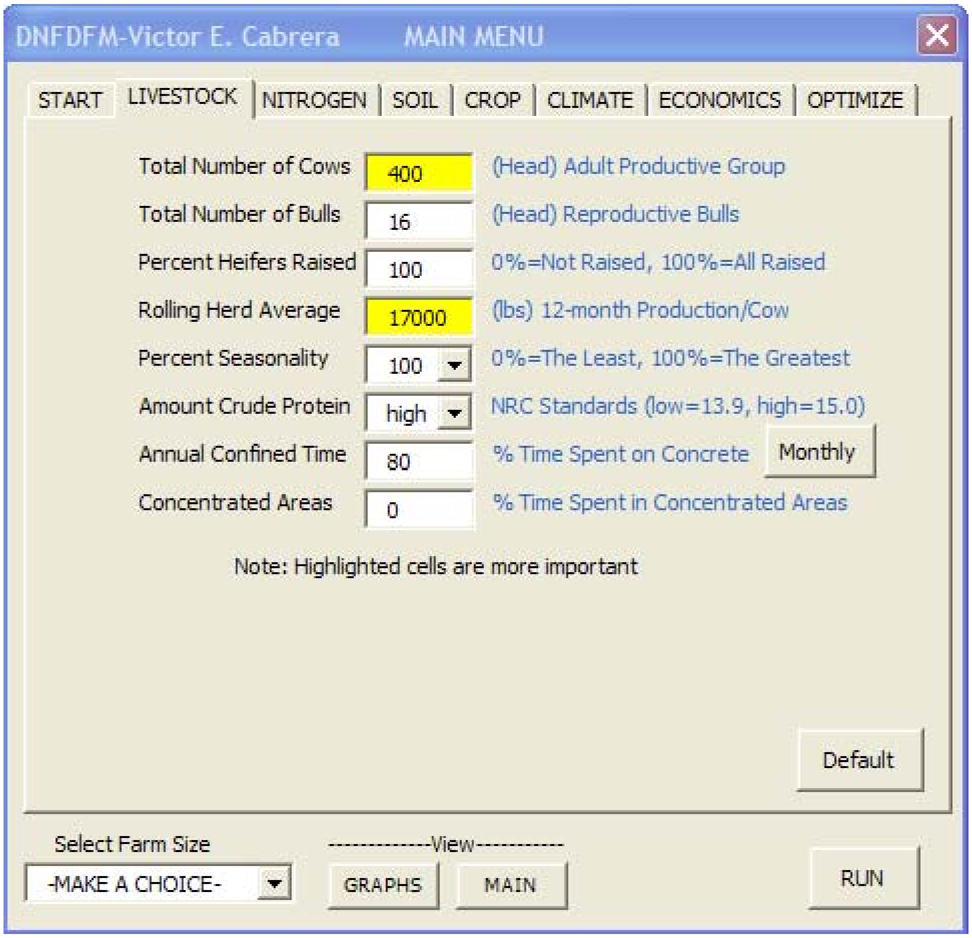


Figure 7-7. The livestock module control

7.4.3 The Waste System Module

This module allows the user to customize and define specific farm parameters about the N lost in the waste system and each one of its components and the water utilization by the farm (Figure 7-8).

Numbers vary greatly in different management systems. For example Van Horn et al. (1998) presents an average system for Florida in which there is an estimated total loss (total N lost, TNL) of 28.81% of N through the waste system with specific characteristic in all components. These values are used as default, but ultimately the users must change them to better mimic their known specific conditions.

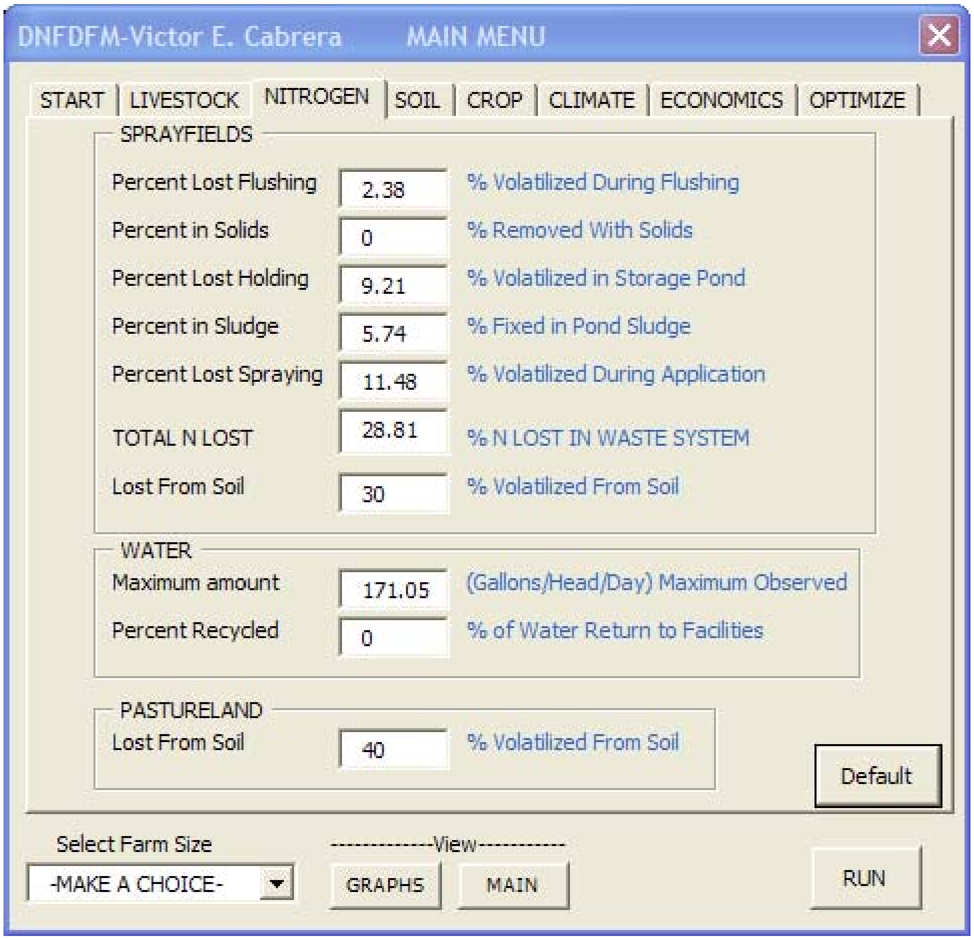


Figure 7-8. The waste management control

7.4.4 The Soil Module

In order to run the crop systems, the user first selects the location of the farm either by clicking in a map or by selecting from a menu (Figure 7-9). Through this soil control, the user locates the farm, which in turn determines the type of soils in which the forage crops will be grown. The "all soils" option means the average results across all ten different soil types.

7.4.5 The Forage Systems Module

The crop systems are defined in a user-friendly menu located in the crop tab (Figure 7-10). The forage system control allows the user to input data in up to 10 fields, which detail field size, the type of field (sprayfield or pasture), and the sequence of forage crops.

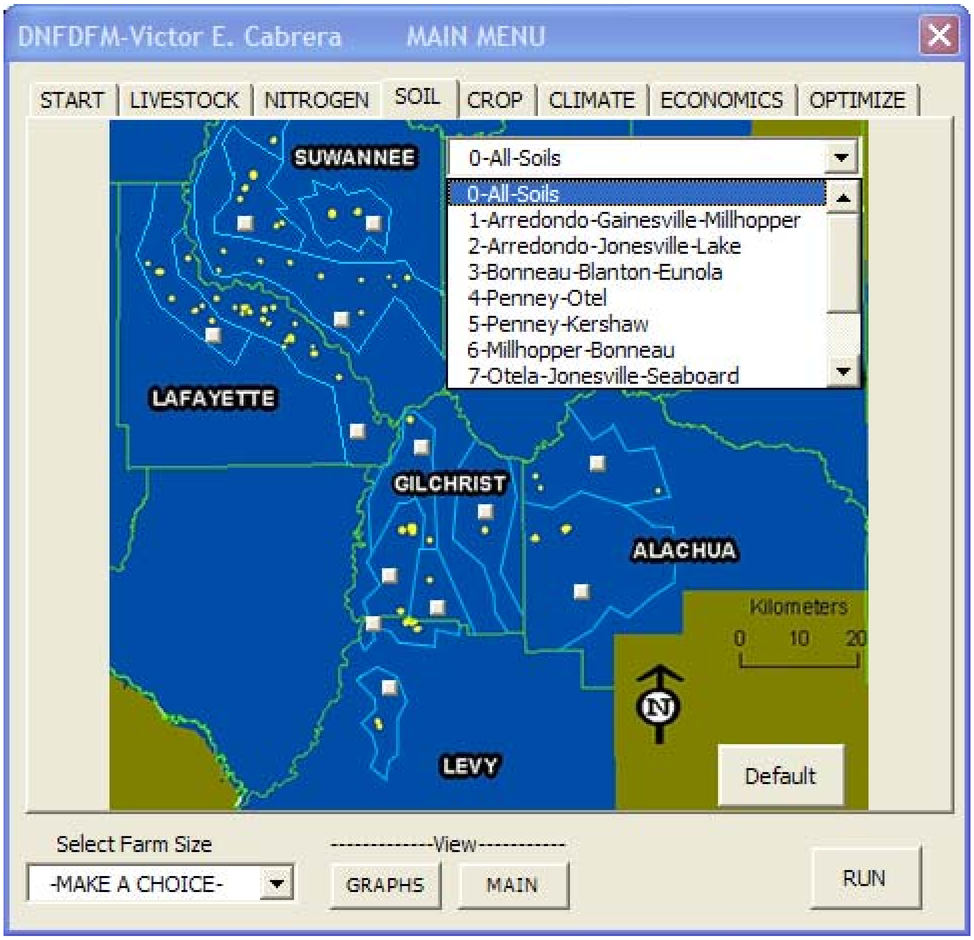


Figure 7-9. Dairy farm location and soil type by farm component control

7.4.6 The Climatic Module

The climatic module defines the forecasted climatic conditions under which the forage systems will grow. It is a user choice based on a classification of climatic years based on El Niño Southern Oscillation (ENSO) in El Niño, La Niña, and Neutral years. The climatic component allows the user to select the starting year of the simulation and run for a selected number of years, Figure 7-11. “43-yr Average” option means the average climatic conditions for 43 years (1956-1998) of crop model simulations. Graphs that describe the climatic conditions under different ENSO phases are available for the user to review after clicking a button located in this tab. After selecting the run timeline, the user can select the forecasted climatic years. The concept is to devise management options that would yield more desirable outputs according to ENSO phases.

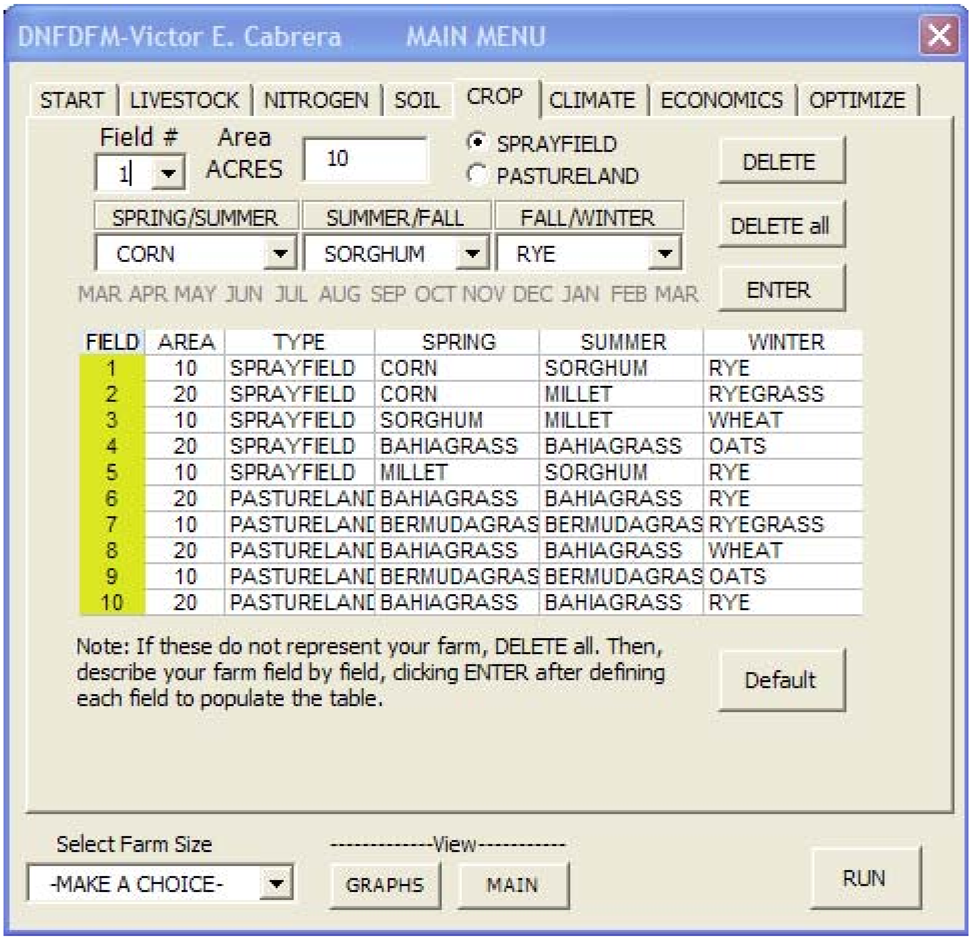


Figure 7-10. Forage systems component control

7.4.7 The Economic Module

The economic module requires current farm economic data inputted at the beginning (Figure 7-12). Profitability is estimated every month and is sensitive to the manure N recycled on-farm and the amount of biomass produced as feed inside the farm gate. This module estimates a monthly balance of revenues less expenses based on detailed information inputted by the user. As a guide for the user, it shows at the beginning an average for Florida farms published by the DBAP (De Vries et al., 2000); the user must personalize these values.

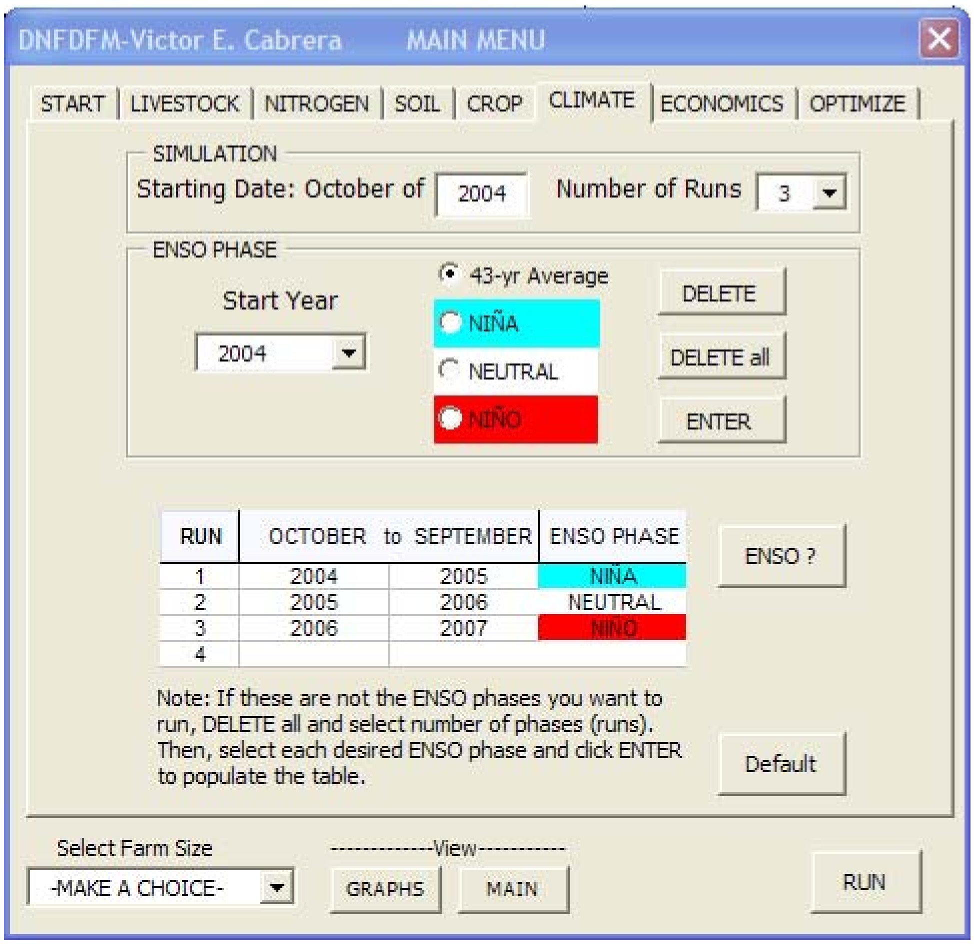


Figure 7-11. The climatic component control

The user has the option to fix or use stochastic milk prices. The stochastic milk price is a monthly random function based on 10 years of information (1993-2002); a graph that describes these monthly distributions is available for the user to review by hitting a button located together with the stochastic choice, and is shown in Figure 7-13. Additionally, the economic menu has the option of inputting the estimated value of N as fertilizer and the value of the dry matter produced on the farm.

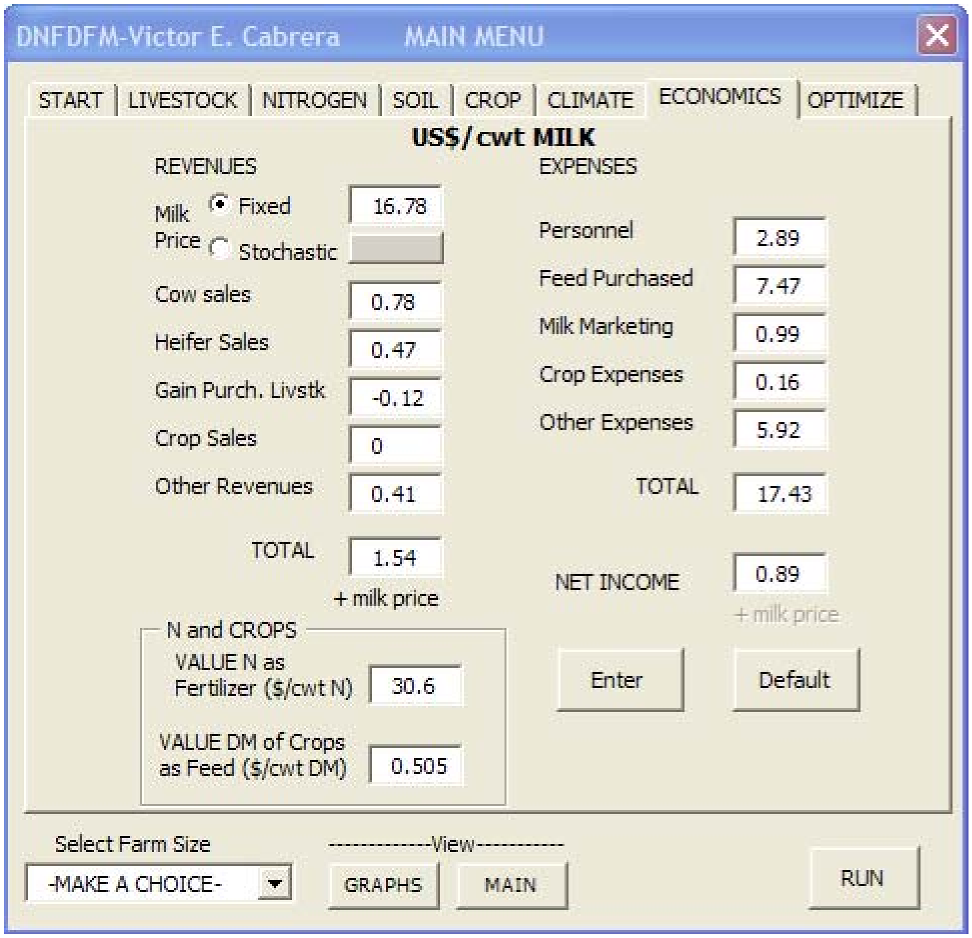


Figure 7-12. The economic component control

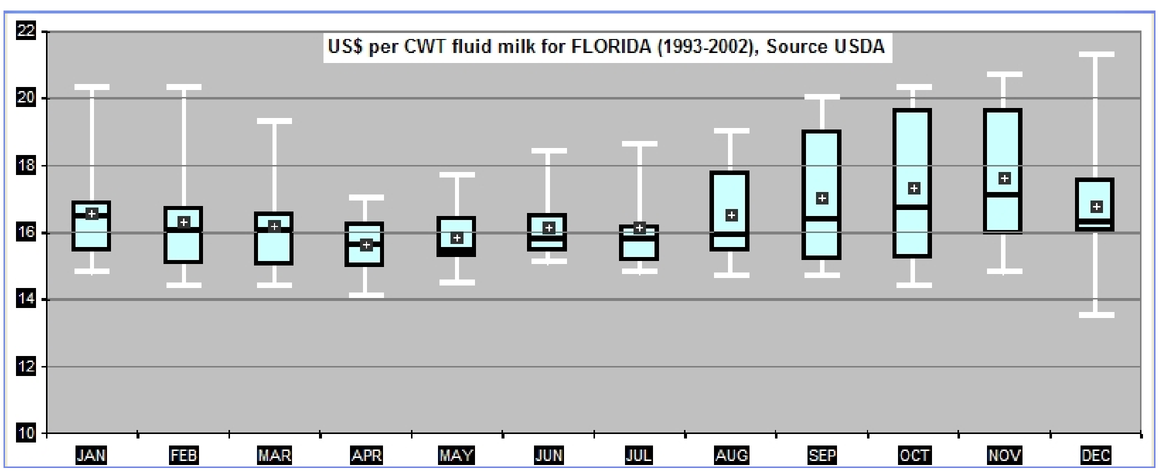


Figure 7-13. Distribution of milk prices in north-Florida

7.4.8 The Optimization Module

The optimization function is triggered by a button called optimization located in the tab called optimize (Figure 7-14).

