MODELING NUTRIENT MOVEMENT IN THE ROOT ZONE USING GLEAMS

by

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(Under the Direction of Matthew Smith)

ABSTRACT

Dairy manure operations such as flush facilities and storage lagoons result in the accumulation of large volumes of dilute liquid manure. Land application of liquid waste can recycle slurry by using nutrients for plant growth. However, high application rates of liquid manure has led to nutrient concentrations that exceed acceptable drinking water standards in underlying shallow groundwater in Georgia (Hubbard et al., 1987). During 1991-1994, the University of Georgia Coastal Plain Experiment Station and the USDA-ARS Southeast Watershed Research Laboratory conducted a study to measure the amount of nutrients in soil resulting from land application of dairy waste. The present study uses the Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) Model to simulate nutrient movement within the root zone and compare it to the data gathered during the field study. The model was able to simulate concentrations within an order of magnitude. Research shows that GLEAMS should not be expected to provide mirror images of the real data but to represent the overall processes with reasonable accuracy since the modeling parameters were obtained from historical data.

INDEX WORDS: Dairy manure, Land application, GLEAMS, Root zone, Nitrate.

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B.S. Biological Engineering, The University of Georgia, 1999

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2004

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December 2004

DEDICATION

To my family, for their encouragement and support throughout all the years I have been far away from home.

ACKNOWLEDGEMENTS

I would like to thank my committee members, Dr. Matthew Smith, Dr. David Gattie, Dr. George Vellidis, and Dr. Richard Lawrence, for their feedback during the modeling process. Dr. Smith always welcomed questions and played an important role during the model setup. My work involving the GLEAMS model could not have been possible without the valuable help of Dr. Vellidis, who provided me with land application and weather data; and Dr. Knisel, for his coaching during the modeling process. I am grateful for Dr. Newton's help for answering endless questions concerning crop rotations and field management.

My special gratitude to Dr. Risse, Debbie Borden, and Hillary Smith Tanner in Engineering Outreach; working with them was a fabulous learning experience, which opened many doors in my professional career. Finally, Dr. Gattie, Dr. Tollner, and Dr. Verma, thank you for believing in my potential and supporting my work.

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Chapter 1

INTRODUCTION

It is a common practice for swine and dairy production to use gravity fed water to flush manure from confinement facilities (Merkel, 1981; Sweeten and Wolfe, 1994). The water is then routed to a series of storage/treatment lagoons. Facilities such as the one described have been in common use for the past 30 years and are eligible for cost-share funds and technical assistance in many watersheds and water quality improvements projects sponsored by USDA and other agencies (Lowrance and Hubbard, 2001). While providing efficient and cost effective manure collection, flush facilities and lagoons produce a relatively large volume of dilute liquid manure from a relatively small mass of concentrated feces and urine. Proper management of liquid manure involves the land application of nutrients needed for crop production, nutrient removal in a treatment system, or both.

Land application of liquid manure has the potential to recycle large volumes of slurry by using the nutrients available in manure for plant growth, replacing conventional inorganic fertilizers. Loading rates that do not exceed the assimilative capacity of the application site are a function of the nutrient uptake rates of the plants and microorganisms, the physical and chemical adsorption properties of the soils, the climate, and the management regime (Vellidis *et al*, 1996). In addition to uptake and removal in crop harvest, nitrogen may be lost from liquid manure management systems as nitrogen gas (N_2) due to denitrification and ammonia (NH_4–N) volatilization.

Even though land application systems are a positive solution for animal waste disposal, research has shown that application rates of liquid manure from dairy operations have led to nutrient concentrations that exceed acceptable drinking water standards in underlying shallow groundwater in the coastal plain of Georgia (Hubbard et al., 1987). Therefore, there is a need to monitor the loading rates and the fate of these nutrients being sprayed into the field. In this study the amount of nitrogen and phosphorous used and leached through the unsaturated or vadose zone will be quantitatively predicted using a computer model. In 1991, the University of Georgia Coastal Plain Experiment Stations (CPES) and USDA-ARS Southeast Watershed Research Laboratory began a three-year study on an experimental site to measure the amount of nutrients in soil resulting from land application of dairy waste. These data will be used to evaluate the results calculated by the model.

The computer model chosen to simulate the movement of nutrients through the root zone is called Groundwater Loading Effects of Agricultural Management System (GLEAMS) and it is designed to provide estimates of the impact management systems, such as planting dates, cropping systems, irrigation scheduling, and tillage operations, have on the potential for chemical movement (Knisel et at., 2000). Application rates, methods, and timing can be altered to account for these systems and to reduce the possibility of root zone leaching. The model also accounts for varying soils and weather in determining leaching potential. GLEAMS can also be useful in long-term simulations for pesticide screening of soil/management. The model tracks the movement of nutrients with percolated water, runoff, and sediment. Upward movement of nutrients and plant uptake are simulated with evaporation and transpiration. Erosion in overland flow areas is estimated using a modified Universal Soil Loss Equation (Knisel and Davis, 2000).

1.1 Objectives

The overall objective is to determine the ability of GLEAMS to simulate the movement of nutrients through the root zone for a field irrigated with liquid dairy manure. This will be achieved by:

1. Parameterizing the model using the soils, weather, and land application rates recorded at the CPES, Tifton, Georgia.
2. Comparing the model results with the actual data obtained from the field samples.

1.2 Hypothesis

GLEAMS will reasonably predict the movement of nutrients along the vadose zone and could be validated using real data gathered at the CPES.

1.3 Benefits

This research paper aims to assess the effectiveness of chemical transport models, such as GLEAMS, to simulate and predict water runoff and nutrients losses from a dairy manure operation in the coastal plain of Georgia. The results of the simulation will be compared with field observations from a controlled experiment. The results could be used to establish application rates without overloading the system, efficient cropping systems and rotations and develop best management practices. If accurate, it can be used to simulate diverse scenarios with different soils profiles and management systems to predict the effects of organic and inorganic fertilizer applications without the need for on-site experiments. Moreover, this type of technology could prevent the further contamination of water resources and will bring solutions to wastewater problems.

Chapter 2

LITERATURE REVIEW

Dairy, livestock, and poultry production in the Southeast is a continuously growing industry. Increasing numbers of animals, regardless of unit size, are located in specialized structures. Farms dedicated to animal production have limited space for manure distribution, sometimes provoking detrimental effects in water sources nearby. However, many rural areas depend upon the value-added nature of animal production for their economic prosperity (Newton et al., 1995). The utilization of manure on a regular, year-round basis offers the potential for recycling large volumes of waste by using available nutrients in the slurry for plant growth in place of conventional inorganic fertilizers (Vellidis, 1996). Manure utilization has been investigated to determine seasonal application, and the cost of nutrient loss, odor control, and overflow. Forage crops and crop rotations have been the focus of most research since there is a demand for forages in dairy cattle diets, and forage production removes more nutrients from the application site than grain production (Newton, 1998). Crop rotation consists of selecting a sequence of crops for a field that improves soil quality while producing optimum yields. Proper selection could ensure year-round growth in the Southeastern United States, reducing the need to apply manure onto dormant vegetation or increasing the need of larger storage facilities. Cover crops are plant species grown primarily to benefit the soil or other crops, while they may be harvested as well for seed or forage. In addition, forage rotation allows the maintenance of plants on the soil on a continuous basis protecting the field surface from erosion and curbing the degradation of soil structure.