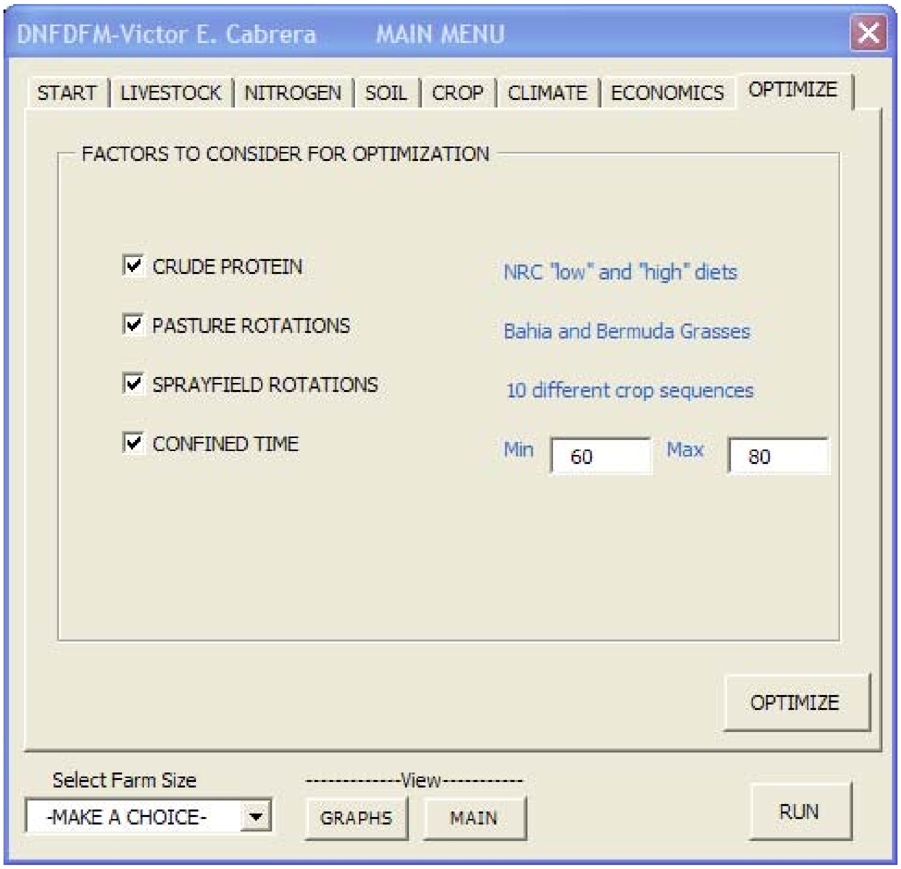


Figure 7-14. The optimization control

The optimization module builds and solves a linear programming matrix with the monthly results of N leaching along with the profitability of several runs. When finished, it shows N leaching minimized for average levels of profit. Results are presented comparing N leaching and profitability by current practices and by optimum practices and the suggested changes in order to reach these levels.

7.5 Results for Synthesized Farms

7.5.1 Synthesized Small Dairy Operation

This farm has 400 adult cows, 16 bulls, and raises 100% of its heifers. The rolling herd average is 17,000 lbs yr^{-1}, the milk production is 100% seasonal, and the amount of crude protein in the diet is "high." The milking cows spend 80% of their time confined. The total N lost through the waste management system is 28.81% and it is estimated that there is an extra 30% N volatilized from the soil when applied; the volatilization by direct deposition in soils is estimated at 40%. The small dairy farm has 70 acres of sprayfields and 80 acres of pasture fields with diverse crops as indicated in Table 7-10.

Table 7-10. Crops in different fields

Field	Area (Ac)	Type	Spring	Summer	Winter
1	10	SPRAYFIELD	CORN	SORGHUM	RYE
2	20	SPRAYFIELD	CORN	MILLET	RYEGRASS
3	10	SPRAYFIELD	SORGHUM	MILLET	WHEAT
4	20	SPRAYFIELD	BAHIAGRASS	BAHIAGRASS	OATS
5	10	SPRAYFIELD	MILLET	SORGHUM	RYE
6	20	PASTURELAND	BAHIAGRASS	BAHIAGRASS	RYE
7	10	PASTURELAND	BERMUDAGRASS	BERMUDAGRASS	RYEGRASS
8	20	PASTURELAND	BAHIAGRASS	BAHIAGRASS	WHEAT
9	10	PASTURELAND	BERMUDAGRASS	BERMUDAGRASS	OATS
10	20	PASTURELAND	BAHIAGRASS	BAHIAGRASS	RYE

The DNFDFM simulation was run for the above conditions, using the average soil type and the overall net income at 0.89 US$ cwt^{-1} milk $produced^{-1}$. The simulation started in October 2004 and followed three consecutive years with 2004/2005 being a La Niña year, 2005/2006 a Neutral year, and 2006/2007 an El Niño year.

Results contained in Figure 7-15 indicate that the overall N leaching in a year would be the lowest for La Niña years (13,528 lbs or 90.2 lbs per acre), followed by Neutral years (7% higher) and by El Niño years (13% higher).

On a monthly basis, the N leaching varies from 150 lbs in April for La Niña years to 6,033 lbs in January for El Niño years with January and February the months with the highest leaching rates (Figure 7-15A). Accumulated biomass increases, as expected, towards the summer months (Figure 7-15B) when higher temperatures and rainfall determine greater plant growth, and profitability is highest between the months of April to July (maximum in May for La Niña years) because the higher N recycled and/or higher biomass accumulation.

Figure 7-16 shows the N leaching and profit variability on a yearly basis for different ENSO phases. Always the overall N leaching is greater in El Niño years than Neutral years and Neutral years will present more leaching than La Niña years. The profitability is inversely related to the N leaching, La Niña years have the highest profitability and El Niño years present the lowest (Fig. 7-16).

7.5.2 Synthesized Medium Dairy Operation

This farm has 800 adult cows, 30 bulls, and raises 100% of its heifers. The rolling herd average is 19,000 lbs yr^{-1}, the milk production is 100% seasonal, the amount of crude protein in the diet is “high” and the milking cows spend 80% of their time confined. The total N lost through the waste management system is 35.31% and it is estimated that there is an extra 30% N volatilized from the soil when applied; the volatilization by direct deposition on soils is estimated in 40%.

The medium dairy farm has 163 acres of sprayfields and 150 acres of pasture with the same crop combinations and the same proportions as indicated in Table 7-10. This arrangement was run under the same soils and profitability conditions of the previous Small farm.

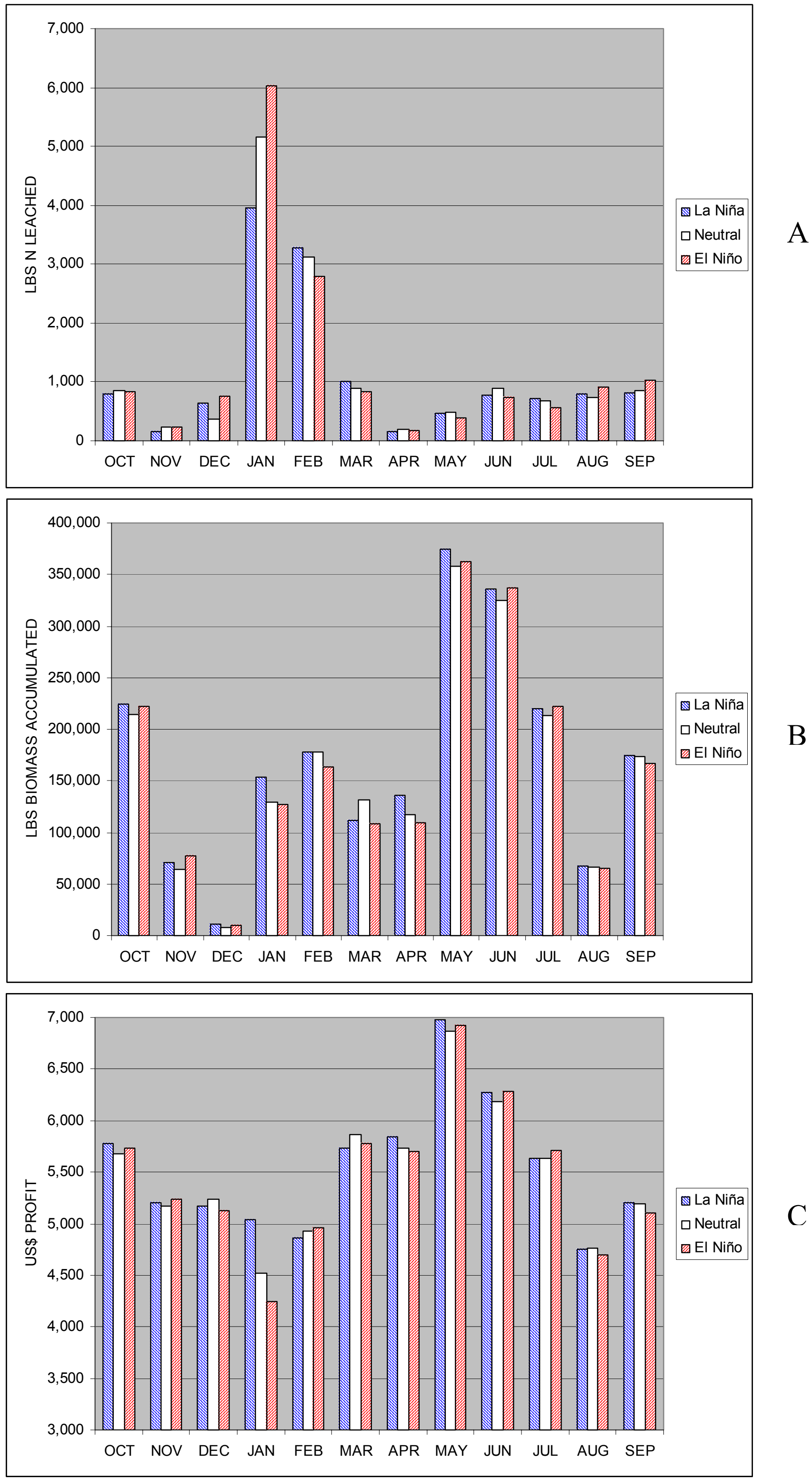


Figure 7-15. Monthly estimations for Synthesized Small north-Florida farm. A) N leaching. B) Biomass accumulation. C) profit.

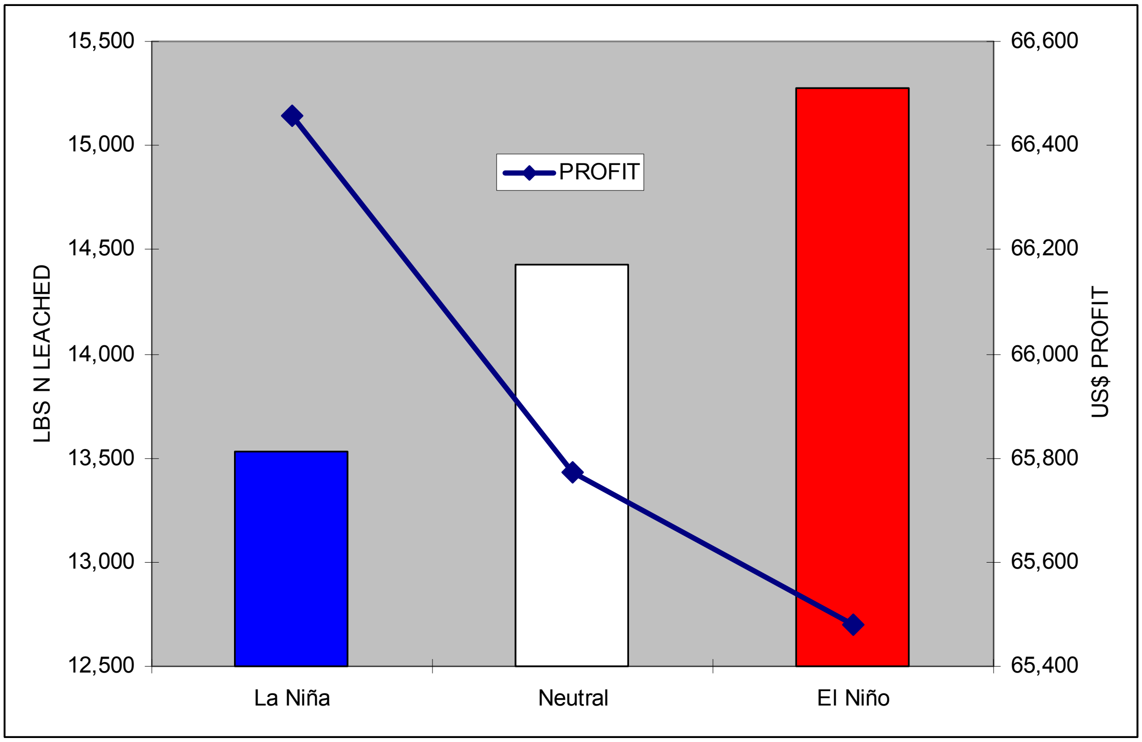


Figure 7-16. Small north-Florida farm, yearly estimated N leaching and profit

Results for the different ENSO phases on a yearly basis are presented in Figure 7-17. Overall N leaching varied from 25,096 to 28,389 lbs yr^{-1} for La Niña and El Niño years, respectively.

7.5.3 Synthesized Large Dairy Operation

This farm has 3,000 adult cows, 120 bulls, and raises 100% of its heifers. The rolling herd average is 20,000 lbs yr^{-1}, the milk production is 100% seasonal, the amount of crude protein in the diet is “high” (NRC standard), and the milking cows spend 80% of their time confined.

The total N lost through the waste management system is 40% and it is estimated that there is an extra 30% N volatilized from soil when applied; the volatilization by direct deposition in soils is estimated at 40%.

The large dairy farm has 642 acres of sprayfields and 1090 acres of pasture with the same crop combinations and the same proportions as indicated in Table 7-10. This arrangement was run under the same conditions of the previous small and medium farms of soils and profitability.

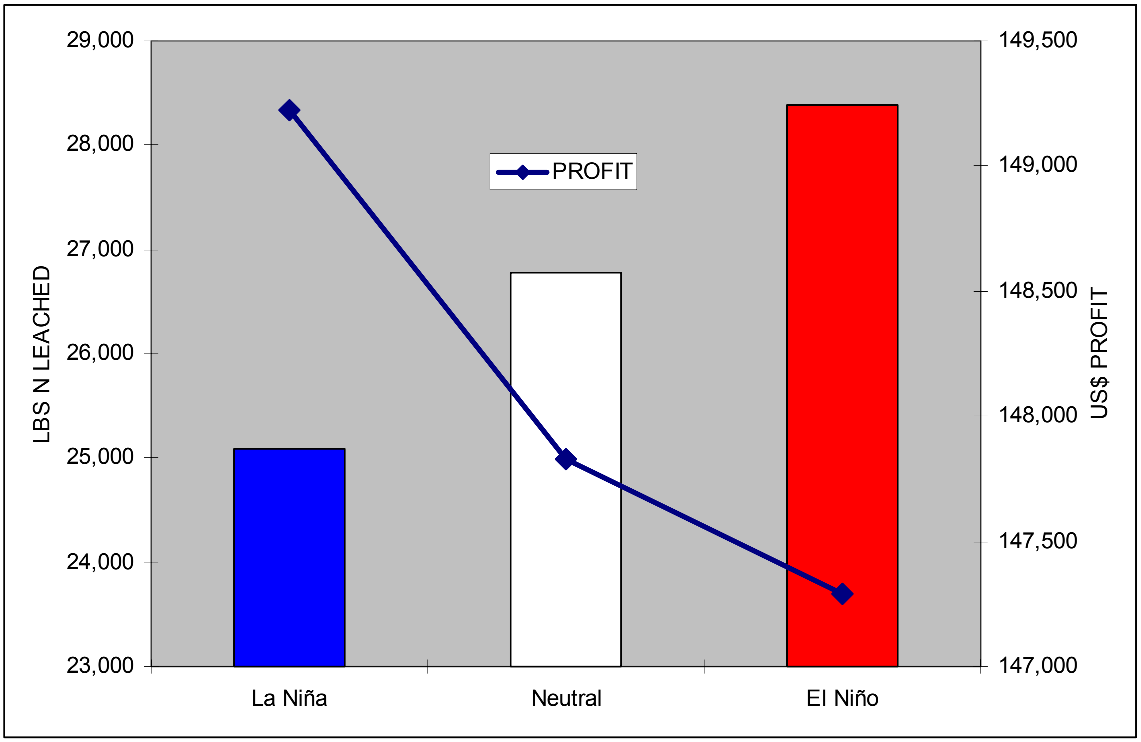


Figure 7-17. Medium north-Florida farm, yearly estimated N leaching and profit

Results for different ENSO phases regarding N leaching and profitability are shown in Figure 7-18 The N leaching is estimated in 81,741 lbs yr^{-1} and the profitability is estimated as US$ 597,397 for a Neutral year.

7.5.4 Comparison of the Three Synthesized Farms

It is important to understand that dairy farms in north-Florida are highly variable and a comparison of them is only an indication of their potential impacts with these synthesized farms; the estimations should be conducted on a specific farm basis. Also, the comparison should be performed on a whole-dairy-farm basis, since they must be accountable for their total impacts rather than per acre or per head of livestock; however having these estimations as well as the absolute values are believed to be illustrative.

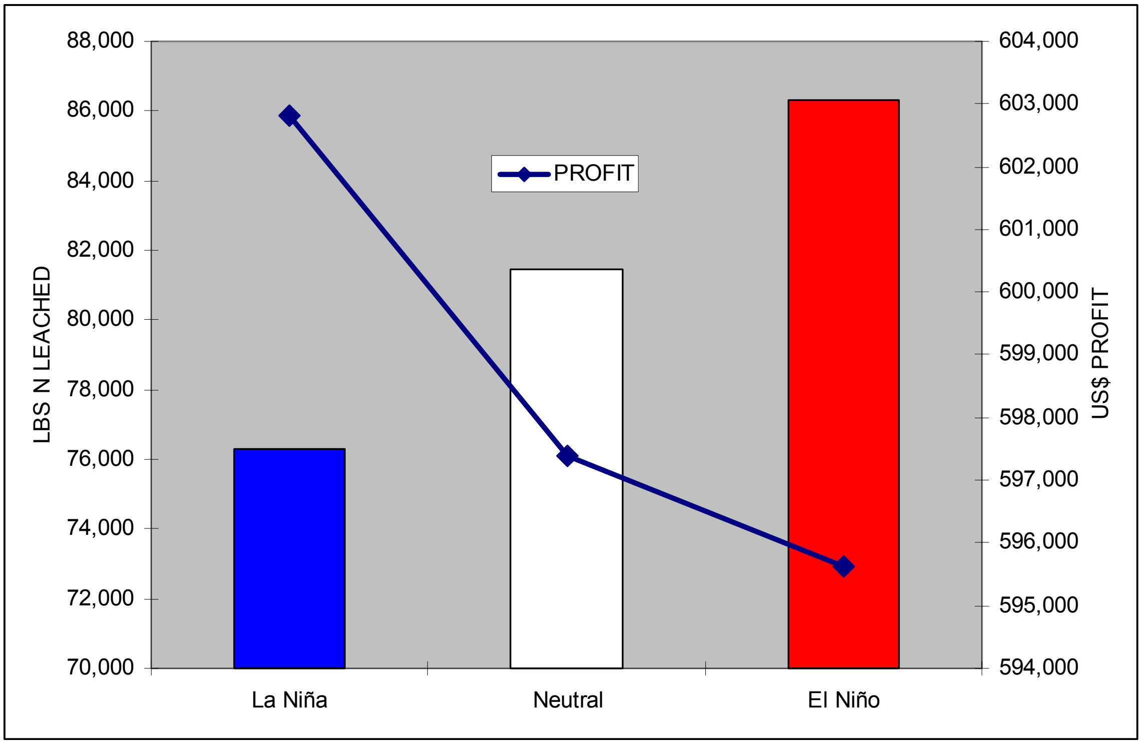


Figure 7-18. Large north-Florida farm, yearly estimated N leaching and profit

Table 7-11 presents the main management differences among the 3 synthesized farms, the cow/land ratios, and the N leached estimated for the overall farm and the ratios of N leached per cow and per acre of land.

The overall environmental impact from N leaching of a large farm is much higher (~80,000 lbs yr^{-1}) than the medium (~26,000 lbs yr^{-1}), and the medium than the small farm (~14,000 lbs yr^{-1}) (Figure 7-19). Because the crop rotations were held proportionally equivalent in the three farms, the ENSO impacts are proportionally similar in the three, with the N leaching highest in El Niño years and lowest in La Niña years.

From Table 7-11, the number of head per unit of land is higher on the small farm and lower on the large farm and because of this, the amounts of N leaching when measured per unit of area or per unit of animal are higher for the small farm than the large farm; it is estimated that a cow in the small farm would leach ~36 lbs N yr^{-1} while a cow in the large farm would leach ~27 lbs N yr^{-1}. When the comparison is switched to N leached per acre, the differences are even more pronounced, the estimated N leached per acre in the small farm is ~96 lbs N yr^{-1}while this estimation is ~47 lbs N $yr^{-1}$for the large farm.