Generally, manure may be applied to land in amounts slightly above the level of the nutrients removed by the crops harvested to account for the losses that might occur such as the loss of nitrogen due to the volatilization of NH_3-N and the loss of nutrients in runoff rain fall events which occur shortly after nutrient application. Moreover, when selecting a cropping system, its ability to take up the maximum amount of environmentally sensitive nutrients such as N and P should be taken into consideration. In cases where animal numbers are high compared to the amount of available land, there is a need to know the maximum application rates for given soil types and crops that can be efficiently utilized by different cropping systems.

Previous studies have analyzed the application of liquid manure to forage production systems and its environmental effects. The purpose of this study is to evaluate the accuracy of GELAMS to predict these effects in order to minimize on-site experimentation. This study will use GLEAMS to predict the movement of nutrients and compare its results to a long-term research project at Tifton, Georgia designed to identify a maximum, environmentally safe application rate of manure nutrients for a triple-cropping system.

2.1 Nonpoint source pollution models

Nonpoint source pollution (NPS) models and hydrological models are usually loading models that simulate the transformation and movement of nutrients, pesticides, and water from their origin to their treatment and/or disposal. NPS models can be classified in a variety of ways, depending on whether they are deterministic (every state is the inevitable consequence of antecedent conditions) or stochastic (involving a random variable), lumped-parameter or distributed-parameter, discrete-event or continuous (Novotny and Olem, 1993).

A deterministic model assumes that a certain set of events lead to a specific outcome, while a stochastic model presumes the outcome to be uncertain and is set up to provide a path or a series of paths towards this uncertainty. Lumped-parameter models treat a watershed or the main portion of it as one unit, employing effective parameters that may or may not have physical significance, whereas distributed-parameter models divide the watershed into smaller homogeneous units with uniform characteristics generally having a physical basis. Discrete-event models simulate the response of a watershed to a designated rainfall event, whereas continuous models provide time-series of water and waste loadings.

Agricultural NPS models can also be classified based on the spatial scale at which they are used, field-scale (unit area) models, or watershed-scale models (Zacharias, 1998). Field-scale models are usually lumped-parameter with continuous long-term simulation, while watershed-scale models may use a lumped or distributed-parameter approach and may be event-oriented (short-term) or continuous (long-term) in time scale. The majority of the agricultural NPS models have an erosion or surface runoff generation component that computes the conversion of precipitation into excess rainfall, based on reduction of surface storage, evapotranspiration (ET), and snow accumulation. Some add a subsurface component that describe the movement of water through unsaturated soil, and have submodels that balance soil moisture with infiltration rate, ET, and water loss due to percolation(Zacharias, 1998). Besides simulating hydrologic processes, these models simulate transformation processes that NPS pollutants undergo (e.g., nutrients transport in leachate and surface runoff) while in the soil profile. Since the focus of this study is on field-scale NPS pollution models that simulate subsurface losses, this paper will focus on GLEAMS.

GLEAMS is a deterministic continuous model that describes the one-dimensional, vertical movement of water and solutes in the root zone (Leonard et al., 1987). The number of processes and the level of detail at which water flow, solute transport, and chemical transformations are simulated may vary. Based on modeling structure, Addiscott and Wagenet (1985) classified solute leaching models into mechanistic and functional models, and as rate and capacity models. Mechanistic models incorporate the most fundamental mechanisms of the process (e.g., water and solute flow), whereas functional models employ simplified descriptions of the processes. Mechanistic models require detailed information about soil hydraulic properties and their results are usually sensitive to the parameter values, whereas functional models require fewer parameters but are applicable to a limited range of conditions. The distinction between rate and capacity models corresponds approximately to the distinction between mechanistic and functional models. A rate model defines the instantaneous rate of change of water content in terms of the product of a hydraulic gradient and a rate parameter, the hydraulic conductivity, and then defines the rate of change of solute concentration in terms of convection and diffusion rate processes (Zacharias, 1998). It is theoretically capable of simulating the transient system response. A capacity model defines changes (rather than rates of change) in amounts of solute and water content. Rate models are, by definition, driven by time. On the other hand, capacity models are driven by the amounts of rainfall, ET, or irrigation and only consider time indirectly (e.g. use daily amounts of rain). Even though the above definitions seem to represent distinct categories of models, it is best to regard them as being at different ends of a modeling spectrum, with a number of hybrids in-between. GLEAMS employs a capacity-based approach for water flow and solute transport.

Finally, models can also be classified into research, management, and screening models, based on their intended application (Wagenet and Rao, 1990). Research models incorporate the basic hydrologic processes and pollutant dynamics in fundamental terms and are intended to provide quantitative estimates of water flow and chemical behavior. However, research models require very detailed data sets in order to simulate the system and such information is not usually available. Management models use process-based components to represent the system; therefore the components are often simpler than the ones needed in research models to ease input set up and computational efficiency. Since the distinction between research and management models is not clear, simplified versions of the research models may be used in management. Screening models, on the other hand, usually consist of analytic solutions intended to categorize the relative behavior of pollutants under restricted conditions (usually, the specific set of conditions and assumptions used in developing the analytic solution).

According to Zacharias (1998), concentrations of pesticide, nitrate, and other agrochemicals measured in field soils vary spatially and temporally. The spatial variability in these observations results from a combination of intrinsic and extrinsic factors while temporal variability is caused mainly by changes in soil characteristics and rainfall patterns over time (Wagenet and Rao, 1985). Intrinsic spatial variability refers to natural variations in soil characteristics, often a result of soil formation processes, such as variations in soil texture that may result from weathering, erosion, or deposition processes; variability in organic matter content, which, in undisturbed sites, can be due to the influence of native plant communities. Studies on the direct effect of spatial variability on nitrate leaching started with screening models and have been gradually moving to more complex models. These studies have shown that spatial variability of flow parameters and spatial variability of chemical parameters influenced the spatial variability of leaching. However, very few studies provided any analysis in terms of actual field-observed spatial variability. Extrinsic factors that produce variations on the total spatial variability of NPS pollutants have not been investigated. More studies evaluating spatial variability of field-scale solute transport, using actual field measurements of soil properties, are needed for a more direct validation of the models, as well as to improve field sampling design and interpretation of results from field studies.