Table 7-11. Comparison of three synthesized north-Florida farms and their estimated annual N leaching

			Small	Medium	Large
	TAC	head	400	800	3000
	BULLS	head	16	30	120
	RHA	lbs yr^{-1}	17,000	19,000	20,000
	Total N Lost Waste System (TNL)	percent	28.81	35.31	40
	SPRAYFIELDS	acre	70	163	642
	PASTURE	acre	80	150	1090
	TOTAL LAND AREA	acre	150	313	1732
	COWS PER ACRE SPRAYFIELDS	head	5.71	4.91	4.67
	COWS PER ACRE PASTURE	head	5.00	5.33	2.75
	TOTAL COWS PER ACRE	head	2.67	2.56	1.73
La Niña	TOTAL N LEACHED	lbs	13,528	25,096	76,318
Neutral		lbs	14,429	26,774	81,471
El Niño		lbs	15,275	28,389	86,319
La Niña	N LEACHED PER COW	lbs	33.82	31.37	25.44
Neutral		lbs	36.07	33.47	27.16
El Niño		lbs	38.19	35.49	28.77
La Niña	N LEACHED PER ACRE SPRAYFIELD	lbs	193.25	153.96	118.88
Neutral		lbs	206.13	164.26	126.90
El Niño		lbs	218.21	174.16	134.45
La Niña	N LEACHED PER ACRE PASTURE	lbs	169.09	167.31	70.02
Neutral		lbs	180.36	178.49	74.74
El Niño		lbs	190.94	189.26	79.19
La Niña	N LEACHED PER ACRE OF TOTAL LAND	lbs	90.18	80.18	44.06
Neutral		lbs	96.19	85.54	47.04
El Niño		lbs	101.83	90.70	49.84

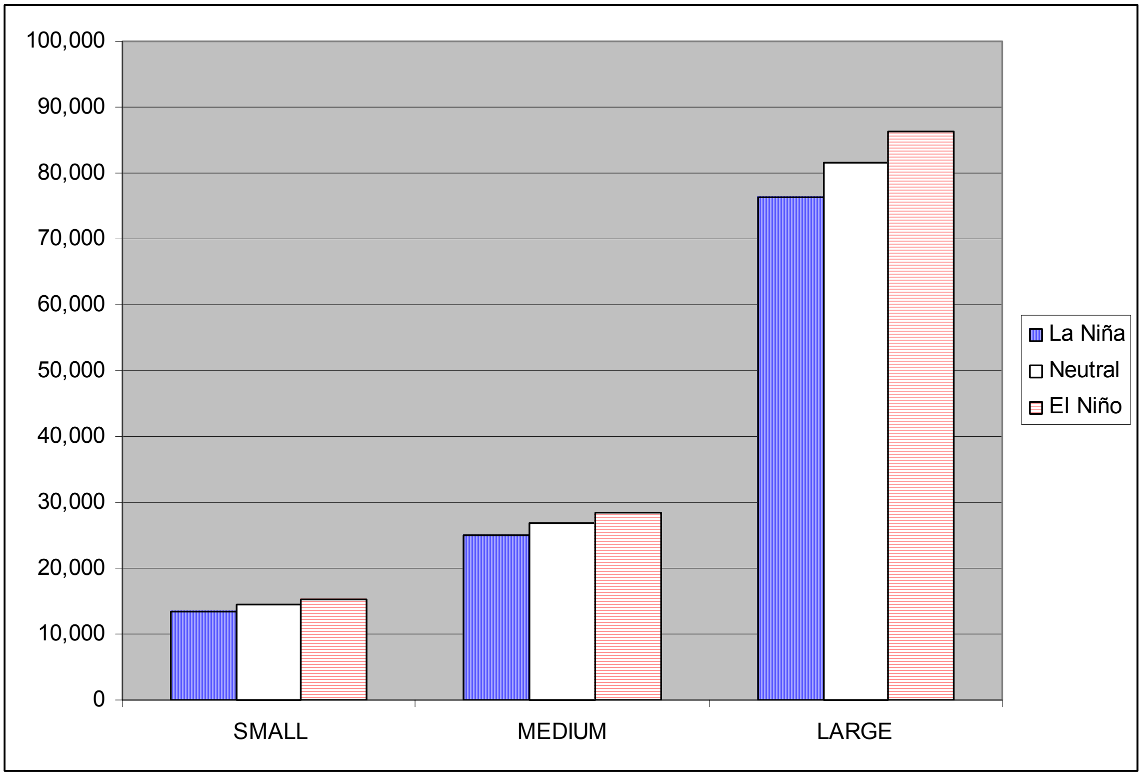


Figure 7-19. Overall N leaching from the synthesized farms

7.6 Conclusions

The present study demonstrates the feasibility of integrating complex models in a user-friendly application in an interdisciplinary approach that includes socio-economic, bio-physical, and environmental components, the Dynamic North-Florida Dairy Farm Model (DNFDFM). The DNFDFM is capable of assessing N leaching from dairy farm systems and the economic impacts of reducing it, with minimum data inputs through the use of simple commands. Different from previous approaches, the DNFDFM estimates seasonal annual and inter-annual climatic variations responding to environmental and managerial dairy characteristics and can be used to study the economic and ecologic sustainability of dairy farms in north-Florida. Specifically, the DNFDFM is a decision support system that includes livestock, waste system, crop models, economic, climatic, soil, and optimization components.

This paper describes all the DNFDFM components, the details among their interactions, and the specific equations that define their dynamic simulation.

From running the simulation part of the DNFDFM for 3 synthesized north-Florida dairy farms, it was found that great differences exist among systems regarding environmental impacts and profitability. Across all of them, higher N leaching occurs in El Niño than Neutral and in Neutral more than La Niña years; the N leaching varies between 13,000 and 86,000 lbs N $year^{-1}$ $farm^{-1}$, 25 and 33 lbs N $year^{-1}$ cow^{-1}, and 44 and 102 lbs N $year^{-1}$ $acre^{-1}$.

Since the model and all its components are well documented and are based on previous models created and/or used by regulatory agencies in Florida, the DNFDFM could serve as an environmental accountability tool for farmers and regulatory agencies as well as an educational tool for Extension.

CHAPTER 8
ECONOMIC AND ECOLOGIC IMPACTS OF NORTH FLORIDA DAIRY FARM SYSTEMS: TAILORING MITIGATION OF NITROGEN POLLUTION

8.1 Introduction

The presence of high levels of N in water is an environmental hazard because it affects human health and ecosystem welfare (Fraisse et al., 1996). The Suwannee River Basin has received much attention in recent years because increased N levels in water bodies (Albert, 2002; Katz et al., 1999; Pitman et al., 1997) and dairies have been identified as an important source of nitrates in the Basin (Andrew, 1994; Katz and DeHan, 1996; Berndt, 1998).

It is critical to keep individual dairy farms environmentally accountable (Ondersteijn et al., 2002), to distinguish between non-point and point sources of pollution (Andrew, 1992), and to test management options that may decrease environmental impacts of dairy farms (Suwannee River Partnership, 2003). The objective of this paper is twofold

- Present and discuss the ecologic and economic impacts of the north-Florida dairy farm systems under different management strategies based on the results of simulating them by using the Dynamic North-Florida Dairy Farm Model (DNFDFM)

- Test combinations of management options that may decrease N leaching in specific dairy farm systems while maintaining profitability

First, a statistical analysis of the main sources of variation based on the results from simulating multiple management strategies in a Synthesized north-Florida dairy farm system is presented. Second, the sources of variation in N leaching and profitability of the Synthesized dairy farm system are graphically discussed. Third, an analysis of optimization that includes reduced N leaching and potential increased profit for the Synthesized farm is presented. And fourth, some cases of real-life applications of the DNFDFM on north-Florida dairy farms are discussed.

Any north-Florida farm is a unique production unit in several aspects. It is recommended that the DNFDFM be used separately for each specific case. Results of this paper are indicative of the usefulness of the model in practical applications.

8.2 Materials and Methods

8.2.1 Dynamic North-Florida Dairy Farm Model

The DNFDFM as described in Chapters 5 and 7 was used as a diagnostic and analytic tool to simulate N leaching and profit under existing conditions and then to optimize practices under different farm scenarios. The DNFDFM is a simple event-controlled, mechanistic, dynamic model coupled to crop and optimization models created to assess N leaching from north-Florida dairy farm systems and the economic impacts resulting from reducing it.

The DNFDFM responds to dairy-specific environmental (climate and soils) and managerial characteristics (total number of cows, milk production, crop land, crop rotations, waste system, etc.) The driver of the DNFDFM is a dynamic adaptation of the framework "balance" and/or "budgeting" of nutrients in dairy farms, commonly used in Florida: Van Horn et al. (1991, 1994, 1998, 2001); NRCS (2001).

The DNFDFM incorporates Markov-chain probabilistic simulation of cow-flows and crop simulation for historical climatic years (El Niño Southern Oscillation), over a period of 43 years (1956-1998); automated optimization of managerial options for different ENSO phases; participatory modelling; and user-friendliness.

The DNFDFM has both simulation and optimization functions. For effects of analyses, simulation refers to a dynamic run of the model for a year and optimization means the process of solving a linear programming optimization matrix built by the results of multiple simulation runs that combine chosen dairy management scenarios.

8.2.2 A Synthesized North-Florida Dairy Farm

In order to study the sources of variation in N leaching and profitability as related to managerial options in a whole north-Florida dairy farm while maintaining confidentiality of specific farms, a Synthesized farm was created using real data. This Synthesized farm combines many real characteristics of dairies in the study area for which the DNFDFM can be run to perform relevant analyses.

This farm has 400 total adult cows (TAC), 16 bulls, and raises 100% of its heifers. The rolling herd average (RHA) is 17,000 lbs cow^{-1} yr^{-1}, and milk production is 100% seasonal. The waste management system includes flushing-lagoon-spraying and has a total N loss (TNL) of 28.81%. When effluent is applied to spray fields, an estimated additional 30% of N is volatilized. When cows directly deposit manure in pastures, an estimated 40% of N is lost through volatilization before it becomes available for the crops. The farm has 70 acres of sprayfields and 80 acres of pasture divided into several fields. There is an overall net income of US$ 0.89 cwt milk^{-1} (Table 8-1).

The Synthesized farm was used for the statistical, graphical, and optimization analyses from sections 2.3, 2.4, and 2.5; while real farm operations were used for analyses in section 2.6.

8.2.3 Statistical Analyses

The DNFDFM was run for the Synthesized farm and various potential environmental and managerial options as scenarios that could impact N leaching and profitability. Scenarios were created by combinations of 10 north-Florida dairy farm soil types, three ENSO phases (La Niña, Neutral, and El Niño climatic years), two levels of confined time (CT, 80% and 60%), 2 combinations of forage sequences in pasture, 10 combinations of forage sequences in sprayfields, and 2 levels of protein in the diet (low and high) (Table 8-2).

Table 8-1. Characteristics of a Synthesized north-Florida dairy farm

TAC	head	400
Bulls	head	16
Heifers	percent	100%
RHA	lbs year^{-1}	17,000
Seasonality	percent	100%
TNL	percent	28.81%
N Volatilized Sprayfields	percent	30%
N Volatilized Pasture	percent	40%
Sprayfields	Acre	70
Pasture	Acre	80
Net Income	US$ cwt^{-1} milk	0.89

The number of combinations for these scenarios was: 12 (months) x 10 (soils) x 3 (ENSO phases) x 2 (CT) x 2 (Pasture) x 10 (Sprayfields) x 2 (CP) = 28,800. Results were measured as monthly estimations of N leaching and profit.

Statistical analyses were performed based on the 28,800 combinations by fitting mixed effects models (Litell et al., 1996) using the PROC MIXED procedure in SAS (SAS institute, 1992). All factors were analyzed as well as their interactions with a 0.05 level of significance.

8.2.4 Graphical Analyses

Graphical analysis was used to visualize and help diagnose the effects of the main factors in the trade-off of N leaching and profit. A series of graphs with selected factor levels was prepared to show the combined effects of these factors with emphasis on

ENSO climatic phases and Soil series and crop systems in sprayfields; pastures and crude protein in the diet; confined time and crude protein in the diet

Table 8-2. Combination of management strategies simulated by the DNFDFM for the statistical analysis

Soil Types	1	Arredondo-Gainesville-Millhopper
	2	Arredondo-Jonesville-Lake
	3	Bonneau-Blanton-Eunola
	4	Penney-Otela
	5	Penney-Kershaw
	6	Millhopper-Bonneau
	7	Otela-Jonesville-Seaboard
	8	Blanton(high)-Lakeland
	9	Blanton(low)
	10	Blanton-Ortega-Penny
ENSO Phases	1	La Niña
	2	Neutral
	3	El Niño
Confined Time (CT)	1	80%
	2	60%
Forages Pasture (PASTURE)	1	bahiagrass-bahiagrass-winter forage
	2	bermudagrass-bermudagrass-winter forage
Forages Sprayfields (FIELDS)	1	Bahiagrass-Bahiagrass-Winter Forage
	2	Corn-Bermudagrass-Winter Forage
	3	Corn-Bahiagrass-Winter Forage
	4	Corn-Millet-Winter Forage
	5	Corn-Corn-Winter Forage
	6	Millet-Sorghum-Winter Forage
	7	Sorghum-Corn-Winter Forage
	8	Millet-Corn-Winter Forage
	9	Corn-Sorghum-Winter Forage
	10	Bermudagrass-Bermudagrass-Winter Forage
Crude Protein (CP)	1	Low
	2	High

In order to compare complete sets of management options, data were compiled in yearly outputs regarding N leaching and profit as the total sum of the individual months from October of one year to September of the next year. The information was summarized in a database from which queries were used to retrieve specific information in order to prepare meaningful figures.

8.2.5 Optimization Analyses

This section analyzed potential management strategies the Synthesized farm might implement to decrease environmental impacts while maintaining profitability. After the farm was simulated, the optimization tool from the DNFDFM was used to minimize (maximize) N leaching (profit) in the Synthesized farm. The Synthesized farm, with an initial set of crop sequences in pastures and sprayfields, was optimized by changing crude protein (CP), confined time (CT), crop sequences in pastures, and crop sequences in sprayfields. These options were selected for the optimization because they are the practical ways north-Florida dairy farms can change their management choices in the short or medium run.

A comparison of current farm practices with practices suggested by the optimizer was performed. This comparison is designed to help the farm management decide on feasible modifications environmentally superior to the initial conditions.

This set of feasible practices was used again to simulate the farm with the DNFDFM and compare these results with those of the original farm practices.

8.2.6 Validation with Real Farms

The simulation and optimization process described above was then performed individually with three real farms in north-Florida. Each owner was visited and the process of simulation and optimization, with discussion and analysis of feasible modifications was achieved with each one of them.

Each farmer collaborated with the process by inputting detailed data on their operations to feed the model. After filling in the appropriate information, a simulation run was performed to show the performance of the model and validate the results with the reports and knowledge from the farmers. This on-site validation was crucial to gain confidence of the farmers in the performance of the model.

Once the validation was concluded, the optimization tool was explained and used to optimize each farm situation. Followed, the results of the optimization were discussed with the farmers. From this discussion, a feasible set of management choices was selected and the DNFDFM simulator was run again in order to obtain the final results.

For anonymity purposes, the results are presented in absolute numbers with only the required details on the characteristics of each one of the farms. The main objective of this section, besides validation, was to demonstrate the utility of the DNFDFM for practical applications in real-life situations.

8.3 Results and Discussion

8.3.1 Statistical Analyses

8.3.1.1 Nitrogen leaching

Results of the significance of the factors and their main interactions regarding the estimation of N leaching are presented in Table 8-3. The statistical model has an R-square equal to 0.9989 and is significant at the 0.01% probability level

There are significant differences for all main factors: soils, month of the year, ENSO phase, confined time, pasture, sprayfields, and crude protein. For example, ENSO phases and their associated climatic patterns determine significantly different amounts of N leaching.

Some interactions among factors were also statistically significant as was the case of interactions among month and ENSO phases, sprayfield rotations, soils, crude protein levels, confined time levels, and pasture rotations; interactions among pasture rotations and sprayfields rotations, crude protein levels, and confined time levels; interaction among sprayfield rotations and confined time; and interactions among month, pasture rotations, and crude protein levels. This means that there are statistically significant differences among these interaction combinations as is the case for example of month of the year and soil types, in which, the N leaching among types of soils are statistical different in each month of the year.

Table 8-3. Significance of factors and main interactions for N leaching

Source	DF	Type I SS	Mean Square	F Value	
Soil	9	287.36	31.93	111352	<.0001
Month	11	6100.83	554.62	1934266	<.0001
ENSO	2	3.48	1.74	6075	<.0001
CT	1	10.89	10.89	37966	<.0001
Pasture	1	19.11	19.11	66638	<.0001
Sprayfields	9	119.98	13.33	46492	<.0001
CP	1	26.76	26.76	93310	<.0001
Month*ENSO	22	99.32	4.51	15745	<.0001
Month*Sprayfields	99	311.10	3.14	10959	<.0001
Pasture*Sprayfields	9	0.63	0.07	243	<.0001
SOIL*Month	99	738.79	7.46	26026	<.0001
CT*Sprayfields	9	2.38	0.26	923	<.0001
Pasture*CP	1	0.00	0.00	14	0.0002
CT*Pasture	1	1.86	1.86	6485	<.0001
Month*CP	11	0.14	0.01	45	<.0001
Month*CT	11	5.00	0.45	1585	<.0001
Month*Pasture	11	24.57	2.23	7790	<.0001
Month*Pasture*CP	11	0.01	0.00	1.96	0.0281

Interactions among month of the year with sprayfield or pasture rotations for the months December, January, and February were not significant; this was because the crop rotation in winter months is the same, as explained in the model description. The potential combinations of other factors not presented in Table 8-3 were not statistically significant at the 0.05 level.

8.3.1.2 Profit

Similar statistical analyses were performed for the profit variable (Table 8-4). This model has an R-square of 0.9941 and is significant at the 0.01% probability level.

Table 8-4. Significance of factors and main interactions for profit

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Soil	9	287.36	31.93	111352	<.0001
Month	11	6100.83	554.62	1934266	<.0001
ENSO	2	3.48	1.74	6075	<.0001
CT	1	10.89	10.89	37966	<.0001
Pasture	1	19.11	19.11	66638	<.0001
Sprayfields	9	119.98	13.33	46492	<.0001
CP	1	26.76	26.76	93310	<.0001
Month*ENSO	22	99.32	4.51	15745	<.0001
Month*Sprayfields	99	311.10	3.14	10959	<.0001
Pasture*Sprayfields	9	0.63	0.07	243	<.0001
Soil*Month	99	738.79	7.46	26026	<.0001
CT*Sprayfields	9	2.38	0.26	923	<.0001
Pasture*CP	1	0.00	0.00	14	0.0002
CT*Pasture	1	1.86	1.86	6485	<.0001
Month*CP	11	0.14	0.01	45	<.0001
Month*CT	11	5.00	0.45	1585	<.0001

Significant effect exist in the estimated profit for all main factors and for the interactions among month and ENSO phases, sprayfields rotations, and soils; soil and ENSO phases and sprayfield rotations; and for the interaction among soils, months and ENSO phases. All the individual interactions shown in Table 8-4 were highly significant ($P<0.001$), with the exception of the months of December, January, and February for the sprayfield and pasture rotation interaction, again because the crop rotation in winter does not change.

8.3.2 Graphical Analyses

8.3.2.1 Soil series

Figure 8-1 illustrates N leaching and profitability for soil types in north-Florida dairy farms. Soils of type 6 (Millhopper-Bonneau) are those that leach the most N, but with a medium-low profit level. Soils of type 3 (Bonneau-Blanton-Eunola) are the second highest in N leaching and those with the lowest net return.

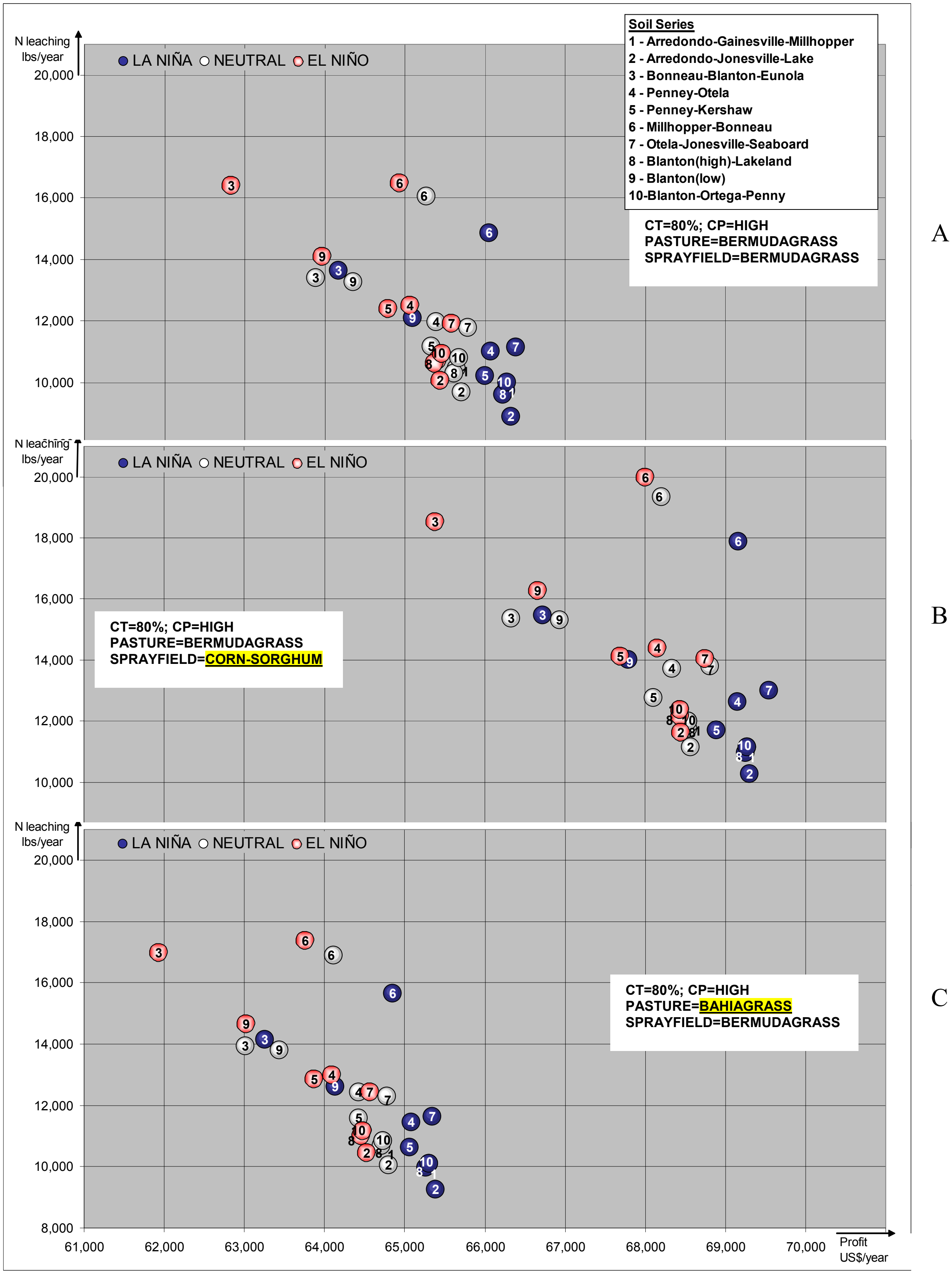


Figure 8-1. Nitrogen leaching and profit for different soil types in north-Florida: Estimations for different ENSO phases for common crop systems

These soils (6 and 3) are very sandy and with very low water holding capacity; soil type 6 is the shallowest and because of that the highest N leaching. This, however, is in certain measure favorable for plant growth and because of that the profitability is not as low as with soil type 3. On the other hand, soils of type 2 (Arredondo-Jonesville-Lake) has the least N leaching of all, followed by soils type 1, 8 and 10 (Arredondo-Gainesville-Millhopper, Blanton (high)-Lakeland, and Blanton-Ortega-Penny), which also have the greatest N uptake and biomass accumulation expressed in farm profitability.