Agricultural NPS models are analytical tools used to evaluate the effects of various agricultural management practices on the surface and groundwater quality. They are valuable for predicting the behavior of nutrients and other chemicals under a wide range of conditions, which may be economically or technically impossible to investigate with real data or experimentally (Ma et al., 2000). Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) is a continuous simulation, field scale model, which is a modified version of the well validated Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) model (Shirmohammadi et al, 1999). It was designed as a field scale model for predicting runoff, erosion, and chemical transport from agricultural management systems. It is applicable to field-sized areas and can operate on individual storms but can also predict long-term averages (2-50 years). It also estimates surface runoff and sediment losses from the field.

The model was not developed as an absolute predictor of pollutant loading but as a tool to compare and analyze complex chemistry, soil properties, climate, cropping systems, and management practices (Knisel and Davis, 2000). It assumes that a field has homogeneous land use, soils, and precipitation. It consists of four major submodels: hydrology, erosion/sediment yield, pesticide transport, and nutrients. Each component describes an aspect of nutrient movement through the root zone and can be modified separately to simulate the multiple cropping systems and management practices.

Many field studies have shown that water and solute movement in field soils is spatially variable. Natural or intrinsic variations in soil hydraulic and retention properties account for part of the spatial variability. In addition, rate parameters, such as saturated hydraulic conductivity, are more spatially variable than capacity parameters, such as wilting point. Extrinsic factors, like nutrient application and tillage, may account for the rest of the spatial variability in chemical distribution in soil. Spatial variability of soil properties is not completely disordered but has structure and can be differentiated by the variations at two different scales. The larger scale variations are viewed as slowly varying trends and localized variations are viewed as locally stationary (Zacharias, 1998).

The available NPS models that simulate solute transport in the unsaturated zone are deterministic, and do not explicitly account for the spatial variations in soil properties and field processes. They consider one-dimensional, vertical movement of water and solutes in the unsaturated zone, and use different approaches and varying levels of complexity. The mechanistic models incorporate the fundamental mechanisms of the process and require detailed input parameter information, whereas functional models employ simpler descriptions of the processes and require fewer parameters. Despite the simplification, functional deterministic models have been shown to give simulations that are at least as good as those of mechanistic deterministic models under field conditions. Besides, model validation studies involving deterministic solute transport models have also indicated that representing spatial variability can lead to a more direct comparison of observed and simulated data, and may improve results.

2.2 Nitrogen Dynamics

Losses in nutrient values are expected in any application system, during collection, storage, and land application itself. Nitrogen losses are especially common due to volatilization and denitrification. In the collection and storage phase, nitrogen can be lost to the air as ammonia and by leaching and runoff. Land application of manure outside the growing season or in amounts that exceed crop needs may result in nitrate leaching losses of 25% or more (Van

Horn and Newton, 1996). Hence, it is expected that high nutrient utilization by crops can be achieved, with low environmental risks, when manure is applied at a time when crops can absorb nutrients and at rates that do not exceed crop needs.

Typically, total nitrogen (TN) in dairy lagoon effluent is composed of two-thirds ammonium nitrogen (NH_4-N) and one-third organic N. The NH_4-N is equivalent to nitrogen fertilizer since it is readily available for plant use during the first year of application, except for losses to the air since it is highly volatile. Organic nitrogen must be mineralized before it is available to plants.

Plant uptake will play an evident role in soil N dynamics. In general, the amount of N accumulated by a crop is affected by: a) the amount of N supplied by the soil or added as fertilizer; b) the genetic potential of the species to absorb N, which is influenced by genetic factors such as tolerance to biotic and abiotic stresses, rooting pattern and physiological N uptake efficiency; c) the growth or yield potential under a set of environmental conditions and soil properties; and d) the ability to retain N in the rooting zone during the period of crop N uptake (Hermanson et al., 2000).

Nitrogen use efficiency is defined as the amount of harvested crop that is produced per unit of N supplied during the growing season. Therefore, to improve N use efficiency means to produce more harvestable biomass per unit of N supplied. This term is very useful because its inverse represents the required N supply to produce a unit of harvestable biomass or unit N requirement (UNR) (Fiez et al., 1995). Typical N uptake efficiencies of major agronomic crops range from 30 to 70%. It is not possible for a plant to deplete all inorganic N from the soil solution. As nitrate and ammonium concentrations decrease, the rate of N uptake also decreases, in a relationship similar to substrate-enzyme reactions (Jackson et al., 1986). A minimum N concentration in the soil is required to drive the N influx into crop roots. Some N losses (volatilization or leaching) from the root profile are expected throughout the season. It could be said that to achieve maximum yields, N must be supplied at high levels. However, according to Mitscherlich's Law, as N supply increases, there is a decrease in the incremental yield per unit of N input (Hermanson et al., 2000). As a result, N use decreases at high levels of N input. On the other hand, if minimal N is supplied so that the soil N is depleted to near zero, minimizing nitrate leaching potential, there is an insufficient concentration of soil N to drive maximum N uptake, and crop yield will be limited. The presence of residual soil N at the end of a growing season is inevitable in intensively managed cropping systems that achieve near maximum or maximum economic yields. Reaching a balance between nutrient input and crop use is the key to a successful residual management system. Besides analyzing cropping systems, it is important to consider the different nutrient species and the respective transformations that will take place within the soil solution.

The main processes governing the presence of N species are mineralization (conversion of organic N to inorganic N), volatilization (release of NH_3-N to the atmosphere), denitrification (the reduction of NO_3-N to N gas and nitrous oxide followed by release of gases to the atmosphere), immobilization (assimilation by the microbial population) and plant uptake. The soil type, the environment, the chemical nature of the soil-waste system, and the waste application parameters (rate, time, and method) affect the rates at which these processes occur.

Organic N can be categorized as rapidly mineralizable, near-term mineralizable, and long-term mineralizable N. The first one consists primarily of uric acid, which is readily degraded and can be used immediately. Near-term mineralizable organic N is converted within a few months, while long-term mineralizable organic N may require years. Most of the mineralization process occurs due to the oxidation of the first two categories of organic N and may occur within weeks or even days after application (Edwards and Daniel, 1992). Mineralization is described as a two-stage process consisting of ammonification (the oxidation of organic N to ammoniacal forms) and nitrification (further oxidation of NH_4-N to NO_3). Formation may be inhibited when conditions favor volatilization (e.g. surface application of waste, high application rate, and high pH of the soil-waste system).

Mineralization may occur rapidly following waste application. Table 2.1 shows the mineralization rates for different types of wastes and management practices. In a study carried out by Pettygrove et al. (2003), samples from ten different liquid dairy manures from anaerobic storage lagoons were collected; organic N content ranged from 100 to 1600 mg/L. Net mineralization of N in a sandy loam soil at 22.3^{o}C was rapid during the first 21 days, and was slow and variable after that.

Table 2.1. General mineralization rates for nitrogen and phosphorus (USDA, 1996).