Also in Figure 8-1 the marked differences among ENSO phases can be observed; there will always be higher N leaching and lower profitability for El Niño years than Neutral years and in Neutral years more N leaching and less profitability than La Niña years.

By exploring the circles with the same number (same soil type) in Figure 8-1, it can be noticed that there is greater difference between La Niña and Neutral years than El Niño and Neutral years, meaning that N leaching and profit are substantially superior to the normal or neutral years during La Niña years. It can also be observed that the distance among different ENSO phases (Figure 8-1 A, B, and C) varies slightly under different scenarios of changing pasture crop systems and/or crop systems in the sprayfields.

By using crop systems that include bermudagrass in spring and summer in both pastures and sprayfields, the lowest N leaching is observed (Figure 8-1A). The inclusion of a corn-sorghum rotation in the sprayfields would increase the profitability, but it would also increase N leaching (Figure 8-1B). If the change includes bahiagrass in the pasture, this would increase slightly the N leaching and decrease the profit (Figure 8-1C).

8.3.2.2 Crop systems in sprayfields

Figure 8-2 displays the relationships among 10 different crop systems in the sprayfields. Evidently, rotation 1 (bermudagrass-bermudagrass) outperforms with the least N leaching system with a medium-low profitability. It is followed by crop system 9 (corn-bermudagrass) which has medium-to-high profitability. Rotations 8 (corn-bahiagrass), 6 (corn-corn) have low-medium N leaching and medium-high profitability.

Crop system 10 that includes bahiagrass-bahiagrass has low-medium N leaching, but the lowest profitability of all. On the other hand, system 5 (millet-sorghum), followed by crop systems 7 (corn-millet), and 2 (corn-sorghum) presents the highest levels of N leaching with medium-high profit. The most profitable crop system is rotation 3 (millet-corn) that has a medium level of N leaching.

As in the previous case, higher N leaching and lower profitability are observed for El Niño, followed by Neutral years. La Niña years presents the lowest N leaching and the highest profit. Even though the differences among ENSO phases across scenarios seem to be similar, there are slight differences that are attributed to other factors such as crops in pastures and soil types (Figure 8-2 A, B, and C). It is also noticeable that the relative differences among ENSO phases vary among crop systems: i.e., there is less difference in crop system 6 between El Niño and Neutral years compared with crop systems 10 and 1.

Confirming the results from Figure 8-1, there is less N leaching with soils type 2 (Figure 8-2C), more with soils type 6 (Figure 8-2B), and medium with soils type 4 (Figure 8-2A). Additionally, bermudagrass in pasture (Figure 8-2C) results in lower N leaching than bahiagrass (Figure 8-2 A, B). With soils type 2 and bermudagrass in pastures, a slightly higher profitability is observed (Figure 8-2C).

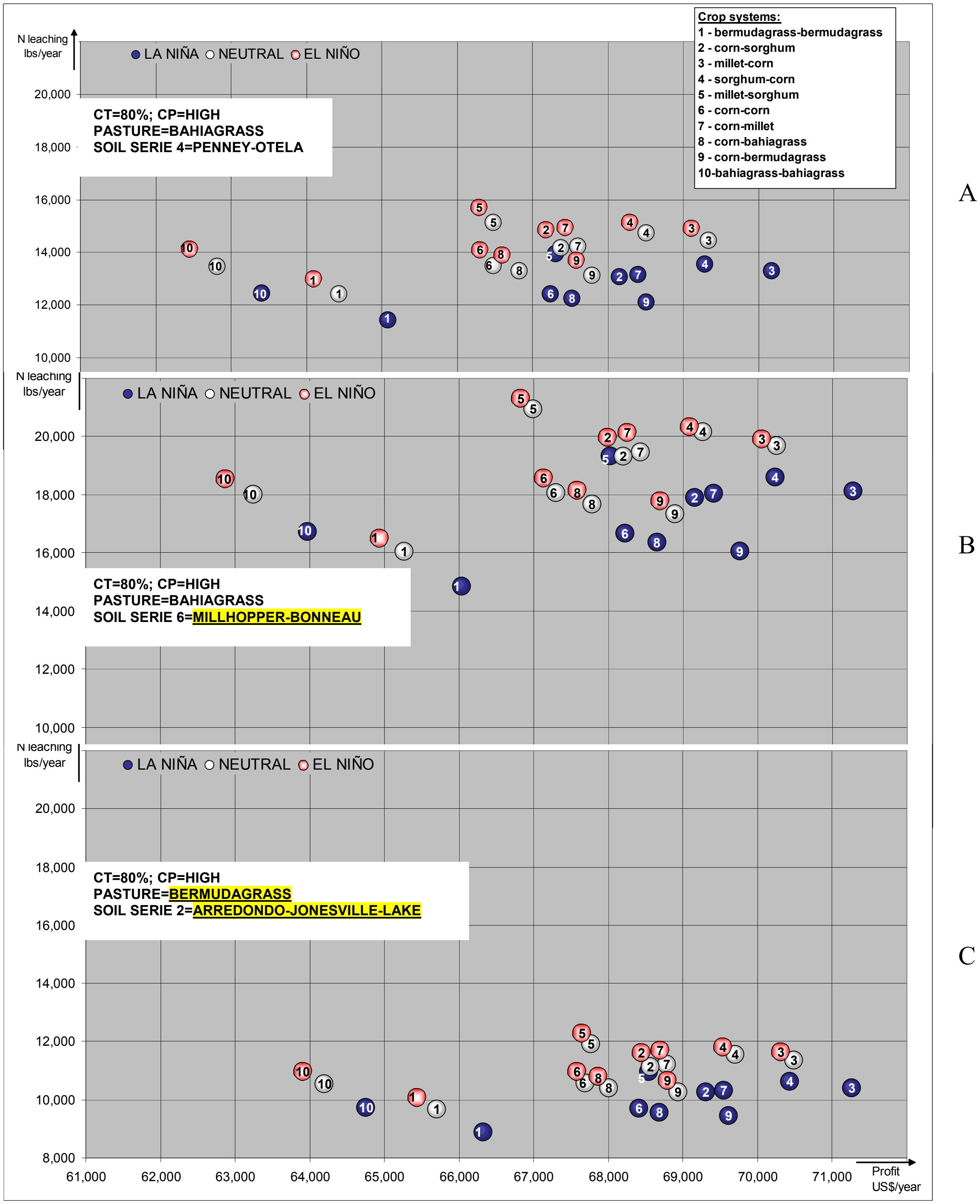


Figure 8-2. Nitrogen leaching and profit for different crop systems in north-Florida: Estimations for different ENSO phases for common pastures and soil types

8.3.2.3 Pastures and crude protein in the diet (CP)

Figure 8-3 shows four management options of the combinations of two pasture crop systems (bermudagrass and bahiagrass) and two CP choices (low and high). Consistently, option 4 (bermudagrass and low CP) has the lowest N leaching and the highest profit; conversely, option 1 (bahiagrass and high CP) has the highest N leaching and the lowest profit.

The CP in the diet has greater effect on N leaching than the pasture crop as evidenced in the fact that option 2 (bahiagrass and low CP) presents less N leaching than option 3 (bermudagrass and high CP). However the pasture crop has greater effect than the CP over profitability: option 3 results in higher profit levels than option 2. As in previous cases, the lowest N leaching and the highest profit are observed in La Niña years; Neutral and El Niño years that are closer together present higher N leaching and lower profitability.

Having bahiagrass or corn-corn in the sprayfield would leach N very similarly, with corn-corn being slightly lower (Figure 8-3 A, C); however, the profitability changes substantially with these two choices. For example, with bahiagrass the estimated profitability for option 3 in a Neutral year would be lower than US$ 63,000 while it would be more than US$ 66,000 when corn-corn is the system in the sprayfield for this Synthesized farm.

The millet-sorghum rotation in the sprayfield would leach substantially higher amounts than the other sprayfield options (bahiagrass and corn-corn) and it would present profitability slightly lower than the corn-corn rotation (Figure 8-3B).

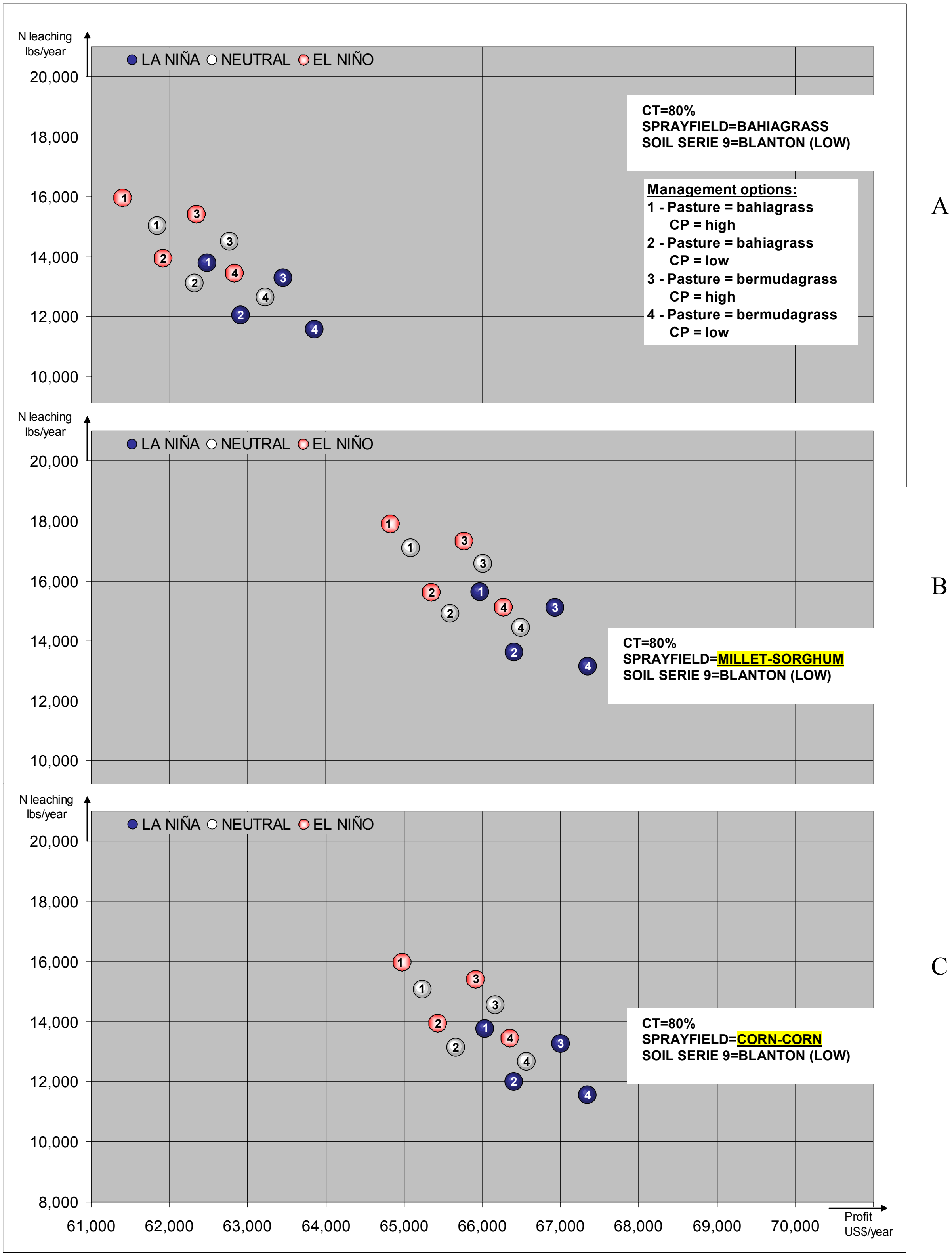


Figure 8-3. N leaching and profit for different pasture crops and crude protein in north-Florida: Estimations for different ENSO phases for common sprayfield crops and soil type

8.3.2.4 Confined time (CT) and crude protein in the diet (CP)

Figure 8-4 displays four management options of the combinations of two possible CT options (80% and 60%) and two CP choices (low and high). Option 4 (CT=60% and CP=low) leaches the least and has the second highest profit and option 1 (CT=80% and CP=high) leaches the most and has the lowest profit. The effect of the CP in the diet is higher than the 20% CT decrease (from 80 to 60%) in the N leaching because option 3 (CT=80% and CP=low) leaches less N than option 2 (CT=60% and CP=high). However, option 3 presents the highest profitability of all and option 2 has the second lowest profit.

By comparing graphs A, B, and C in Figure 8-4 it can be noticed that the lowest N leaching is for the option of having bermudagrass in the pasture and be located in a soil type 5 (Penney-Kershaw). This is closely followed by the option of changing the pasture to bahiagrass, indicating that the effect of reducing N leaching of bermudagrass over bahiagrass in the pasture is not as marked as happens in the sprayfields. The option that includes bermudagrass (Figure 8-4C) has more profit. With the same crop systems, soil type 5 shows substantially greater N leaching and decrease in profit compared with soil type 3.

N leaching is the lowest and profit is the highest when La Niña ENSO phases occur, however this is more marked for soil type 5 than soil type 3. Also, the highest N leaching and the lowest profitability in El Niño years is more marked with soil type 3 (Figure 8-4 B, C).

By exploring relative positions among points in Figure 8-4 A, B, and C, it can be observed that, depending of the management options, there are slight differences in the spatial distributions of the circles.

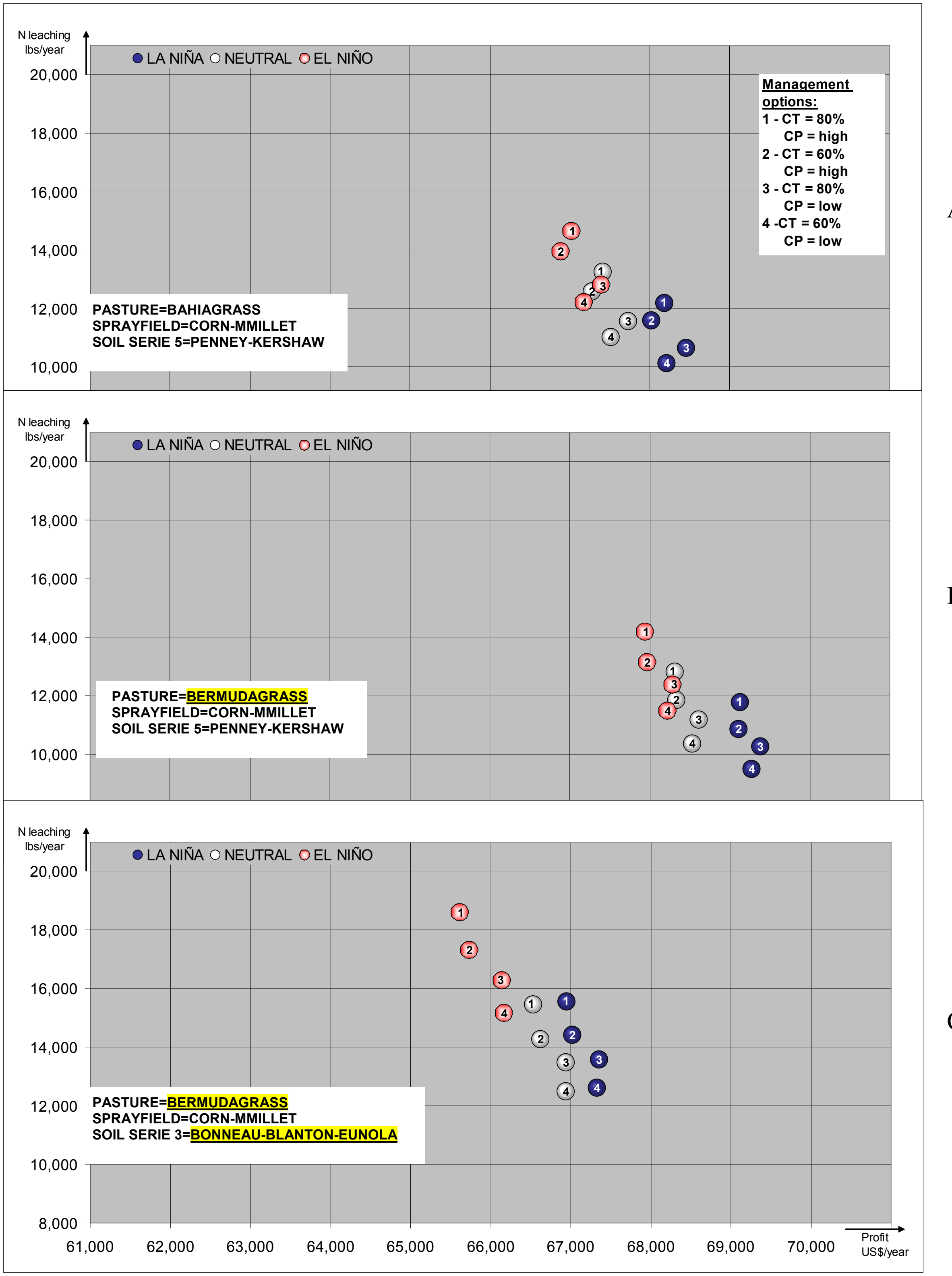


Figure 8-4. N leaching and profit for different confined time and crude protein: Estimations for different ENSO phases for common crop systems and soils

This means that the management options not only change the overall N leaching and profit, but also they have interactions with the climate, the CT and the CP. For example, management option 1 that always has the most leaching, is more different between El Niño and Neutral years and less different between Neutral and La Niña years in Graph C compared with Graphs A and/or B, In Graphs B and C, it presents the lowest profitability. However in Graph A, it appears to be the second lowest in profit.

8.3.2.5 Isolated effects of single managerial changes in the Synthesized farm

Figure 8-5 displays the impacts of four management changes, one at a time, regarding A) sprayfield crop system, B) pasture crop system, C) CT, and D) CP for the Synthesized farm. The initial conditions were set up to be sprayfield rotation = millet-sorghum, pasture = bahiagrass, CT = 80%, and CP = "high."

All the tested changes in Figure 8.5: A) sprayfield crop system = bermudagrass, B) pasture crop = bermudagrass, C) CT = 60%, and D) CP = "low" decrease the overall N leaching. However this decreasing of N leaching is, by far, greater when the change is in the sprayfield rotation indicating the high sensitivity of the farm to the crop systems installed on sprayfields. The second highest decrease in N leaching occurs when the CP is decreased from "high" to "low" levels. The third highest decrease is by changing the CT (from 80 to 60%). The least decrease in N leaching happens when the pasture system is changed from bahiagrass to bermudagrass, indicating that dairy systems may not be as sensitive to the pastures as to the other factors.