Waste and Management Practice	**Years after initial application**					
	1	**2**	**3**	**1**	**2**	**3**
	Nitrogen			**Phosphorus**		
	Percent Available (cumulative)					
Fresh poultry manure	90	92	93	80	88	93
Fresh swine or cattle manure	75	79	81	80	88	93
Layer of manure from pit storage	80	82	83	80	88	93
Swine or cattle manure stored in covered storage	65	70	73	75	85	90
Swine or cattle manure stored in open structure or pond (undholailuted)	60	66	68	75	85	90
Cattle manure with bedding stored in roofed area	60	66	68	75	85	90
Effluent from lagoon or diluted waste storage pond	40	46	49	75	85	90
Manure stored on open lot, cool-humid	50	55	57	80	88	93
Manure stored on open lot, hot-arid	45	50	53	75	85	90
Table assumes annual applications on the same site. If a one time application, the decay series can be estimated by subtracting year 1 from year 2 and year 2 from year 3. For example, the decay series for nitrogen from fresh poultry manure would be 0.90, 0.02, 0.01; the decay series for phosphorus from manure stored in open lot, cool-humid, would be 0.80, 0.08 and 0.05. The decay rate becomes essentially constant after 3 years.						

The net N mineralization during the first 21 days averaged 15-20% of the applied organic N. Liquid manure density, total suspended solids, and organic N content were related to each other. Mineralization is usually modeled as a first-order process with a relationship between inorganic N in the soil-waste system and time.

In most situations, very little nitrite exists in a system at any one time because the conversion of ammonium to nitrite is generally the rate-limiting step. Consequently, nitrite oxidation, into nitrate, follows quickly. Research has focused on nitrification because of the possible harmful health effects of NO_3 accumulation and leaching in drinking water sources. It had been determined that nitrification will not proceed at significant rates until volatilization essentially ceases. Edwards and Daniel (1992) stated that an initial lag of 10 days was found following application of poultry manure to a sandy loam before significant accumulation of NO_3 occurs.

Table 2.2. Nitrogen volatilization losses during handling and storage of dairy manure (Structures and Environment Handbook Midwest Plan Service, 1983).

Method	Nitrogen Loss (percent)
Solid	
Daily scrape and haul	15-35
Open lot	40-60
Liquid	
Anaerobic pit	15-30
Above ground storage	10-30
Earthen storage	20-40
Lagoon	70-80

Volatilization is a rapid process that occurs mostly within one week after waste application. Table 2.2 shows the percent volatilization for different waste management practices. Volatilization losses may significantly reduce the amount of N available for pollution and plant uptake. Giddens and Rao (1975) found that 48% of the total N in surface-applied poultry manure volatilized after 10 days of air-drying. Volatilization is usually modeled as a first-order process in which nitrification is assumed to be negligible while volatilization is occurring.

Even with a strict management system, there is considerable N loss through ammonia volatilization. Shortly after application, conditions favor volatilization of NH_3 rather than nitrification. It is estimated that nearly half of the manure N from dairy cows is in urea or ammonia form (mostly from the urine). This portion is volatilized very rapidly because of the rise in pH and the accumulation of NH_4-N (which inhibits nitrification) immediately after disposal. Anaerobic conditions also inhibit nitrification. The factors that favor volatilization include high temperature, low soil ion exchange capacity, rate of air movement across soil-waste surface, surface application, and the NH_3-N concentration gradient between soil-waste system and the atmosphere.

The loss of N_2 in the gaseous form is referred as the denitrification (conversion from $NO_3 \rightarrow NO_2 \rightarrow N_2$) and requires microbiological available C and anaerobic conditions. Anaerobic conditions may occur after land application of manure with high moisture content or after intense rainfall events, especially for poorly drained soils. There have been reports of rapid conversion of NO_3-N to gaseous forms following flooding. Greatest NO_3-N losses have been noted after 30-days aerobic incubation; virtually all NO_3 disappeared within 96 hours following saturation. Lesser losses of NO_3 were observed for longer aerobic incubation periods because the availability of C decreases as microorganisms utilize it. Denitrification can be expressed as a first-order or zero-order process.

Depending on the C:N ratio of the soil-waste system, microbial immobilization may occur under aerobic conditions. Immobilization is responsible for reducing inorganic N within 1-2 weeks after land application.

2.3 Crop Responses

According to Newton et al. (1995) crop yield response diminished with increasing manure input. A somewhat similar pattern was observed for nutrient removal by crops, except for rye in the rotation (for N and P removal) increased as manure application increased. At the lowest application rate, bermudagrass (BG) was responsible for 60% of the N and P removed while at the high application rate corn and rye removed similar amounts of N (35%). BG accounts for 30% of the N and 15% of the P removed while corn accounted for 60 % of the P (rye accounts for the remaining 25% of P).

Significant volatilization of N will occur because it is easily converted to ammonia and lost in the air as gas. Hence, nutrient content will be relatively less than the amount originally excreted since manure composition changes as time passes. In addition to volatilization, liquid will drain from the solids and manure will be diluted with the flush water. According to Van Horn et al. (1998) liquid manure handling could dilute manure to a solids content of less than 5%. Almost no nitrate occurs in manure, nitrification will occur once manure has been incorporated into the soil. The major forms of N in dairy manure are either organic N or urea N that is easily converted to ammonia and be lost to the air as gaseous ammonia. Some advantages of liquid manure handling are that it has low labor requirements and can result in relatively few nutrient losses when irrigation is frequent and growing crops are available to utilize the nutrients. Crop growth models employed by GLEAMS are empirical in nature. Processes such as management practices and tillage operations are explicitly defined in GLEAMS (Ma et al., 2000).

Since N uptake is influenced by overall plant vigor, growth, and therefore, yield, N uptake will often be expressed as a function of yield and biomass. This information is often used when identifying timing strategies for N fertilization, and synchronizing N mineralization with appropriate crops that will absorb the N as it is mineralized. N uptake also depends on root distribution; therefore, information on typical rooting depths would have to be included.

2.3.1 Corn (*Zea mays L.*)

Corn is grown for silage feed for livestock, grain feed (field corn) and sweet corn for human consumption. Most of the information available on soil-corn-N relationships focuses on field corn. Table 2.3 shows a summary (Hermanson et al., 2000) of ten recent N fertility experiments on corn. The experiments revealed a wide range of total N accumulation across many environments, management practices and fertilizations. The average experimental unit of N uptake was fairly consistent, ranging from 0.015 to 0.028 kg plant N/kg grain yield.

Over time, N uptake by corn is typically portrayed as a sigmoidal curve. Figure 2.1 describes the curve with little N uptake at the very beginning of growth, then a rapid acceleration until flowering, followed by lower rates or no net N gain during grain-filling (Hermanson et al., 2000). These patterns will vary yearly. Under favorable growing conditions, N accumulation rates are relatively constant from 6 weeks after planting to maturity (15 weeks).

Table 2.3. Summary of N accumulations in corn reported in selected research studies.

Location	Soil	Management Practice	Total N Uptake[1] Range	Mean	NHI[2]	UNU[3]	FNR[4]	Reference
			kg N/ha	kg N/ha	kg N/ha	kg N/ha	%	
Salisbury, MD	Typic Hapludult	Hairy vetch cover; NT	96-189	155	-	0.018	38	Clark et al., 1995
Rock Springs, PA	Typic Hapludult	Cont. corn; NT	107-142	124	-	0.017	-	Fox et al., 1986
Tifton, GA	Kandiudult Quartzipsamment	Irrigated	199-285	221	0.59	0.020	-	Gascho and Hook, 1991
Mead, NE	Typic Argiudoll	Irrigated	90-198	131	0.66	0.020	59	Kessavalou and Walters, 1997
Puyallup, WA	Aquic Xerofluvent	Prev. vetch, AWP	140-180	160	-	0.008	-	Kuo et al., 1996
Quebec, Canada	Grey Br. Luvisol Humic Gleysol	Cont. corn	97-251	174	0.58	0.020	35-57	Liang and MacKenzie, 1994
Lincoln, NE	Pachic Argiustoll AbrupticArgiaquoll	Soybean-corn	53-114	84	0.79	0.015	46	Maskina et al., 1993
VA	Typic Hapludult	CT, NT	80-180	164	0.64	0.028	-	Menelik et al., 1994
Guelph, Ontario	Gleyed Melanic Brunisol	Manure/Urea	60-140	116	-	0.020	-	Paul and Beauchamp, 1993
Aurora, NY	Aeric Hapludalf	Hairy vetch; NT	44-152	94	-	0.020	49	Sarrantonio and Scott, 1988

[1] Total N Uptake = total plant N (harvested plant part + other above ground parts, not including roots)
[2] NHI = Nitrogen Harvest Index (grain N/total uptake)
[3] UNU = Unit N Uptake; units of N in total plant (except roots)/ unit yield. Values shown are the mean of the various treatment of that study.
[4] FNR = Fertilizer N Recovery = estimated portion of applied N taken up by the plant. Values shown are the mean and range for the various treatments of the study.

In other years, N accumulation rate may decline during grain filling, particularly with lower N rates (Reeves et al., 1993). Senescing leaves are prone to volatilization of ammonia (NH_4-N), which contributes to the losses. Considering the time lapsed between planting and significant N uptake, sporadic applications are recommended, particularly for irrigated sandy soils or humid climates. For example, Gascho and Hook (1991) recommend 25% of the fertilizer N to be applied at planting, and the remaining applied throughout the growing season. The accelerated phase of corn N uptake occurs after that for winter wheat, but preceded bean (Figure 2.1).

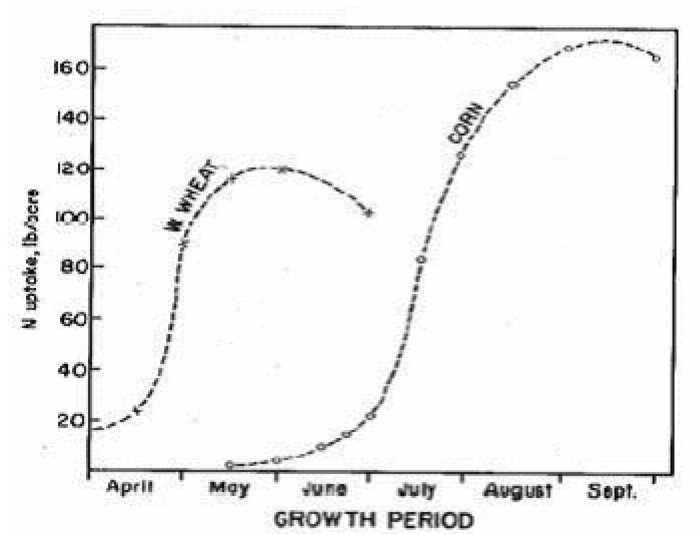

Figure 2.1. Comparative seasonal N uptake patterns for wheat and corn under Nebraska conditions (Bock and Hergert, 1991).

Corn root morphology is affected by several environmental and genetic factors (Olson and Sander, 1988). Residual soil nitrate can been used by corn to a depth of 180 cm (Gass et al., 1971), although effective corn rooting depths in irrigated cropping of central Washington is thought to be considerably less, perhaps as shallow as 30 to 60 cm. Corn roots were mainly observed in the top 20 cm A horizon of a North Carolina soil, with fewer roots measured in the 30 to 60 cm B horizon (Durieux et al., 1994). Increasing N fertilization increased the proportion of roots found in the A horizon. High bulk density and soil compaction can increase the proportion of shallow roots; such is the case of soils in Tifton that present a plinthic layer at approximately 75 cm depth that will limit root growth.

2.3.2 Tifton 44 Bermudagrass (*Cynondon dactylon L.)*

The two main factors that limit forage production are water and fertility of the soil. Water is the most important because plants will not grow in the absence of water, no matter how much fertilizer is available. Fertility, especially nitrogen, is the second most important limiting factor for production. In comparison to other plants, hybrid bermudagrass is water-efficient. Figure 2.2 depicts the relationship between the amounts of water needed to produce a pound of dry matter. Adding plant nutrients or fertilizer can improve the water efficiency of hybrid bermudagrass even more. In theory, since plants use nitrogen to build amino acids and proteins, the number of new cells that a plant can produce is directly related to the amount of nitrogen it is able to absorb. Thus, the more nitrogen and water available, the more the plants will grow. However, it is important point out that while organic fertilizers do provide N to bermudagrass, the effect is much slower than using synthetic N fertilizers.

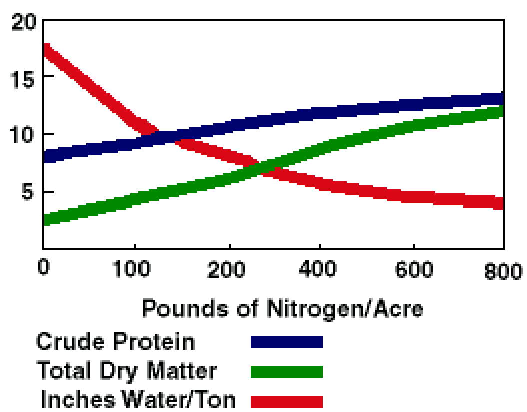

Figure 2.2. Effects of N rates on percent protein, yield, and inches of water/ton (Stickler and Bade 1997).

Although the results will vary, the general outcome will be similar. As the rate of nitrogen increases, the percent crude protein and yield increase dramatically, while the amount of water used to produce a ton of forage goes down. With low nitrogen rates, a high of 17.6 inches of water is needed to produce a ton of dry matter (Stichler and Bade, 1997). Adequate nitrogen fertilization is necessary to fully utilize the amount of water received by a crop. Water without fertilization will not produce new plant tissue.