The effect of these changes in the overall profit varies. For the case of maximum N leaching decrease (sprayfield sorghum-millet to bermudagrass), there is also a maximum decrease in the profitability of the farm. For the change in the CT, there is no variation in

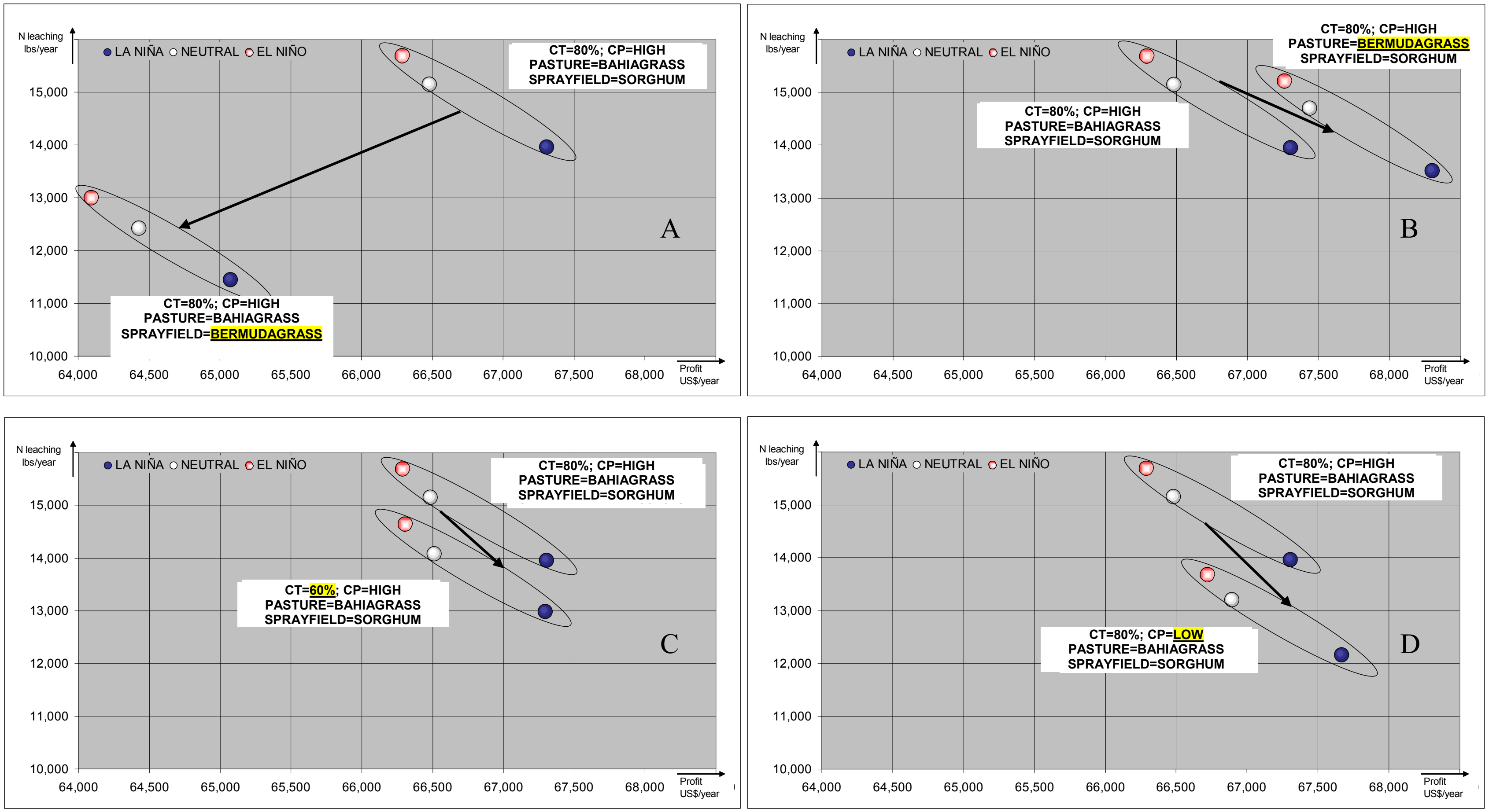


Figure 8-5. Impacts of management changes for the Synthesized farm with soils type 4 (Penney-Otela). A) Sprayfield crop system. B) Pasture crop system. C) Confined time (CT). D) Crude protein (CP).

the profitability level. And for the other options (change in pasture and CP) there is a slight increase in farm profitability.

Even though in Figure 8-5 the changes in N leaching and profitability seem to be of similar magnitudes, they are quite different in terms of proportions. As a percent, the decrease in N leaching is five or six times greater than the change in profitability. This has great connotation for the potential changes farmers could adopt in order to pursue environmental and economic sustainability.

8.3.3 Optimization Analysis: Decreasing Environmental Impacts and Increasing Profitability

8.3.3.1 The Synthesized dairy farm "as is"

The Synthesized north-Florida dairy farm was simulated with the following management practices: crude protein in the diet "high", CT 80%, and the forage crops described in Table 8-5. This is a common scenario for many north-Florida dairy farms.

Table 8-5. Crops in different fields in the Synthesized farm

Field	Area (Ac)	Type	Spring	Summer	Winter
1	10	SPRAYFIELD	CORN	SORGHUM	RYE
2	20	SPRAYFIELD	CORN	MILLET	RYEGRASS
3	10	SPRAYFIELD	SORGHUM	MILLET	WHEAT
4	20	SPRAYFIELD	BAHIAGRASS	BAHIAGRASS	OATS
5	10	SPRAYFIELD	MILLET	SORGHUM	RYE
6	20	PASTURELAND	BAHIAGRASS	BAHIAGRASS	RYE
7	10	PASTURELAND	BERMUDAGRASS	BERMUDAGRASS	RYEGRASS
8	20	PASTURELAND	BAHIAGRASS	BAHIAGRASS	WHEAT
9	10	PASTURELAND	BERMUDAGRASS	BERMUDAGRASS	OATS
10	20	PASTURELAND	BAHIAGRASS	BAHIAGRASS	RYE

The yearly results for profit and N leaching are summarized in Figure 8-6. There is lower N leaching in La Niña years than Neutral years (6.67%) and Neutral years have lower N leaching than El Niño years (5.86%). El Niño years present 12.92% more N leaching than La Niña years (Figure 8-6). Conversely, profit is lower in El Niño years than Neutral years (1.47%) and Neutral years present lower profit than La Niña years (0.45%). El Niño years result in 1.47% less profit than in La Niña years.

N leaching varies from 13,528 lbs for the whole farm for a La Niña year to 15,275 lbs for an El Niño year. An estimated 14,429 lbs of N are leached in a Neutral year. Profit varies from US$ 65,480 for an El Niño year to US$ 66,455 in a La Niña year. An intermediate figure of US$ 65,773 was obtained for a Neutral year.

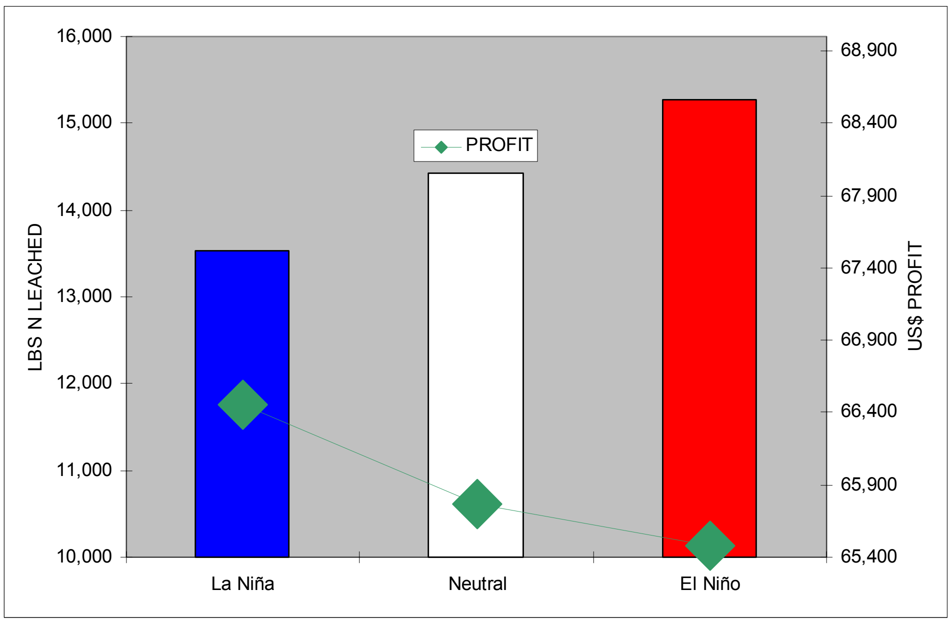


Figure 8-6. Nitrogen leaching and profit with current practices for a Synthesized north-Florida farm

8.3.3.2 Optimization of the Synthesized farm

The linear programming optimizer included in the DNFDFM included combinations of the following management options: confined time (CT), crude protein (CP), pasture forage rotations, and sprayfield forage sequences. The optimizer found a set of management practices with better characteristics of N leaching and profit when compared with the baseline situation of the farm. The selected management options are summarized in Table 8-6 and results comparing with the original situation are presented in Figure 8-7.

The management strategies selected by the optimizer were a "low" CP level; a variable level of CT, 60% of CT for cows that will use 59% of the pasture and 80% of CT for cows that use 41% of the pasture; a bermudagrass-bermudagrass-winter forage sequence for all pasture land; variable areas of forages for sprayfields for different ENSO phases; as seen in Table 8-6.

With these combinations, the optimizer estimated that N leaching would vary from 10,146 lbs year^{-1} for a La Niña year to 11,497 lbs year^{-1} for an El Niño year. An intermediate figure of 10,838 lbs year^{-1} was the outcome for a Neutral year (Figure 8-7).

Table 8-6. Management strategies selected by the optimizer

CP		low	
CT		60%	59% of the pasture
		80%	41% of the pasture
Pasture	bermudagrass-bermudagrass-winter forage		
Sprayfields		Acres	
	La Niña	22.72	corn-corn-winter forage
		15.44	bermudagrass-bermudagrass-winter forage
		13.51	corn-bermudagrass-winter forage
		9.57	millet-corn-winter forage
		8.75	corn-bermudagrass-winter forage
	Neutral	20.90	corn-corn-winter forage
		16.74	bermudagrass-bermudagrass-winter forage
		12.22	corn-bermudagrass-winter forage
		11.22	millet-corn-winter forage
		8.93	corn-bermudagrass-winter forage
	El Niño	21.52	corn-corn-winter forage
		15.97	bermudagrass-bermudagrass-winter forage
		12.99	corn-bermudagrass-winter forage
		11.20	millet-corn-winter forage
		8.33	corn-bermudagrass-winter forage

Comparing these values with the previous results of the farm “as is,” substantial variations are noticed. N leaching could be decreased up to 25% and profit could still be increased by approximately 3.15%, in all ENSO phases.

8.3.3.3 Feasible practices for the Synthesized farm

In reality, farmers cannot easily change all practices proposed by the optimizer. For instance, the slight changes in areas of the sprayfields may not be feasible. However, dairy farmers would be able to change some or part of the proposed practices.

The optimization results serve as the guidelines for making such changes, taking into account that these optimization results would present better environmental outputs. By cross-referencing results achieved by the optimizer with the proposed practices, changes that are “feasible” for farmers can be determined.

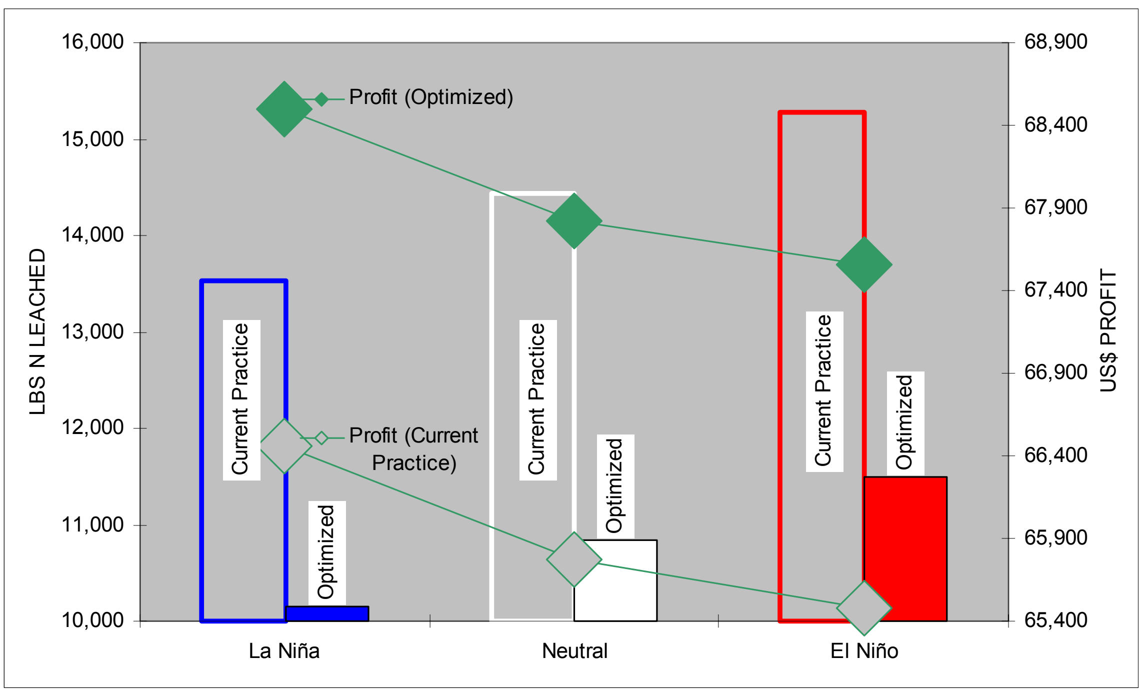


Figure 8-7. Optimized vs. current practice yearly N leaching and profit for a north-Florida Synthesized farm

Scenario One. The optimization proposes a decrease in CP in the diet from "high" to "low." This is a possible change for a dairy farmer to make. Next, the optimization proposes to switch the CT between 80 and 60% for different group of cows. It is believed that it would be difficult for the farmer to implement this specific change, so CT levels would remain at 80%. Finally, the optimization proposed a series of crops for different ENSO phases. It is assumed that the farmer can rather easily implement similar, though not identical, changes to the farm management practices. Feasible crop systems for the farm are shown in Table 8-7. This implements bermudagrass instead of bahiagrass in pastures and sprayfields, and includes more in corn than sorghum and/or millet in sprayfields.

With these "feasible" combinations the DNFDFM simulation was re-run. Results estimated that the N leaching would vary from 10,410 lbs year^{-1} for a La Niña year to 11,820 lbs year^{-1} for an El Niño year. A Neutral year would result in N leaching of 11,130 lbs year^{-1} (Figures 8-8 and 8-9).

Table 8-7. Feasible crop systems in Synthesized dairy farm

Field	Area (Ac)	Type	Spring	Summer	Winter
1	23	SPRAYFIELD	CORN	CORN	RYE
2	15	SPRAYFIELD	BERMUDAGRASS	BERMUDAGRASS	RYEGRASS
3	14	SPRAYFIELD	CORN	BERMUDAGRASS	WHEAT
4	19	SPRAYFIELD	CORN	CORN	OATS
5	80	PASTURE	BERMUDAGRASS	BERMUDAGRASS	OATS

Comparing these N leaching values with the original, farm "as is," it is noticed that N leaching could be greatly reduced by using a "feasible" set of practices instead of the "as is" practices." By implementing these practices, N leaching would be reduced in the order of approximately 23% in all ENSO phases, and the profit could still increase by 2.5%.

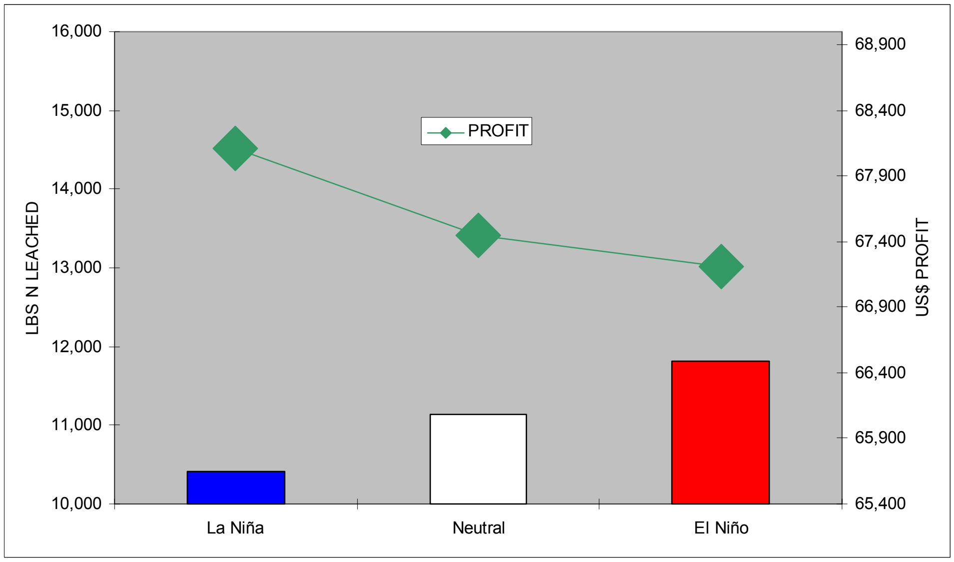


Figure 8-8. "Feasible" yearly N leaching and profit for a Synthesized north-Florida farm

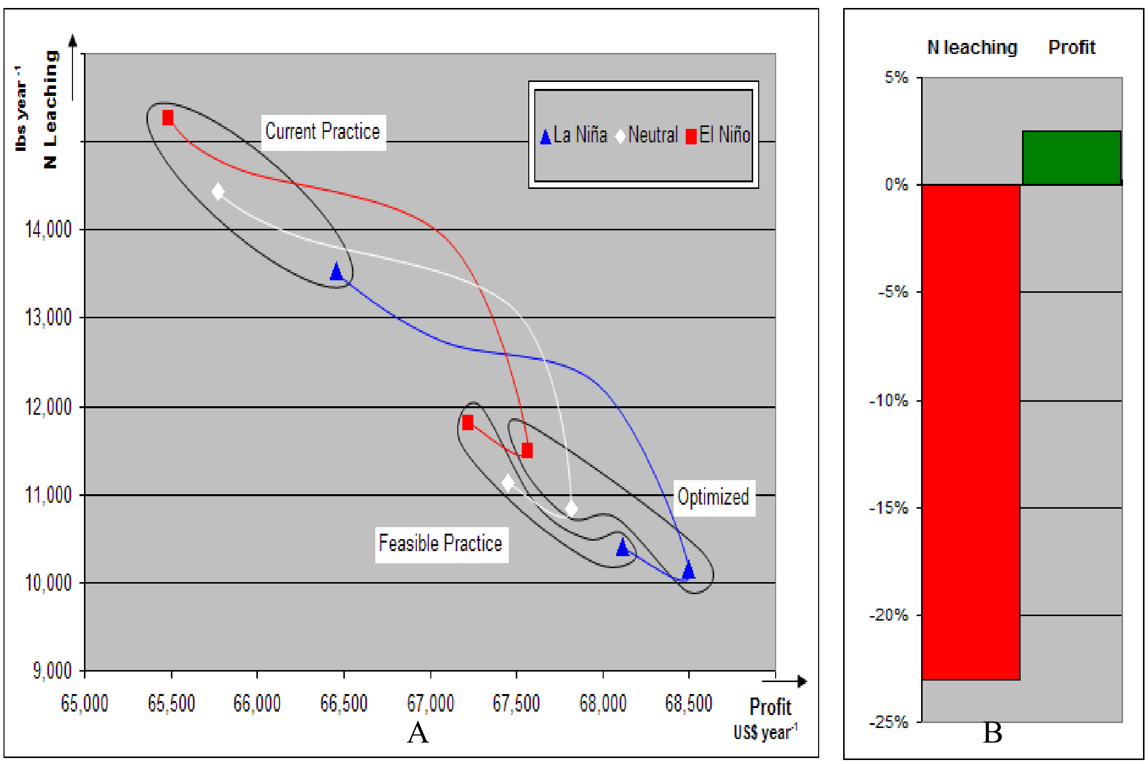


Figure 8-9. Optimization of a Synthesized north-Florida farm, scenario One. A) Current, optimized, and feasible practices and B) percent of N leaching and profit variation from current to "feasible" practices.

Scenario two. Another potential scenario simulated the case where the farmer would be resistant to change the CP in the diet. The DNFDFM was run maintaining the

CP in the "high" mode and holding all the other management choices as scenario One. In this scenario the major changes between the original "as is" farm and the proposed management strategy lies in the crop systems in the pastures and sprayfields. Crop systems were based on those proposed by the optimization runs, in the same way as the previous "feasible" practices that are stated in Table 8-7.

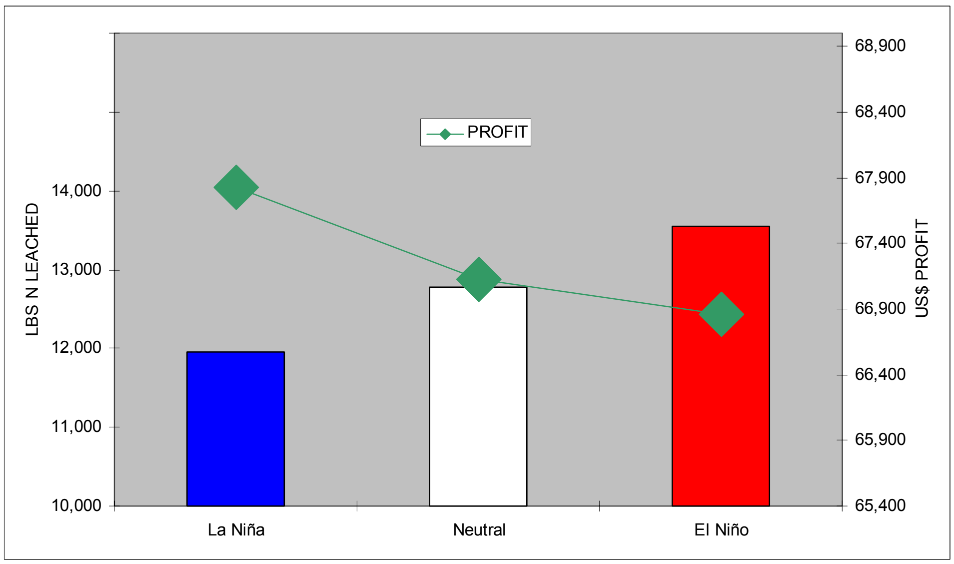


Figure 8-10. "Second feasible" yearly N leaching and profit for a north-Florida Synthesized farm

Results of this simulation demonstrate that the farmer would still be able to decrease N leaching substantially and marginally increase the profitability of the farm, even though the farmer does not want to change the CP in diet. Expected N leaching varied from 11,195 lbs year^{-1} in a La Niña year to 13,549 lbs year^{-1} in an El Niño year. N leaching was 12,723 lbs year^{-1} for a Neutral year. Compared with the original practices, the overall decrease in N leaching would be more than 11% and profit would increase slightly more than 2% for all ENSO phases (Figure 8-10).