Warm-season perennial grasses utilize nitrogen, phosphorus, and potassium at a ratio of approximately 4-1-3. Therefore, to produce 1 ton of dry forage, bermudagrass must absorb approximately 50 pounds of nitrogen per acre, 15 pounds of phosphorus, and 42 pounds of potassium. If the number of tons of forage desired multiplies these numbers, the product will equal approximately the pounds of nutrients needed. For example, for 4 tons of production, it will take approximately 30 inches of water during the growing season, and 200 pounds of nitrogen, 60 pounds of phosphorus, and 168 pounds of potassium (Stichler and Bade, 1997).

Splitting the applications of fertilizer throughout the growing season improves efficiency, which means that a greater percentage of the nutrients are utilized by the plants (Hardeman et al., 2000). It is important to test the soil every 2 to 3 years to determine if the natural mineral content of the soil is changing. In addition, many soils have the capability to provide some nutrients almost indefinitely. Fertilizer rates should be adjusted to maintain soil nutrients, without excessive buildup.

Whether the grass is grazed by livestock or harvested mechanically, the stage or level of maturity of the plant tissue will also determine its quality. Without proper harvest timing, high-quality forage will rapidly turn into "cardboard." Research conducted in Georgia on Coastal bermudagrass produced the following results (Table 2.4).

Although the yield was higher for an individual cutting at 6 weeks, the amount of protein produced per acre was almost the same as the amount of protein produced after 3 weeks. In these tests, cutting twice at 3-week intervals would produce twice the protein and almost twice the forage per acre as cutting at 6-week intervals.

Table 2.4. Effects of cutting intervals on quality of yield (Stichler and Bade, 1997).

Cutting	Interval	Yield (Weeks)	Percent Tons per Acre	Lb. Dry Protein	Percent Matter per Acre	Percent Leaf	Percent Stem
3	7.9	18. 5	2442	83	17	27	65. 2
4	8.4	16.4	2317	79	21	29.1	61.9
5	9.2	15.4	2329	70	30	30.6	59.3
6	10.3	13. 3	2292	62	38	31. 6	58
8	10.2	10. 7	1898	56	44	32.9	54.1
12	10.4	9	1612	51	49	33.4	51
The information given herein is for educational purposes only.							

Hybrid bermudagrass can produce high quality forage but like any other crop, proper variety selection, adequate soil preparation for planting, correct planting, adequate fertility, along with irrigation management, and, finally, timing of harvest will result in high quality feed and efficient uptake.

2.3.3 Abruzzi Rye (*Secale cereale L.*)

Cereal rye has a wide range of adaptability. It shows the widest geographic distribution of all cereal crops since its production is possible from temperate to subtropical zones. Its wide range of adaptation can be attributed to its winter hardiness and tolerance of marginal soils (Stoskopf, 1985). Rye is considered as one of the best cover crops during the winter months; it has a low requirement for lime (McLeod, 1982); and can out-yield other cereals on droughty, sandy, infertile soil. It is an annual grass (McLeod, 1982). Minimal temperatures for germinating cereal rye seed vary from 25 to 31^{o}C and 13 to 18^{o}C (Stoskopf, 1985). Starzycki (1976) stated that 3-5^{o}C or higher is required to germinate, with the optimal range being 25-31^{o}C. According to Stoskopf (1985), for vegetative growth to occur, a minimum temperature of

4^{o}C is required. Once well established, cereal rye can withstand temperatures as low as -35^{o}C (-31^{o}F). Cereal rye grows best on well-drained loam or clay loam soils, but even heavy clays, light sands, and infertile or poorly drained soils are feasible for rye growth.

The extensive root system of cereal rye enables it to be the most drought-tolerant cereal crop (Evans and Scoles, 1976), and its maturation date can change based on moisture availability. Cereal rye grows best with ample moisture, but in general it does better in low rainfall regions, and it can out yield other cereals on droughty, sandy, infertile soils (Stoskopf, 1985). Maturation date of cereal rye varies according to soil moisture, but vegetative growth stops once reproduction begins. Kutschera (1960) reported that cereal rye generally roots to a depth of 90-230 cm.

Rye produces large amounts of organic matter; however, biomass yields are not always great. In a three-year field trial in Georgia, cereal rye biomass averaged only 4,030 kg/ha (Hargrove, 1986), and Brinton (1989) mentioned only 1,240-1,460 kg/ha of dry biomass. Cereal rye produces more fall and early spring growth than oat (Miller, 1984).

Rye may stabilize and prevent leaching of excess soil or manure nitrogen. The mean N content of three year field trial in Georgia was 38 kg/ha (Hargrove, 1986), whereas Brinton (1989) listed a mean nitrogen content of 8 -16 kg/ha. Schonbeck (1988) noted that cereal rye has been shown to be allelopathic towards other plants, but some of the suppressive effects may relate to tie-up of soil nitrogen by decomposing rye residues. McCracken et al. (1989) documented first-year residual effects of nitrogen fertilization and cover crops of hairy vetch and rye in corn. One year after discontinuing the practice, the residual effect of N-fertilization was to increase N uptake by corn by 20.4 kg/ha over that seen with corn residue alone. Ranells and

Wagger (1996) found that, based on linear correlation coefficients, initial C:N ratio was a consistently significant predictor of N release by cover crop residues.

2.3.4 Crop Rotation

It is generally accepted that manure can be applied to land slightly above the level of the nutrients removed by the crops harvested, especially when animal numbers are high in relation to the amount of available land. Therefore, there is a need to determine the maximum application rates for given soil types and crops that can be used to take up the maximum amount of environmentally sensitive nutrients such as N and P.

Due to luxury consumption of N in plants with higher N applications, particularly for rye, the total N harvested in the three crops continued to increase after dry matter yields plateaued. The N application rate reported (382, 494, 741, 988 kg N/ha) is the amount of N pumped to the irrigation sprinklers (Johnson, et al., 1995). Losses of N through volatilization during irrigation (e.g. 20%), surface runoff, and acceptable losses to the groundwater potentially make the application of 741 kg N/ha in environmental balance with a total harvest of 590 kg N. These data do not show what happened to the excess N with the 980 kg N application. Preliminary data show that the nitrate levels in drainage water underneath the center pivot were similar to levels under many corn fields fertilized with commercial fertilizer but were slightly above the environmental standard of 10 ppm of NO_3-N required for safe drinking water. Due to the close proximity of the plots, they could not differentiate between application rates but presumably most of the excess came from the 980 kg N /ha applications.

Data in Table 2.5 show that it is possible for N removal in crops to be greater than that applied, e.g., 423 kg N harvested with 382 kg N applied. For this to happen, N must have originated from soil reserves of N carried over from previous years, from N in rainfall (often estimated at about 17 kg N/year), or from N fixation from the air (not likely without legumes in the system). However, with a deficit of N in the soil, gaseous losses from the soil might be reduced appreciably permitting the gain from rainfall to make a positive contribution. This gain might not be enough to make up the difference in the plots with the 382 kg N application rate. However, it could explain much of the difference in the 508 kg N harvest with the 494 kg N application.

Table 2.5. Annual nutrient uptakes by different cropping systems (Nordstedt et al., 1996).

Estimated kg harvest/ha:			
Crop	**DM**	**N**	**P**
#1(382 N/ha)	23,390	377	55
#2 (494 N/ha)	24,200	452	57
#3 (741 N/ha)	28,158	525	60
Estimated recoveries:			
Corn silage	16,000	208	35
Bermudagrass	18,000	346	40
Bermudagrass/rye	20,000	403	43
Bermudagrass harvested, (100.8 cm rain)[2]:			
0 N/ha	2,160	30	-
100 N/ha	7,920	132	-
300 N/ha	14,220	323	-
600 N/ha	17,460	442	-
900 N/ha	18,900	554	-
Amount excreted/cow/yr:			
Lower estimate	223	40	88
Higher estimate	267	46	146

[1] Dry matter (DM) and N data from Johnson et al., 1991
[2] Data cited by Staples, C.R. 1989. Proc. West Florida Dairy Prod. Seminar. Fl. Coop. Ext Sen. Dairy Science Dept, Univ. R., Gainesville, 32611.

Although, Johnson et al. (1991) did not report P application rates, P recoveries and recoveries of several other minerals were estimated from feed composition tables (NRC, 1988). These data and data for several other example crops and systems are also shown in Table 2.5. Phosphorus recoveries were 55 to 60 lbs per acre. The P harvests are of particular interest since more acres would appear to be required to accommodate manure P than manure N. Although it is tempting to compare data in this table directly with estimated excretion rates to estimate acreage needed for manure disposal, factors such as volatilization of N, surface and groundwater runoff, and export of some manure fractions off the farm must be considered in the budgeting procedure.

Other forage crops, even legumes, like alfalfa and perennial peanut, have been proposed as being good crops for consuming large quantities of manure nutrients since legumes take up soil N in preference to fixing N from the air when free N is available in the soil to "scavenge." Although there may be potential for greater recovery of P in the enormous quantity of biomass harvested in giant elephant grass than from other crops, the estimated digestible energy value of the harvested forage would be low.

The Georgia cropping system would seem to have tremendous potential for Southern United States because a large part of the harvest is corn silage, which is a high-energy forage that fits the feeding management that most dairymen use for high producing cows and the sod base is bermudagrass which grows well in a warm season. The alfalfa, perennial peanut and giant elephantgrass systems are more hypothetical at this point and need further testing.

One of the major strengths of using flushed manure systems along with irrigation, is that additional water can be applied along with fertilizer nutrients so that full response to added nutrients is possible. After designing the essential components of the manure management system and estimating total manure nutrient excretion, the next step to account for what happens to nutrients on the farm. Many alternatives can be developed to avoid nutrient leakage to the environment, including the utilization of a cropping system and a land application system that are in nutrient balance. If land with an appropriate cropping system is available to utilize all nutrients, it is important to apply manure onto cropland soon after it is produced to recover the maximum amounts of N.

Chapter 3

SITE CHARACTERISTICS AND DESIGN

The data to be used to parameterize and validate the model were collected in a previous study carried out by USDA-ARS Southeast Watershed Research Laboratory and The University of Georgia Coastal Plain Experiment Station (CPES). The three-year study investigated the environmental and economical feasibility of land applying liquid dairy manure on a year-round forage production system.

3.1 Site Description (Vellidis et al., 1996)

The dairy manure application was initiated in June 26, 1991, on a 6.5 ha field that had never received manure applications. The site is located in Tifton, GA, at The University of Georgia CPES. Manure was collected from a freshwater flush-cleaned CPES research dairy loafing area and passed over a 1 x 6 mm fixed screen to remove large solids before being routed to a two-stage storage lagoon.

The field was used for conventional corn production until 1985 and then was planted with Tifton 88 Bermudagrass (*Cynondon dactylon L.*) sod for forage production. The site received commercial inorganic fertilizer at rates recommended by The University of Georgia Cooperative Extension Service. Fertilizer application was discontinued in 1990 and the Tifton 88 Bermudagrass was replaced with Tifton 44 Bermudagrass (*Cynondon dactylon L.*) in the spring 1991. CPES scientists defined the operational cropping system. It consisted of overseeding abruzzi rye (*Secale cereale L.*) into the Tifton 44 Bermudagrass (*Cynondon dactylon L.*) in the fall, followed by a rye haylage during the end of March (Newton, 2004). Silage corn (*Zea mays*

L.) was planted applying minimum tillage into the bermudagrass and rye stubble in the spring, followed by summer crops of hay or silage from the residual bermudagrass. During the summer, hay was harvested on a monthly schedule.

The land was comprised primarily of Tifton loamy sand (fine loamy, siliceous, thermic Plinthic Kandiudults), which contains argillic and plinthic horizons of low permeability. These horizons tend to restrict downward percolation. At a depth of approximately 1 m, these soils are underlain with plinthite and Miocene age materials of very low permeability. Past research has shown that in the plinthic soil in Tifton upland, 99% of infiltrating water moves down slope as a shallow lateral flow (Hubbard and Sheridan, 1983). The slope of the site ranges from 1.5 to 2.0%.

An automated 5.6 ha, three-tower center pivot irrigation system was installed on the site. The irrigated area was divided into quadrants along the topographic lines; each quadrant represented a treatment area with different irrigation rates. The quadrants were designated as North, South, East, and West. Each received target nitrogen-based liquid manure application rates of 600, 200, 800 and 400 kg N/ha yr, respectively. The application rates were selected so the lowest rate was restrictive to plant growth and the highest rate was excessive for the maximum plant growth based on N uptake rates. The center pivot system could be used to apply water from the manure storage lagoons or from a freshwater pond. Liquid manure was applied at intervals of 7 to 14 days based on weather conditions and storage capacity of the holding lagoons. The four loading rates were achieved by applying larger volumes of liquid manure for the higher N rates. For the 200, 400, 600 and 800 kg N/ha yr loading rates, this corresponded to approximately 5, 10, 15, and 20 mm of liquid manure per application, respectively. Freshwater was applied to the all quadrants following liquid manure application to equalize the depth of water applied. Periodically, freshwater was also applied to meet crop evapotranspiration demand.

3.2 Soil Samples

Since the soils characteristics for the referenced field were unavailable, data from a nearby field with the same soils series, Tifton loamy sand was used. Ma et al. (2000) conducted a study on a field owned by the Abraham Baldwin Agricultural College (ABAC). Soil properties were obtained from 24 pedon samples taken along four downslope transects. Saturated hydraulic conductivity was measured with undisturbed cores (60-mm i.d., 89-mm height) by the constant head method. The cores were then analyzed for their soil bulk density and water retention. Soil water content at 33 kPa and 1500 kPa suctions were measured in pressure chambers from loose soil. Particle size distribution and organic carbon content were determined by the methods of Day (1965) and Walker-Black (Nelson and Sommers, 1982), respectively.