Although the best management practices reached with the optimizer and the feasibility of the farm worked similarly for the different ENSO phases, small changes can be still implemented for better results according to different ENSO phases. However, these specific analyses should be performed for each farm on an individual basis, because site-specific interactions of the livestock, waste management systems, and the environmental parameters can have a great impact on results.

8.3.4 Examples of Applications of the DNFDFM to Specific Farms

8.3.4.1 Farm One

This is a small farm with about 400 TAC, 10 bulls, 0% of heifers raised on-farm, and a RHA of 15,000 lbs year^{-1} cow^{-1}. The amount of CP was "high." This is mostly a grazing farm with only 37% CT. The estimated N lost from the waste system was 30.81% and, it has soil type 2. This farm has 2 sprayfields; one of 40 acres and the other of 80, but in both of them the crop rotations are the same: sorghum-sorghum-winter forage. As pasture, this farm has 120 acres of bahiagrass-winter forage rotation. The farmer mentioned that at the moment the net income for the farm was US$ 0.00 cwt^{-1} milk^{-1}. That is, the farm was just breaking even.

A simulation run for this farm with its current conditions indicated that estimated N leaching per year varied from 1,668 in La Niña years to 1,802 in Neutral years to 1,879 in El Niño years. Estimated net profits varied from US$ 5,868 to 5,848 to 5,839, respectively (Figure 8-11). Though a small amount of profit was indicated in the simulation, it satisfied the farmer that the model was very good.

The solution presented by the optimizer estimated that N leaching could decrease approximately 20% and profit could increase approximately 5% by changing some management practices. The optimizer suggested decreasing the CP level from "high" to "low;" maintaining confined time at 37%; changing the pasture field rotations to bermudagrass-winter forage; and introducing millet, bermudagrass, and corn in different fields and seasons in the sprayfields.

After seeing these results, the farmer mentioned that probably not all the proposed changes could be implemented. The farmer said that it would be worthwhile to try the proposed changes in the pasture and sprayfields. So the simulation model was run again for only these proposed "feasible changes." The "feasible practices" showed that for this farm, N leaching could be decreased up to 9%, while profit could still be increased approximately 3% (Figure 8-11).

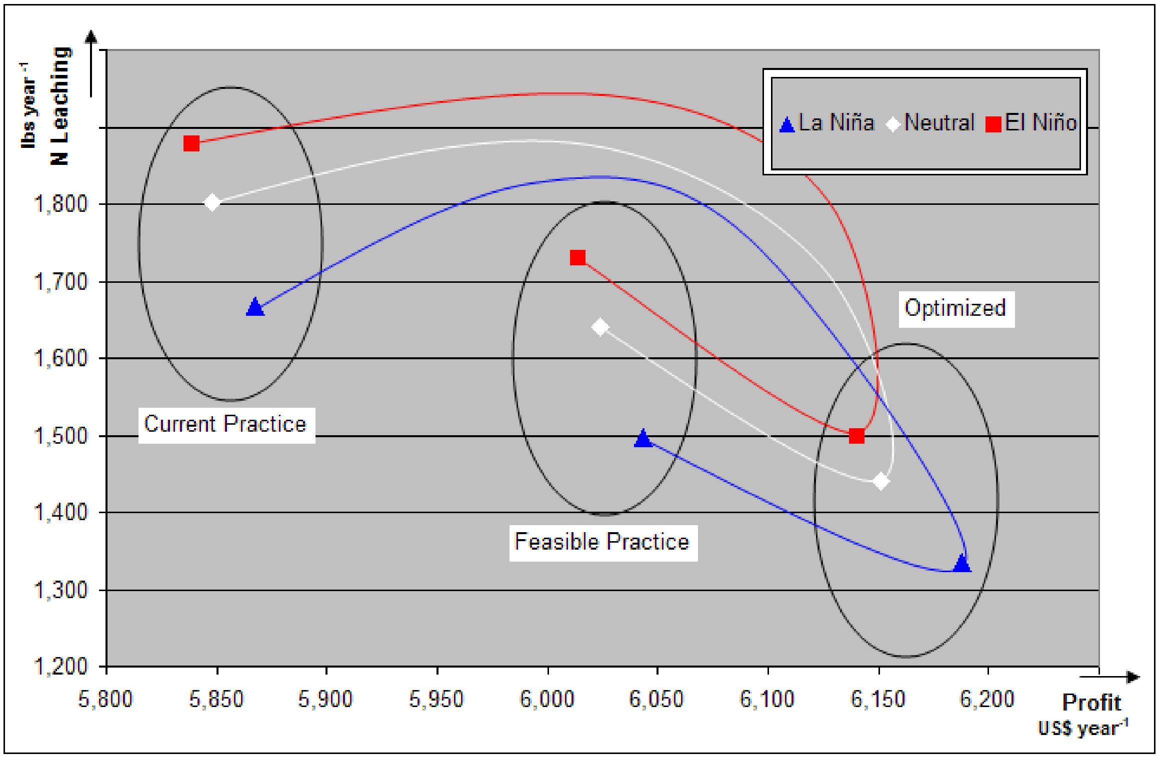


Figure 8-11. Farm One: N leaching and profit for different management strategies

8.3.4.2 Farm Two

Farm Two is a medium-sized farm with 600 TAC, 22,400 lbs cow^{-1} of RHA, no bulls, 100% of heifers raised on-farm, "high" protein in the diet, and 100% CT. This farm has a 35.31% estimated loss of N during waste handling, soil type 1, 155 acres of sprayfields with sorghum-millet-winter forage, and 300 acres of pasture with bahiagrass-bahiagrass-winter forage, and an estimated net income of US$ 0.80 cwt^{-1} milk^{-1}.

For this second farm, the DNFDFM simulation estimated that N leaching would be 13,914, 14,954, and 15,466 lbs N year^{-1} for La Niña, Neutral, and El Niño years, respectively. Using the optimizer, it was determined that these rates could be decreased to 9,633, 10,375, and 10643, respectively (Figure 8-12). This would represent an overall decrease in N leaching of more than 30%. Regarding profit, the optimization found that with this combination of factors, profit would have a small increase of about 0.5%.

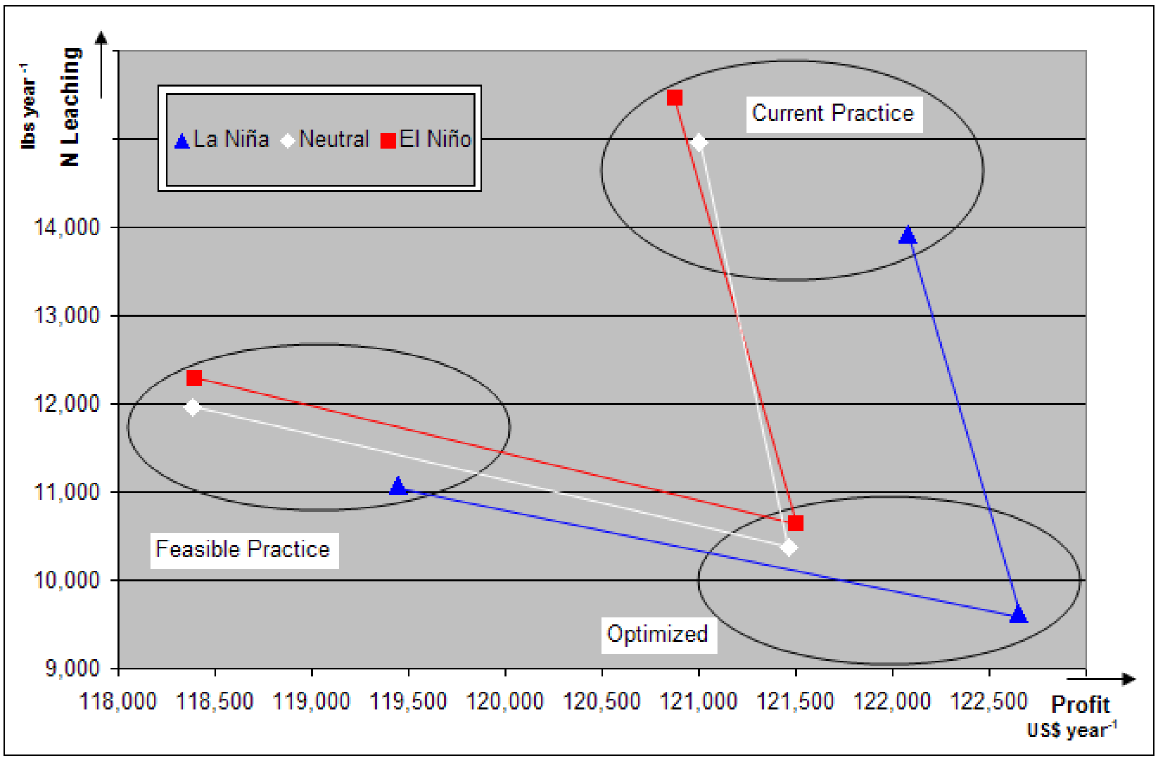


Figure 8-12. Farm Two: N leaching and profit for different management strategies

The optimization proposed changes in cropping patterns. One management change was to substitute sorghum for corn in the spring-summer season. Another proposed adjustment was to substitute bahiagrass for bermudagrass in the pastures. Also, the optimizer proposed adjustment in CP and CT. The farmer said that it would be possible to change the diet and some of the crops, but that confined time was fixed.

A re-run of the model with these "feasible" parameters showed that N leaching could be reduced by changing crops and crude protein in this farm. The solution found that this farm could decrease N leaching up to 20% by changing only feasible practices. However, in this specific farm, the farmer would give up 2% of estimated profits by implementing these management changes. The farmer felt comfortable with that option, stating that a 2% decrease in net income would not be threatening to the farm's survival; however, decreasing N lost by 20% would be a plus for sustainability.

8.3.4.3 Farm Three

This is a large operation in the study area with the following characteristics: 3,000 TAC, 20,000 lbs cow^{-1} of RHA, 80% CT, 120 bulls, 100% of heifers raised and a CP "high." It has 450 acres of sprayfields with corn-sorghum-winter forages, and 800 acres of pasture with bahiagrass-bahiagrass-winter forage. The net income was estimated by the farmer as US$ 1.12 cwt^{-1} milk^{-1}.

Simulation results showed that this farm would release 92,008, 98,059 and 104,326 lbs of N year^{-1} for La Niña, Neutral, and El Niño years, respectively (Figure 8-13). The optimizer found that N leaching could be decreased to 67,531, 73,771, and 77,562 lbs of N year^{-1} for La Niña, Neutral, and El Niño years, respectively. This approximately 25% decrease in N leaching could be performed while still slightly increasing profit (<1%) from US$ 585,018 to 590,336, from US$ 580,270 to 585,389, and from US$ 578,375 to 583,880, for La Niña, Neutral, and El Niño years, respectively.

The optimization found that these levels could be achieved by changing cropping patterns, CT, and CP levels in the diet. The farmer confirmed that this farm would be willing and capable to change to the suggested practices. Therefore, in this case, the "optimized" solution was equal to the "feasible" solution. This big dairy operation would be able to decrease its N pollution by 25% and still slightly increase profitability.

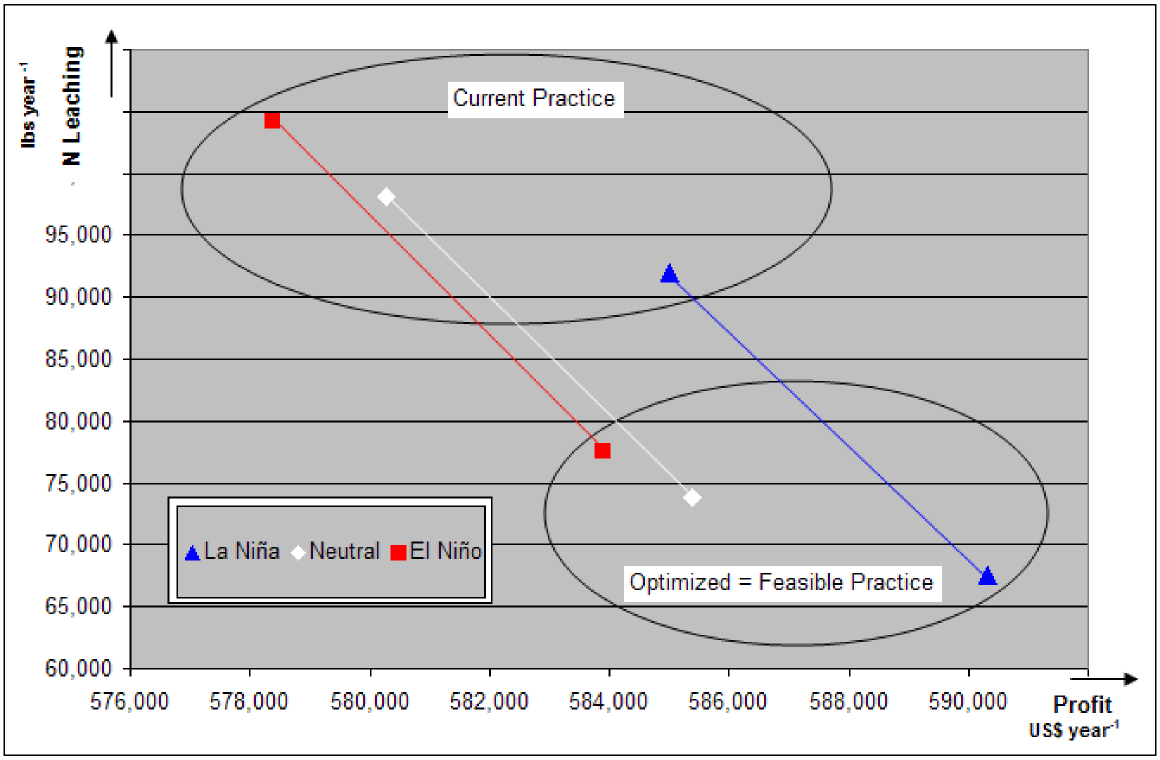


Figure 8-13. Farm Three: N leaching and profit for different management strategies

The "proposed" and "feasible" changes included millet and bermudagrass in the sprayfields in the spring season, and replace sorghum with corn and bermudagrass in the summer season; replace the bahiagrass with bermudagrass in the pasture; reduce the CT to 68%; and change the CP to "low."

8.4 Conclusions and Recommendations

Statistical analyses showed that N leaching and profit are significantly sensitive to parameters of all main factors and several combinations of them. Consequently, the performance of the DNFDFM is highly sensitive to specific dairy farm parameters. Estimations of N leaching and profitability of the DNFDFM change substantially with different farms; therefore the analyses should be performed on an individual basis with specific farms.

Graphical representations of different farm management options regarding N leaching and profit indicated consistently that

- Nitrogen leaching is the lowest and profit the highest for La Niña ENSO phases; exactly the opposite happens for El Niño years
- There are marked differences for soil types, with soil series of the types Millhopper, Bonneau, Blanton, Eunola more prone to leach N and have less profit, and soil series of the types Arredondo, Jonesville, Lake, Ortega, Penny less prone to leach N
- Crop systems that include bermudagrass, corn, and bahiagrass leach less N and crop systems that include millet and sorghum tend to leach more N
- Decreasing the amount of crude protein in the diet impacts by decreasing the N leaching and increasing profitability
- Decreasing the confined time for a Synthesized farm decreases the N leaching and it could also slightly decrease the profitability.
- Individual management changes in the Synthesized farm showed that there is higher sensitivity of the N leaching to changes in sprayfields and lower sensitivity to changes in pastures

The optimization analysis using the DNFDFM with data of a synthesized north-Florida dairy farm demonstrated the power of the model in proposing ecologically and economically sound alternatives to specific dairy farms. For the case of a north-Florida Synthesized farm, the optimizer was able to combine factors to decrease up to 25% the N leaching and still increase profitability more than 3%.

The applications of the DNFDFM in real farms, besides serving as a validation of the model, confirmed the usefulness of the model in practical applications. For the 3 farms in which it was tested, the optimizer was able to find practices better than current practices that would have lower environmental impacts and still maintain profitability levels. By using the concept of “feasible” practices, which are those practices proposed by the optimizer that the farmer feels are feasible to implement, it was possible to reduce the N leaching by 9%, 20%, and 25% in a small, a medium, and a large farm, respectively, in north-Florida. These farms would reduce their N leaching while maintaining their profitability levels.

The optimization analyses found that some practices would work across north-Florida dairy farm operations in reducing N leaching. These are to change the crude protein to “low” standards and promote bermudagrass instead of bahiagrass in pasture and sprayfields. The other crop systems, the confined time, and other potential management choices would present different outputs to specific dairy farm conditions.

CHAPTER 9
SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The Suwannee River Basin has received much attention in recent years and more so in recent months because increased N levels in water bodies. Dairy waste is an important factor contributing to this water N pollution, but dairies may reduce their total N loads by adjusting management strategies. Improvements in climate variation predictions (lead times of 6 to 12 months) can play an important role in devising management strategies that dairy farmers could adopt to pursue economic and ecological sustainability.

The main aim of this dissertation was to test management options that decrease nutrient overflow in dairy systems under different climatic conditions while maintaining profitability through the creation and use of simulation and optimization models. Whole-dairy-farm system simulation was used to test alternative management strategies that would not be practical to test under regular experimental designs. Dynamic, event-controlled, process-based, and empirical models were coupled with optimization models to represent north-Florida dairy farms. User friendliness of models and high interaction with stakeholders were always pursued. The Dynamic North-Florida Dairy Farm Model (DNFDFM) was intended to be an environmental accountability tool for dairy farmers and regulatory agencies capable of simulating and optimizing any individual north-Florida dairy farm. Economic and ecological impacts were studied along with the effects of seasonal or climate variability for different dairy farm types.

General results indicated that north-Florida dairy farms could substantially decrease N leaching and maintain profitability levels by adjusting crop sequences in sprayfields, crop rotations in pastures, crude protein in the diet, and confined time of milking cows. Climatic conditions greatly affect N leaching: during “El Niño” years, when higher rainfall and colder temperatures are experienced, higher N leaching is estimated than in “La Niña” years, when lower rainfall and hotter temperatures are observed; in “Neutral” years, medium N leaching is registered. Farmers could vary crop proportions to better prepare for these different climatic forecasts.

In Chapter 2, an intense literature review was used to explore the hypotheses that

- An N pollution problem exists in the Suwannee River Basin
- Dairy farms are major contributors to this problem

Results clearly indicated that not only does the problem of N pollution exist, but also there is an increasing trend of N concentrations in ground and surface waters. Although the N levels are currently below the regulatory standards (<10 mg L^{-1}), they are always above the background, and so measures of mitigation are needed to avoid uncontrollable situations in the near future. Dairy farms are indeed major contributors to the problem through manure applications that exceed the carrying capacity of the soils and crops. However, substantial differences exist among dairy farms because of temporal, spatial, and climatic conditions. It is highly recommended, therefore, to assess point sources of pollution and keep individual dairy farms environmentally accountable. Components inside dairy farms and their interactions also vary greatly in their environmental impacts and these need to be taken into consideration when analyzing complete dairy farm systems.

In Chapter 3 a Sondeo, a Survey, and several Focus Groups were used as instruments to capture the Suwannee River Basin stakeholders’ perceptions regarding

- Water contamination
- Current environmental regulations
- Potential adoption of climate forecast innovations

It was found that most of the stakeholders perceived that there is an environmental problem of water pollution that needs to be addressed. However, some farmers, technicians, and extensionists challenged this fact and showed skepticism of the gravity of the problem. Major efforts are needed to clearly communicate to all groups of stakeholders, especially to the skeptical ones about the real problem and its potential consequences. Most of the farmers agree with current environmental regulations and many of them are very thankful to have the opportunity to participate in incentive-based programs. Nonetheless, most of them also believe that regulations will be the major challenge they will have to face in the future. Some farmers are in disagreement with current regulations because of technical and/or administrative aspects. Therefore, regulatory agencies should work collaboratively with all stakeholders' groups to test the economic and ecologic feasibility of promoted best management practices, BMPs. Two-thirds of dairy farmers would use climate forecast products in crop decisions for selecting forage crops, changing planting dates, and/or planning areas of forage; some of them would additionally benefit from this climate forecast use in livestock, feedstock, and waste management. The main barriers to climate forecast adoption is the lack of flexibility of north-Florida dairy farms and the management resources required for their implementation. Consequently, forecast innovations must fit narrow niches of application and require realistic management efforts in order to be adopted. Further research calls for the inclusion of climate variability forecasts into BMP experiments. Commitment in extension and outreach programs to deliver climate forecasts together with their regular products is also required to diffuse these climate innovation products.

Chapter 4 describes the collaborative process of building the Dynamic North-Florida Dairy Farm Model (DNFDFM) with the stakeholders. Multiple feedback loops were used during a two-year iterative process that included initial developments, creation of a prototype model, and calibration and validation of a final model that simulates monthly N leaching and cash flows on north-Florida dairy farm systems affected by a climatic component determined by the El Niño Southern Oscillation (ENSO) phenomenon. Participatory modeling can enhance the creation of adoptable and adaptable user-friendly models that include environmental, economic and biophysical components. These component models were embedded in the DNFDFM. By providing farmers, policy makers, and other stakeholders with a more holistic view of current practices, common ground among them was more easily identifiable and collaboration was therefore fostered. By having stakeholders participate in the creation and development of the models, there is increased chance that the final product will better represent the reality and interests of stakeholders, and consequently a greater chance that the model will be adopted by interested users.

Chapter 5 tested the hypothesis that there could be better ways to estimate N excretion from dairy cows than those commonly used. This chapter described and analyzed the creation of a new model, the north-Florida livestock model, which is the driver of the DNFDFM. This model introduced dynamic components, parameterization of north-Florida herd environmental and management conditions, minimum requirement of initial data, and calibration with farmers' participation. Results of this model regarding N received by land (lbs acre^{-1}) were compared with those yielded by the two most commonly used approaches in Florida. This comparison suggested that previous models have either overestimated or underestimated N excretion and did not account for seasonality. This new model is believed to be more accurate because it captures more realistic and relevant characteristics of north-Florida dairy operations. Results showed great variability in manure N production due principally to season of the year, number of cows, milk production levels, and size of farm. Values indicated that some fields may receive as little as 3 lbs N acre^{-1} month^{-1} and other fields may receive as much as 145 lbs N acre^{-1} month^{-1}.

Chapter 6 assessed the potential N leaching of north-Florida dairy forage systems under the premise that these crop systems are the main means of recycling the always abundant manure N produced as a consequence of milk production. Findings were summarized for incorporation into the DNFDFM. Eight focus groups with stakeholders and 21 interviews with dairy farmers were performed in order to collect information about the forage systems and their parameters; additional information was collected from published sources, farm records, and official regulatory agencies. It was found that the common forage systems in north-Florida dairy farms include a spring/summer forage (corn, sorghum, millet, bermudagrass, or bahiagrass), a summer/fall forage (corn, sorghum, millet, bermudagrass, or bahiagrass), and a fall/winter forage (rye, oats, wheat, or ryegrass). Crop models contained in the Decision Support System for Agricultural Transfer, DSSAT v4.0, were used to predict monthly N leaching and biomass accumulation in these forage crop systems under different parameters of

- Crop sequences
- Manure N received
- Seasonal climatic conditions
- Soil characteristics
- Other variable management specifications

After creating, calibrating, and validating the common forage systems for north-Florida, these crop models were run for 43 years of daily weather data (1956-1998). Results indicated that higher N leaching and lower biomass accumulation are predicted for El Niño followed by Neutral years; La Niña years showed the lowest N leaching and the highest biomass accumulation. Winter in general, and January and February, specifically, are the critical months with the highest N leaching. The best forage systems to prevent N leaching are those that start in spring-summer with bermudagrass or corn; have bermudagrass, bahiagrass or corn in summer; and finish with winter forages. Systems that leach the most N are those that include millet and/or sorghum. Water holding capacity and pH among soil types may explain most of the great variability found in N leaching.

Chapter 7 describes the DNFDFM, a simple, event-controlled, mechanistic, dynamic model that couples livestock, crop and optimization models created to assess N leaching from entire north-Florida dairy farm systems and the economic impacts resulting from reducing it. The model responds to dairy-specific environmental (climate and soils) and specific characteristics of

- Herd management
- Waste handling system
- Crops in sprayfields
- Crops in pastures
- Economic/financial situation

The DNFDFM is used to simulate an existing system, optimize management options to diagnose sources of problems and suggest improvements in the system, and then simulate the modified system to compare it with the existing system. The model could also be used for pre-testing BMPs for specific farms and also for designing new dairy farms.

The driver of the livestock and crop portions of the DNFDFM is a dynamic adaptation of the framework “balance” and/or “budgeting” of nutrients in dairy farms, commonly used in Florida. The DNFDFM incorporates Markov-chain probabilistic simulation of cow-flows and crop simulation for historical climatic years (El Niño Southern Oscillation). It also includes automated optimization of managerial options, participatory modelling, and user-friendliness. This chapter discussed the model structure, its components, its functioning, and its limitations.

The DNFDFM should be used on an individual farm basis with the specific environmental and managerial conditions of each dairy farm. As an indication, outputs of running the model for some representative, but synthesized north-Florida dairy farms indicated that a small dairy farm would leach between 34 and 38 lbs N $year^{-1}cow^{-1}$; while a medium farm would leach between 31 and 35 lbs N $year^{-1}cow^{-1}$; and a large operation would leach between 25 and 29 lbs N $year^{-1}cow^{-1}$ for La Niña and El Niño years, respectively.

Chapter 8 presents and discusses results of simulating and optimizing synthesized and real dairy farms in north-Florida using the DNFDFM. The chapter included statistical, graphical, optimization, and application analyses. Results indicated that there is significant and great variability among soil types, i.e. soil type 6 (Millhopper-Bonneau) leaches the most N and soil type 2 (Arredondo-Jonesville-Lake) leaches the least N. A crop system that included bermudagrass-bermudagrass had the least N leaching and those that had sorghum-millet leached the most N. Higher crude protein in the diet or 20% higher confined time of milking cows created significantly higher amounts of N leaching.

The optimization analysis using the DNFDFM with data from a Synthesized north-Florida dairy farm demonstrated the capability of the model in proposing ecologically and economically sound alternatives for specific dairy farms. The optimizer was able to combine factors to decrease N leaching up to 25% and still increase profitability by 3%.

The applications of the DNFDFM in real farms, besides serving as a validation of the model, confirmed its usefulness in practical and real applications. For the 3 farms, in which it was validated, the optimizer was able to find better than current practices that would have lowered environmental impacts and still maintained profitability levels. By using the concept of "feasible" practices, which are those proposed by the optimizer that the farmer feels can be implemented, it was possible to reduce by 9%, 20%, and 25% the N leaching in a small, a medium, and a large farm in north-Florida. The optimization analyses found that some practices would be especially useful to north-Florida dairy farm operations in reducing N leaching. These are to decrease the crude protein in the diet and promote bermudagrass instead of bahiagrass in pastures and sprayfields. The other crop systems, the confined time and other potential management choices would present different outputs to specific dairy farm conditions.

The DNFDFM can help farmers and other major stakeholders in making complicated decisions in optimizing both profitability and sustainability. Some practical, real-life envisioned applications are listed below.

The DNFDFM has been conceived and developed with farmers, consequently it is expected that most of the benefits of its direct use return to these dairy farmers:

- The DNFDFM can be an important tool devising management strategies dairy farms could follow according to predicted long-term climate conditions

- The DNFDFM could help farmers maintain or gain compliance while maintaining profitability levels

- It can help in the design and testing of best management practices (BMPs) at the farm level. The virtual testing of these practices would decrease the risk of failure, save money, and decrease the time of implementation and re-design

- The DNFDFM could be used as a tool in the decision of design and implement a new dairy operation. Similarly, the model could be helpful in the decision of locating new or moving farms

- The model could be especially important in the reporting process dairy farms need to do to the official regulatory agencies. Dairy farmers could use it as a tool of individual environmental accountability

- The DNFDFM would allow farmers to demonstrate their stewardship towards environmentally sound practices and account for individual point-source pollution

- The model could also be used as an administrative tool, inside the dairy farm, for record keeping and/or planning administrative activities, since it computes economic outputs, along with all major activities

The utility of the DNFDFM would be diminished if regulatory agencies would not accept and/or not use the model. It is envisioned that the regulatory agencies would find relevant uses for it:

- The DNFDFM could be used by the regulatory agencies to assess all the points expressed above, and additionally

- The model used on several farms could help regulatory agencies devise regional environmental practices according to forecasted climate conditions

- Regulatory agencies would be able to assess the economic impacts of proposed BMPs and the need of having financial help for farmers in order to comply

- The model could be important as an accountability tool for the regulatory agencies to demonstrate to activist groups and the general public the effectiveness of the regulations and the proposed practices

It is also believed that activist groups (i.e., environmental groups) and the public in general would appreciate the model and its use:

- These groups could use it for most of the above uses, and additionally
- These groups may be interested in assessing potential regional impacts of the dairy industry according to climate conditions
- It would give them a more holistic view of the dairy farm enterprise and its components, and realistic options towards decreasing environmental impacts

It is also envisioned that the model would serve the scientific community in some meaningful ways:

- It may help scientists assess trends/relationships between N pollution in water and estimated dairy farm releases by the DNFDFM
- Scientists could follow parts of the methods/frameworks used in the conception, design, implementation, and use of the DNFDFM to be applied to other studies

The DNFDFM could still further be improved in order to better serve its purposes. Modifications, without losing user-friendliness that would improve its functionality are listed below.

- The livestock and waste components would be improved by the inclusion of farm-specific culling/reproduction rates
- Specific details inside the livestock component could still be adjusted for major accuracy. Some examples are
    - Include an exponential function of calves/heifers gain of weight by using exponential parameters instead of the current constant rate. This incorporation would only have very slight changes in the pasture component and negligible overall impacts in the farm
    - The general dietary protein function included following the NRC standards could be broken down to include information about the use of total crude protein, rumen protected amino acids, non-protein N, and ruminally degradable and undegraded protein. This incorporation would require parameterize experimental data and a higher level of inputs for running the model

- The DNFDFM should be capable of handling an increase/decrease in herd size and/or field size inside a run in order to simulate the desire or the real conditions of expansion/reduction of a farm and perform analyses under those conditions

- The model would benefit from higher customization of the crop model results. It would imply increasing the number of factors used to run the crop models and implement the results in the model. Especially important would be to:
    - Include daily weather information for other meteorological stations in the study area.
    - Include direct manure deposition in pastures
    - Seasonality of crops according to climate conditions
    - Seasonality of crop for harvesting
    - Specific winter forages

- The model would improve with the inclusion of more detailed economic factors such as fixed costs and the initial costs as well as the value of the infrastructure and their depreciation and the specific costs of compliance

- The DNFDFM would benefit by including stochastic results according to climate ENSO phases. It would imply reassembling the distribution of crop model results for different climate years into a probabilistic function

- The optimization process could be faster if adjustment variables would be kept from one simulation to the next one

- Optimization could be improved if more decisions could be chosen. Also optimization could be improved if non-linear optimization methods and multi-objective approaches are used.

LIST OF REFERENCES

Adams, A.L. 1998. Dietary fat effects on rumen fermentation, milk production, and reproduction of dairy cattle, and economic implications for dairy production. Ph.D. thesis, University of Florida. Gainesville, FL.

Albert, M. 2002. Monitoring and modeling the fate and transport of nitrate in the vadose zone beneath a Suwannee River Basin vegetable farm. M.S. thesis, University of Florida. Gainesville, FL.

Alvira, D., Cabrera, V.E., Galindo, S., Haile, S., Mtenga, K., Rios, F., Tripathi, N., Villagomez, J.A. 2003. Nutrient management in the Suwannee River Basin: perceptions of stakeholders. University of Florida, Food and Resource Economics Department, Staff Paper Series, SP 04-2. Gainesville, FL.

American Society of Agricultural Engineers. 1990. Manure production characteristics. Engineering practices subcommittee, ASAE Agric. Sanit. Waste Manag. Comm. ASAE Standard D384.1, Am. Soc. Agric. Eng., St. Joseph, MI.

Andrew, W.J. 1994. Nitrate in ground water and spring water near four dairy farms in north Florida 1990-1993. US Geological Survey, Water-Resources Investigations Report 94-4162, 63 p. Tallahassee, FL.

Andrew, W.J. 1992. Reconnaissance of water quality at nine dairy farms in north Florida, 1990-1991. US Geological Survey, Water-Resources Investigations Report 92-4058, 39 p. Tallahassee, FL.

Archer, D., Eklund, J., Walsh, M., Forcella, F. 2002. WEEDEM: A user-friendly software package for predicting annual ryegrass and wild radish emergence. In: Spafford, J.H., Dodd, J., Moore, J.H. (eds.), WEEDS: "threats now & forever?" p. 252-253. In Proc. 13th Australian Weeds Conf., Perth, WA, September 8-13, 2002. Department of Primary Industries, Water and Environment, Government of Tasmania. Hobart, Tasmania, Australia.

Asbury, C.E., Oaksford, E.T.1997. A comparison of drainage basin inputs with in stream nutrient loads for seven rivers in Georgia and Florida, 1986-90. US Geological Survey Water Resources-Investigations Report 97-4006, 8 p. Tallahassee, FL.

Bastidas, E. 2001. Assessing potential response to changes in the livelihood system of diverse, limited-resource farm households in Carchi, Ecuador: modeling livelihood strategies using participatory methods and linear programming. Ph.D. thesis, University of Florida. Gainesville, FL.

Bernard, H.R., 1994. Research Methods in Anthropology: Qualitative and quantitative approaches. Sage. Newbury Park, CA.

Berndt, M.P., Hatzell, H.H., Crabdall, C.A., Turtora, M., Pitman, J.R., Oaksbord. 1998. Water quality in the Georgia-Florida coastal plain, Georgia and Florida, 1992-1996. Circ. 1151. U.S. Geological Survey, Reston, VA.

Bisoondat, M., Woodard, K.R., Sollenberger, L.E., French, E.C., Portier, K.M., Graetz, D.A., Prine, G.M., Van Horn, H.H. 2002. Dairy effluent effects on herbage yield and nutritive value of forage cropping systems. Agron. J. 94, 043-1049.

Boote, K.J., Jones, J.W., Hoogenboom, G. 1998. Simulation of crop growth: CROPGRO model. In Peart R.M., Curry R.B. (eds.) Agricultural systems modeling and simulation. Marcel Dekker, New York.

Børsting, C.F., Kristensen, T., Misciattelli, L., Hvelplund, T., Weisbjerg, M.R. 2003. Reducing N surplus from dairy farms. Effects of feeding and management. Livest. Prod. Sci. 83,165-178

Center for Ocean-Atmospheric Prediction Studies. 2003. ENSO index according to JMA SSTA (1868-present). COAPS-Florida State University. Accessed January, 2004 ftp://www.coaps.fsu.edu/pub/JMA_SST_Index/

Chambers, R. 1994. The origins and practice of participatory rural appraisal. World Dev. 22, 953-959.

Chambliss, C.G. (ed.). 1997. Florida forage handbook. Florida Coop. Extension Service, IFAS, Electronic Data Information Source, University of Florida. Gainesville, FL. Available at: http://edis.ifas.ufl.edu/pdffiles/AG/AG17000.pdf

Conway, G. R. 1990. Agroecosystems. In: Jones J.G.W., Street, P.R. (eds.). Systems theory applied to agriculture and the food chain. Elsevier Applied Science, New York.

Copeland, R., David, J., Hansard, P. 1999. Nitrate source impacts on private drinking well waters in northwest Lafayette County, Florida. p. 1-6, Ambient Monitoring Section, FL Department of Environmental Protection. Ambient Newsletter 3, 3, August, 1999. Available at: http://www.dep.state.fl.us/water/monitoring/docs/news/news9908.pdf.

Dent, B.J., McGregor, M.J., 1994. Rural and farming systems analysis. A European perspective. Oxford Univ. Press, Oxford, UK.

Department of Environmental Protection (DEP). 2001. Florida water conservation initiative. Agricultural working group. A report of the Florida Department of Environmental Protection. Orlando, FL.

De Vries, A. 2004. Economic value of late replacement when cow performance is seasonal. J. Dairy Sci. *In Press*.

De Vries, A. 2001. Statistical process control charts applied to dairy herd reproduction. Ph.D. thesis. University of Minnesota, Saint Paul, MN.

De Vries, A., Giesy, R., Ely, L., Webb, D., Andreasen, A., Broadus, B., Miller, P., Seabright, T, Vann, C., de Araujo, A. 2000. Dairy business analysis project: 2000 financial summary. University of Florida, Institute of Food and Agricultural Sciences, AN 135. Gainesville, FL.

Edwards, T.M., Barbeau, T.R., Guillette, L.J. Jr. 2003. Effects of nitrate contamination on reproduction growth, and development of animals associated with Florida's Springs. In Proc. Florida Springs Conference. Gainesville, FL. Feb. 5-7, 2003. Florida Center for Library Automation, Gainesville, FL.

Environmental Literacy Council. 2002. Non-point source pollution. The Environmental Literacy Council, Washington DC. Accessed December, 2003 http://www.enviroliteracy.org/article.php/413.html.

Fan, A.M., Wilhite, C.C., Book, S.A. 1987. Evaluation of the nitrate drinking water standard with reference to infant methemoglobinemia and potential reproductive toxicity. Regulatory Toxicology and Pharmacology 7, 135-137.

Felsot. A. 1998. Re-examining the Link between Nitrates and "Blue-Baby" Syndrome: A Necessary First Step For Managing Ground Water Quality to Protect Public Health. Cooperative Extension, Washing State University. Accessed April, 2004, http://www.aenews.wsu.edu/Oct98AENews/aenewsoctober98.htm#anchor545063.

Florida Agricultural Statistics Service. 2003. Livestock, dairy and poultry page. U.S. Department of Agriculture. Accessed March, 2004, http://www.nass.usda.gov/fl.

Florida Department of Environmental Protection (FLDEP). 2004. EPA 319 Grant Program. Accessed, May, 2004 http://www.dep.state.fl.us/water/nonpoint/319h.htm.

Florida Department of Environmental Protection (FLDEP). 2001. Basin status report: Suwannee. Division of Water Resource Management. Bureau of Water Management, Tallahassee, FL. Available at: http://www.dep.state.fl.us/water/basin411/suwannee/ status/SUWANEE.pdf

Florida Geographic Data Library. 1995. Data download. Accessed October, 2002 ftp://ftp1.fgdl.org/pub/county/

Florida Geological Survey, Department of Natural Resources. 1992. Florida's ground water quality monitoring program background hydrogeochemistry. Florida Geological Survey Special Publication No 34. Tallahassee, FL.

Fontaneli, R.S., Sollenberger, L.E., Staples, C.R. 2001. Yield, yield distribution and nutritive value of intensively managed warm-season annual grasses. Agron. J. 93, 1257-1262.

Fontaneli, R.S., Sollenberger, L.E., Staples, C.R. 2000. Seeding date effects on yield and nutritive value of cool-season annual forage mixtures. Soil Sci. Soc. Florida Proc. 59, 60-67.

Forman, D., Al-Dabbagh, S., Doll, R. 1985. Nitrates, nitrites, and gastric cancer in Great Britain. Nature 313, 620-625.

Fraisse, C.W., Campbell, K.L., Jones, J.W., Boggess, W.G. 1996. GIDM: A GIS-based model for dairy waste management analysis. In Proc. Symposium on GIS and Water Resources, Ft. Lauderdale, Sep 22-26, 1996. American Water Resources Association, Middleburg, VA.

Geurtz, J.L.A., Joldersma, F. 2001. Methodology for participatory policy analysis. European Journal of Operational Research 128, 300-310.

Geurtz, J.L.A., Vennix, J. 1989. Verkenningen in Beleidsanalyse: Theorie en Praktijk van Modelbouw en Simulatie. Kercke-bosch, Zeist.

Giesy, R., de Vries, A., Bray, D. 2002. Florida dairy farm situation 2002. Cooperative Extension Service, IFAS, University of Florida. Gainesville, FL.

Gijsman, A.J., Hoogenbomm, G., Parton, W.J., Kerridge, P.C. 2002. Modifying DSSAT crop models for low-input agricultural systems using soil organic matter-residue module from CENTURY. Agron. J. 94, 462-474.

Ham, L.K., Hazell, H.H. 1996. Analysis of nutrients in the surface waters of the Georgia-Florida coastal plain study unit, 1970-1991. US Geological Survey, Water-Resources Investigations Report 96-4037, 67 p. Tallahassee, FL.

Hammer, G.L., Nicholls, N., Mitchell, C. 2000. Applications of Seasonal Climate Forecasting in Agricultural and Natural Ecosystems: The Australian Experience. In: Hammer G.L., Nicholls, N. and Mitchell, C. (eds.). Applications of seasonal climate forecasting in agricultural and natural ecosystems —the Australian Experience, Kluwer Academic, The Netherlands.

Hansen, J.W. 2002a. Applying seasonal climate prediction to agricultural production. Agr. Syst. 74, 305-307.

Hansen, J. W. 2002b. Realizing the potential benefits of climate prediction to agriculture: issues, approaches, challenges. Agr. Syst. 74, 309-330.

Hazell P.B.R., Norton, D. 1986. Mathematical programming for economic analysis in agriculture. Macmillan, New York.

Herrero, M., Fawcett, R.H., Silviera, V., Busqué J., Bernués, A., Dent, J.B. 2000. Modelling the growth and utilisation of kikuyo grass (*Pennisetum clandestinum*) under grazing. 1. Model definition and parametrisation. Agr. Syst. 65, 73-97.

Hildebrand, P.E. 1990. Farming systems research-extension. p. 169-180. In: Jones J.G.W., Street, P.R. (eds.). Systems theory applied to agriculture and the food chain. Elsevier Applied Science, New York.

Hildebrand, P.E. 1981. Combining disciplines in rapid appraisal: The Sondeo approach. Agri. Admin. 8, 423-432.

Hornsby, D., Ceryak, J., Zwanka, W. 2003. Groundwater quality report. Department of Water Resources, Suwannee River Water Management District. Live Oak, FL.

Hornsby, D., Ceryak, J., Zwanka, W. 2002b. Groundwater quality report. Department of Water Resources, Suwannee River Water Management District. Live Oak, FL.

Hornsby, D., Ceryak, R., 1999, Springs of the Suwannee River Basin in Florida: Suwannee River Water Management District Report WR99-02. Live Oak, FL.

Hornsby, D., Mattson, R., Mirti, T. 2002a. Surface water quality and biological annual report. Department of Water Resources, Suwannee River Water Management District. Live Oak, FL.

Houston, T. B., Hazen, M.W., Mathews, T.C., Brown, G.A. 1965. Soil Survey of Suwannee County, Florida. USDA Natural Resour. Conserv. Serv., Washington, DC.

Hubbard, R.K., Thomas, D.L., Leonard R.A., Butler, J.L. 1987. Surface runoff and shallow ground water quality as affected by center pivot applied dairy cattle waste. Trans. ASAE 30, 430-437.

Jagtap, S.S., Jones, J.W., Hildebrand, P., Letson, D., O'Brien, J. J., Podestá, G., Zierden, D., Zazueta, F. 2002. Responding to stakeholders' demands for climate information: from research to applications in Florida. Agr. Syst. 74, 415-430.

Johnson, J.C., Newton, G.L., Butler, J.L. 1991. Recycling liquid dairy cattle waste to sustain annual triple crop production of forages. p. 41-50. In Proc. 28th Annual Florida Dairy Production Conf., Gainesville, FL. 9-10 Apr. 1991. Dairy Sci. Dep., CES, IFAS, Gainesville, FL.

Jones J.W., Hansen, J.W., Royce, F.S., Messina, C.D. 2000. Potential benefits of climate forecasting to agriculture. Agr. Ecosyst. Environ. 82, 169-184.

Jones, J.W., Hoogenboom, G., Porter, C.H., Boote, K.J., Batchelor, W.D., Hunt. L.A., Wilkens, P.W., Singh, U., Gijsman, A.J., Ritchie, J.T. 2003. The DSSAT cropping system model. Eur. J. Agron. 18, 235-265.

Jones J.W., Thornton, P.K., Hansen, J.W. 1997. Opportunities for systems approaches at the farm scale. p1-18. *In* Teng et al., (ed.) Applications for systems approaches at the farm and regional levels. Syst. Approaches for Sustainable Agric. Dev. 5. Kluwer Acad. Publ., Dordrecht, The Netherlands.

Jones, J.W., Tsuji, G.Y., Hoogenboom, G., Hunt, L.A., Thornton, P.K., Wilkens, P.W., Imamura, D.T., Bowen, W.T., Singh, U. 1998. Decision support system for Agrotechnology transfer: DSSAT v3. p. 155-177. In Tsuji, G.Y., Hoogenboom, G., Thornton, P.K. (eds.). Understanding options for agricultural production. Kluwer Acad. Publ., Dordrecht, The Netherlands.

Jonker, J.S., Kohn, R.A., High, J. 2002. Dairy herd management practices that impact N utilization efficiency. J. Dairy Sci. 85, 1218–1226

Katz, B. 2000. Sources of nitrate contamination of spring waters, Suwannee River basin, Florida. In Proc. Florida Springs Conference, Gainesville, FL. Feb. 9-10, 2000. Florida Center for Library Automation, Gainesville, FL.

Katz, B., Hornsby, D., Bohlke, F., Mokray, M. 1999. Sources and chronology of nitrate contamination in spring waters, Suwannee River Basin, Florida. US Geological Survey, Water-Resources Investigations Report 99-4252, 54 p. Tallahassee, FL.

Katz, B.G., Bohlke, J.K. 2000. Monthly variability and possible sources of nitrate in ground water beneath mixed agricultural land use, Suwannee and Lafayette counties, Florida. US Geological Survey Water-Resources Investigation Report 00-4219, 28 p. Tallahassee, FL.

Katz, B.G., DeHan, R.S. 1996. The Suwannee River basin pilot study: Issues for watershed management in Florida. Fact Sheet FS-080-96. U.S. Geological Survey. Reston, VA.

Keating, B.A., McCown, R.L. 2001. Advances in farming systems analyses and intervention. Agr. Syst. 70, 555–579.

Kelly, T.C. 1995. A bioeconomic systems approach to sustainability analysis at the farm level. Ph.D. thesis, University of Florida. Gainesville, FL.

Knowlton, K.F. 2000. Are Jerseys part of the answer? The Jersey Journal 47, 81.

Kross, B.C., Ayebo, A., Fuortes, L.J. 1992. Am. Fam. Physician 46, 183-188.

Lanyon, L.E. 1994. Dairy manure and plant nutrient management issues affecting water quality and the dairy industry. J. Dairy Sci.77, 1999-2007.

Leonard, R.A., Knisel, W.G., Still, D.A. 1987. GLEAMS: Groundwater Loading Effects of Agricultural Management Systems. Trans., Amer. Soc. of Agric. Engrs. 30,1403-1418.

Levin, S.A. 1991. The mathematics of complex systems. p. 215-226. In: Mooney, H.A., Medina, E., Schindler, D.W., Schulze, E.D., Walker, B.H. (eds.). Ecosystem experiments, scope 45. John Wiley & Sons, West Sussex, England.

Litell, R.C., Milliken, G.A., Strouop, W.W., Wolfinger, R.D. 1996. SAS system for mixed models. SAS Inst., Cary, NC.

Mavromatis, T., Jagtap, S.S., Jones, J.W. 2002. El Niño-Southern Oscillation effects on peanut yield and N leaching. Climate Res. 22, 129-140.

Mayer, D.G., Belward J.A., Burrage, K. 1996. Use of advanced techniques to optimize a multi-dimensional dairy model. Agr. Syst. 50, 239-253.

Meinke, H. Baethgen, W.E., Carberry, P.S., Donatelli, M, Hammer, G.L., Selvaraju, R., Stockle, C. 2001. Increasing profits and reducing risks in crop production using participative systems simulation approaches. Agr. Syst. 70, 493–513.

Meinke, H., Hochman, Z. 2000. Using seasonal climate forecasts to manage dryland crops in northern Australia - experiences from the 1997/98 seasons. pp. 149–165. In: Hammer G.L., Nicholls, N. and Mitchell, C. (eds.) Applications of seasonal climate forecasting in agricultural and natural ecosystems - The Australian Experience, Kluwer Academic, The Netherlands.

Mirvish, S.S. 1990. The significance of human health of nitrate, nitrite, and N-nitroso compounds. In Nitrate Contamination: Exposure, Consequence, and Control. NATO ASI Series, Vol. G30. Bogardi et al. (Eds.). Springer Verlag, Berlin.

Mourits, M.C.M., Huirne, R. B.M., Dijkhuizen, A.A., Kristensen, A.R., Galligan, D.T. 1999. Economic optimization of dairy heifer management decisions. Agr. Syst. 61, 17-31.

National Research Council (NRC). 2001. Nutrient Requirement of dairy cattle (7th Ed.). National Academy Press, Washington, DC.

National Research Council (NRC). 1995. Nitrate and nitrite in drinking water. National Academy Press, Washington, DC.

National Research Council (NRC). 1985. The health effects of nitrate, nitrite, and N-nitroso compounds: National Academy of Sciences, Washington, DC.

National Research Council (NRC). 1978. The health effects of nitrate, nitrite, and N-nitroso compounds: National Academy of Sciences, Washington, DC.

Natural Resource Conservation Service (NRCS). 2002. Soil survey geographic (SSURGO) database. Accessed December, 2002 http://www.ncgc.nrcs.usda.gov/branch/ssb/ products/ssurgo/

Natural Resource Conservation Service (NRCS). 2001. Water budget and nutrient balance worksheet, WATNUTFL Vers. 2.0. Part 650, Engineering Field Handbook. 210-VI-EFH. Gainesville, FL.

Nelson, R.A., Holzworth, D. P., Hammer, G. L., Haymand, P. T. 2002. Infusing the use of seasonal climate forecasting into crop management practice in North East Australia using discussion support software. Agricultural Systems 74, 393-414.

Nennich, T., Harrison, J.H., Meyer, D., Weiss, W.P., Heinrichs, A.J., Kincaid, R.L., Powers, W.J., Koelsch, R.K., Wright, P.E. 2003. Development of standard methods of estimate manure production and nutrient characteristics from dairy cattle. ASAE 701P1203, 263-268.

Newton, G.L., Johnson, J.C., Davis, J.G., Vellidis, G., Hubbard, R.K., Lowrance, R. 1995. Nutrient recoveries from varied year round applications of liquid dairy manure on sprayfields. p. 113-122. In Proc. 32nd Annual Florida Dairy Production Conf., Gainesville, FL. April, 1995. Dairy Sci. Dep., CES, IFAS. Gainesville, FL.

Norman, D., Collison, M. 1985. Farming systems research in theory and practice. pp16-30. In: Remenyi J.V. (ed.) Agricultural systems research for developing countries. Australian Centre for International Agricultural Research Proceedings No. 11, ACIAR, Canberra, Australia.

O'Brien, J.J., Zierden, D.F., Legler, D., Hansen, J.W., Jones, J.W., Smajstrla, A.G., Podestá, G., Letson, D. 1999. El Niño, La Niña and Florida's Climate: Effects on Agriculture and Forestry. The Florida Consortium: The Florida State Univ., the Univ. of Florida, University of Miami. Tallahassee, FL.

Ondersteijn C.J.M., Beldmanb, A.C.G., Daatselaar, C.H.G., Giesen, G.W.J., Huirne, R.B.M. 2002. The Dutch mineral accounting system and the European nitrate directive: implications for N and P management and farm performance. Agr. Ecosyst. Environ. 92, 283-296.

Onema, J., Koskamp, G.J., Galama, P.J. 2001. Guiding commercial pilot farms to bridge the gap between experimental and commercial dairy farms: the project 'cows and opportunities.' Neth. J. Agr. Sci. 49(2-3), 277-296.

Paine, M., Weatherly, J., Crawford, A., Champion, S. 2002. Farmlets as learning platforms: a national approach to farming systems research, development and extension in the Australian dairy sector. p. 729-738. In Proc. Fifth IFSA European Symposium, Florence, Italy 8-11 April 2002. International Farming Systems Association, European Group, Dip. di Economia Agraria e delle Risorce Territoriali, Facolta di Agraria, Universita degli Studi di Firenze, Florence, Italy.

Parton, W.J., Schimel, D.S., Cole, C.V., Ojima, D.S., 1979. Analysis of factors controlling soil organic matter levels in Great Plains grasslands. Soil Sci. Soc. Am. J. 51, 1173-1179.

Phillips, J.G., Cane, M.A., Rosenzweig, C. 1998. ENSO seasonal rainfall patterns and simulated maize yield variability in Zimbabwe. Agric. For. Meteorol. 90, 39-50.

Pittman, J.R., Hatzell, H.H., Oaksford, E.T. 1997. Spring contributions to water quantity and nitrate loads in the Suwannee River during base flow in July 1995. U.S. Geological Survey Water-Resources Investigations Report 97-4152. 12p. Tallahassee, FL.

Powers, L.E., McSorley, R. 2000. Ecological principles of agriculture. Delmar, Albany, New York.

Ribaudo, M., Gollehon, N., Aillery, M., Kaplan, J., Johansson, R., Agapoff, J., Christensen, L., Breneman, V., Peters, M. 2003. Manure management for water quality costs to animal feeding operations of applying manure nutrients to land. Agricultural Economic Report 824. Resource Economics Division. Economic Research Service. U.S. Department of Agriculture. Washington, DC.

Robertson, M.J., Carberry, P.S., Lucy, M. 2000. Evaluation of a new cropping option using a participatory approach with on-farm monitoring and simulation: a case study of spring sown mungbeans. Aust. J. Agr. Res. 51, 1–12.

Rosenhead, J. (Ed.), 1989. Rational analysis for a problematic world: problem structuring methods for complexity, uncertainty and conflict. Wiley, Chichester, UK.

Rymph, S., Boote, K.J. 2004. Modifying the Code of CropGro to Predict Growth of a Perennial Tropical Forage Grass. p. 66-67. In Proc. Biological Systems Simulation Conference, Gainesville, FL. 8-10 March 2004. University of Florida, IFAS, Gainesville, FL.

St-Pierre, N.R., Thraen, C.S., Jones, L.R. 1999. Forecasting herd structure, milk production and their variances for production risk management. Extension Research. Special Circ. 169-99. The Ohio State University. Columbus, OH.

SAS Institute. 1992. SAS/STAT software: Changes and enhancements. Release 6.07. SAS Tch. Rep. SAS Inst., Cary, NC.

Saxton, K.E. Rawls, W.J., Romberger, J.S., Papendick R.I. 1986. Estimating generalized soil-water characteristics from texture. Soil Sci. Soc. Amer. J. 50(4), 1031-1036.

Scragg, P.K.R., Dorsch, M.M., McMichael, A.J., Baghurst, P.A. 1982. Birth defects and household water supply. Med. J. Australia 2, 577-579.

Slabaugh, J.D., Jones, A.O., Puckett, W.E., Schuster, J.N. 1996. Soil survey of Levy County, Florida. USDA Natural Resour. Conserv. Serv., Washington, DC.

Staples C.R., Tervola, R.S., French, E.C. 1997. Forage Production Practices by Dairy Producers in the Suwannee Valley. Cooperative Extension Service, IFAS, University of Florida. Gainesville, FL.

Stewart, D.W., Shamdasani, P.N. 1990. Focus groups: theory and practice. Sage. London.

Stewart, J.C. 1990. Drinking water hazards: how to know if there are toxic chemicals in your water and what to do if there are. Envirographics Publishing. Hiram, OH.

Stoorvogel, J.J., Bouma, J., Orlich, R.A. 2004. Participatory research for systems analysis: prototyping for a Costa Rican banana plantation. Agron. J. 96(2), 323-336.

Strange, M., Krupicka, L. 1984. Farming and cancer, in It's not all sunshine and fresh air. Center for Rural Affairs, Walthill, NE. p. 41-53.

Suwannee River Partnership. 2004a. Suwannee River Partnership Background. Suwannee River Water Management District. Accessed May, 2004, http://www.srwmd.state.fl.us/features/suwannee+river+partnership/background.htm

Suwannee River Partnership. 2004b. Suwannee River Partnership Background. Suwannee River Water Management District. Accessed May, 2004, http://www.srwmd.state.fl.us/resources/22x11.pdf

Suwannee River Partnership. 2003. Suwannee River Partnership Programs and Research. Suwannee River Water Management District. Accessed February, 2003, http://www.srwmd.state.fl.us/features/suwannee+river+partnership/programs+and+research.htm

Thomas, B.P., Cummings, E., Wittstruck, W.H., 1985. Soil survey of Alachua County, Florida. USDA Natural Resour. Conserv. Serv., Washington, DC.

Thornley, J.H.M., Johnson, I.R.. 1990. A mathematical approach to plant and crop physiology. Clarendon Press. Oxford.

Tomlinson, A.P., Powers, W.J., Van Horn, H.H., Nordstedt, R.A., Wilcox, C.J. 1996. Dietary protein effects in N excretion and manure characteristics of lactating cows. Trans. ASAE 39(4),1441-1448.

Twatchtmann, D. 1990. Regulation of dairies in Suwannee River basin. Memorandum. Florida Department of Environmental Regulation, Tallahassee, FL.

Uryasev, O. Gijsman, A.J., Jones, J.W., Hoogenboom, G. 2003. SBUILD Create/edit soil input files for evaluation and application on crop simulation models for DSSAT v4. Agricultural and Biological Engineering Department, University of Florida. Gainesville, FL.

US Environmental Protection Agency (USEPA). 2003. National Pollutant Discharge Elimination System Permit Regulation and Effluent Limitations Guidelines and Standards for Concentrated Animal Feeding Operations; Final Rule. Federal Register. 68(29), 7175-7274. Feb.

US Department of Agriculture (USDA), Natural Resources Conservation Service. 1999. Nutrient Management Policy, NRCS General Manual, Title 190, Part 402. Available at: http://www.nrcs.usda.gov/technical/ECS/nutrient/gm-190.

US Department of Agriculure (USDA). Natural Resources Conservation Service. 1996. Agricultural waste management field handbook, Chapter 11: Waste utilization. Soil Conservation Service. 210-VI-NEH-651.11. Available at: http://www.info.usda.gov/CED/ftp/CED/ neh651-ch11.pdf

US Department of Agriculure (USDA). Natural Resources Conservation Service. 1992a. Agricultural waste management field handbook, Chapter 4: Agricultural waste characteristics. Soil Conservation Service. 210-VI-NEH-651.04. Available at: http://www.info.usda.gov/CED/ftp/CED/neh651-ch4.pdf

US Department of Agriculure (USDA). Natural Resources Conservation Service. 1992b. Agricultural waste management field handbook, Chapter 4: Agricultural waste characteristics. Amendment FL-9, FL651.1004(f). Soil Conservation Service. 210-VI-NEH-651.04-FL-9, FL651.1004(f)

US Department of Agriculure (USDA). Natural Resources Conservation Service. 1992c. Agricultural waste management field handbook, Chapter 6: Role of plants in waste management. Soil Conservation Service. 210-VI-NEH-651.06. Available at: http://www.info.usda.gov/CED/ftp/CED/neh651-ch6.pdf.

Van Horn, H.H. 1997. Manure Issues: Identifying nutrient overload, odor research report. Department of Dairy and Poultry Sciences, Univ. Florida. Gainesville, FL.

Van Horn, H.H., Newton, G.L., Kidder, G., French, E.C., Nordstedt, R.A. 2001. Managing dairy manure accountability: worksheets for nutrient budgeting. Coop. Ext. Serv. Circ. 1196, Univ. Florida. Gainesville, FL.

Van Horn, H.H., Newton, G.L., Nordstedt, R.A., French, E.C., Kidder, G.K., Graetz, D.A., Chambliss, C.G. 1998. Dairy manure management: Strategies for recycling nutrients to recover fertilizer value and avoid environmental pollution. Florida Coop. Ext. Serv. Circ. 1016. Univ. Florida. Gainesville, FL.

Van Horn. H. H., Nordstedt, R.A., Bottcher, A.V., Hanlon, E.A., Graetz, D.A., Chambliss, C.F. 1991. Dairy manure management: strategies for recycling nutrients to recover fertilizer value and avoid environ-mental pollution. Florida Coop. Ext. Serv. Circ. 1016, Univ. Florida, Gainesville, FL.

Van Horn, H.H., Wilkie, A.C.,Powers,W.J., Nordstedt, R.A. 1994. Components of dairy manure management systems. J. Dairy Sci. 77, 2008-2030.

Vellidis, G., Davis, J. Lowrance, R., Williams, R. 1993. Soil water nutrient concentrations in the vadose zone of a liquid dairy manure land application site. Paper no. 93-2549. In 1993 Int. Winter Meeting, Chicago. 14-17 Dec. 1993. Am. Soc. Agric. Eng., St. Joseph, MI.

Verburgh, L.D., 1994. Participative policy modeling, applied at the health care insurance industry. Ph.D. thesis. Benda, Nijmegen, The Netherlands.

Vereijken, P. 1997. A methodological way of prototyping integrated and ecological arable farming systems (I/EAFS) in interaction with pilot farms. Eur. J. Agron. 7, 235-250.

Vigil, J., Warburton, S., Haynes, W.S., Kaiser, L.R. 1965. Nitrates in municipal water supply cause methemoglobinemia in infant: Public Health Report, v. 80, no 12, p 112-119.

Vrba, J. 1981. General aspects of ground-water nonpoint pollution. In Van Duijvenbooden, W. (eds.). Quality of groundwater. Proceedings of an international symposium. Studies in Environmental Science 17. London, U.K.

Weatherspoon, R.L., Anderson, K., Anzalone, W., Bednarek, W., Chibirka, J., Cummings, E., Dahl, R., French, C., Jakel, D., Johnson, W.R., Neilson, R.W., Shurtliff, D. 1998. Soil survey of Lafayette County, Florida. USDA Natural Resour. Conserv. Serv., Washington, DC.

Weatherspoon, R.L., Cummings, E., Wittstruck, W.H. 1992. Soil survey of Gilchrist County, Florida. USDA Natural Resour. Conserv. Serv., Washington, DC.

Wilkerson, V.A., Glenn, P.B., McLeod, K.R. 1997. Energy and N balance in lactating cows fed diets containing dry or high moisture corn in either rolled or ground form. J. Dairy Sci. 80, 2487-2496.

Williamson, J.C., Taylor, M.Z.D., Torrens, R.S., Vojvodic-Vukovic, M. 1998. Reducing N leaching from dairy farm effluent-irrigated pasture using dicyanamide: a lysimeters study. Agr. Ecosyst. Environ. 69, 81-88.

Woodard, K.R., French, E.C., Sweat, L.A., Graetz, D.A., Sollenberger, L.E., Macoon, B., Portier, K. M., Wade, B.L., Rymph, S.J., Prine, G.M., Van Horn, H.H. 2002. N removal and nitrate leaching for forage systems receiving dairy effluent. J. Environ. Qual. 31, 1980-1992.

Wright, D.L., Teare, D.L.., Rhoads, I.D., Sprenkel, R.K. 1993. Pearl millet production in a no-tillage system. North Florida research and education center, Quincy. Florida Agric. Exp. Stat. Journal Series No: R-03054. North Florida Research and Education Center, Quincy, FL.

Wu, Z., Tozer, P.R., Groff E.B. 2001. Dietary manipulation of to reduce phosphorus and N excretion by lactating dairy cows. Department of Dairy and Animal Science. Pennsylvania State University. University Park, PA.

BIOGRAPHICAL SKETCH

Victor E. Cabrera was born on February 9, 1969, in Cusco, Peru. He received his B.S. and Engineering degrees in agronomy in 1993, from La Molina Agrarian University, in Lima. Victor did a postgraduate course in management of agricultural schools in Spain and France, in 1995. Victor received his M.S. degree in agricultural education and communication from the University of Florida, in 1999. Currently, Victor is finishing his Doctoral degree in interdisciplinary ecology in the School of Natural Resources and Environment at the University of Florida. He will graduate in August 7, 2004.

Victor E. Cabrera has worked as faculty, extension agent, extension programmer, consultant, manager, and research assistant. His website is http://plaza.ufl.edu/vcabrera.