3.3 Sampling

Samples were collected to determine the concentrations and cumulative amounts of NO_3-N, NH_4-N, Total Kjeldahl Nitrogen (TKN), Total Nitrogen (TN), PO_4-P and Total Phosphorous (TP) applied through the liquid manure, assimilated by the crops, stored in the soil, and leached to shallow groundwater. Water and nutrient movement through the unsaturated (vadose) zone was monitored.

Three sample plot areas, 4x4-m, were established within each quadrant as the primary sampling and instrumentation sites. Four cups samplers, installed on 2-m poles so that they would be above the canopy, measured the depth of each liquid manure application. Concentrations and cumulative amounts of applied nutrients were determined from the collected samples (Vellidis et al., 1996).

Soil samples were taken from established locations adjacent to the perimeter of the 12 sample plots at 5 depth increments to 0.3-m before planting and after harvest of each crop. Gaseous loss of N from the soil through denitrification was measured at monthly intervals with intact core samples (Lowrance et al., 1995) taken to a depth of 0.3 m adjacent to the sample plots. At harvest, crop yields, tissue samples, and the soil samples, all taken from the established locations adjacent to the plots, were used to determine plant nutrient uptake.

3.4 High-tension Soil Solution Samplers

Nutrient concentrations in the soil solution of the vadose zone were monitored with a semi-automated network of high-tension soil solution samplers (suctions lysimeters). Eight samplers were installed in three plots of each quadrant. Thus, there were 24 samplers per quadrant, and a total of 96 samplers in the experimental site. A main feature of the solution sampling system was a centralized vacuum source located at the pivot point and a vacuum distribution network (solid lines radiating from the pivot point in Figure 3.1). The idea was to exert a continuous and steady negative pressure (~ -60kPa) on the solution samplers for 24 h before sampling. The system was developed to eliminate the labor-intensive, time-consuming process of evacuating each solution sampler with a hand-held pump.

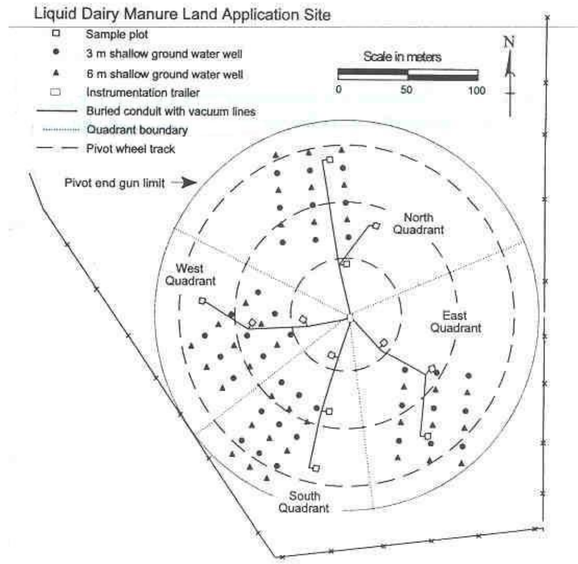

Figure 2–Map of the research site showing the delineation of quadrants, the location of the sample plots, the buried conduit leading to the plots, and the location of the monitoring wells (Drawing by H. L. Batten, 1991).

Figure 3.1. Center pivot coverage area showing the delineation of the quadrants, the location of the sample plots, and the monitoring wells (Newton et al., 1995).

Each sample plot contained two parallel soil solution sampler arrays installed at depths of 0.5, 1.0, 1.5, and 2.0 m, a total of eight solution samplers per plot. Within each array, the individual samplers were installed 1 m apart. The two arrays of each plot were 3 m apart. The solution samplers were constructed from 1 bar, high flow ceramic cups, 48 mm diameter x 60mm long, attached to a 300 mm long, 48 mm OD schedule 40 PVC pipe with epoxy. The top end of the sampler was sealed with a PVC cap. A 6.4 mm Teflon® sampling tube extended from the inside bottom of the ceramic cup to a bulkhead fitting on the PVC cap. A male connector fitting on the cap was used to attach the vacuum line. Each sampler was fitted with lengths of sampling and vacuum tubing which were the only items that protruded above ground when the samplers were installed at their designated depths. Layers of bentonite clay were used during installation to prevent direct flow down the sides of the sampler to the ceramic cup.

The soil solution samplers were sampled on a biweekly schedule. Once the negative pressure had been applied for 24 h, it was released, and a portable, battery-operated peristaltic pump was used to collect a water sample and purge each soil solution sampler. A 400-mL sample was collected from each solution sampler in a 500-mL glass sample bottle, transported back to the laboratory, and stored at 4^{o}C until analyzed. Samples were analyzed for NO_3-N, NH_4-N, TKN, TN, PO_4-P and TP using standard, EPA approved colorimetric techniques.

3.5 Field Results

Most forage crops will accumulate N relative to its availability (luxury consumption) if other no major or minor plant nutrients, sunlight, moisture, and temperature are limited. Actual dry matter and N yields of the three crops in their rotation in response to different rates of liquid manure application are shown in Table 4.1. Harvests of crops yielded 6.2 tons of dry matter per acre (12,400 lbs) with N-deficient application (214 lb N/acre) and yield plateaus at 12.5 to 13.0 tons of DM/acre with manure wastewater applications of 564 lb N/acre or more. On the other hand, crop removals of N continued to increase after DM yields stabilized because of luxury consumption of N, which increased crude protein and N concentrations of crops harvested.

Table 3.1. Yield of forage dry matter and recycled N from crops fertilized with flushed manure through center pivot (Van Horn et al., 1998)

Estimated application of N (lb/ac)	Crop, Tons of dry matter of lbs N/ac							
	T-44 bermudagrass		Abruzzi rye		Corn		Total	
	DM (tons)	N (lb)	DM (tons)	N (lb)	DM (tons)	N (lb)	DM (tons)	N (lb)
214	3.4	91	1.1	47	1.8	44	6.2	182
376	3.4	114	2.0	107	4.4	115	9.8	335
564	4.1	162	2.3	124	6.4	188	12.8	474
712	2.7	111	2.9	172	7.4	236	13.0	519

P removals of 90 lb/acre were possible because of some luxury consumption of P. For example, P removals in year 2 were 49, 79, 89, and 93 lbs/acre in the 6.20, 9.82, 12.80, and 13.00 tons of DM harvested. Application rates were 46, 82, 129, and 180 lbs/acre (Newton et al., 1995). However, consumption of P does not occur to the extent that it does with N. Table 4.2 illustrates the expected range in N and P composition in commonly grown forage crops and the effect that has on crop removals. Other forage crops, even legumes, like alfalfa and perennial peanut, have been proposed as being good crops for consuming large quantities of manure nutrients. When free N is available in the soil, legumes take up soil N in preference to fixing N from the air.

Table 3.2. Estimated N and P removals in crops for a given DM yield due to variation in composition.

Crop	Yield (tons/ac)		N removals		P removal	
	wet	DM	% DM	lb/ac	% DM	lb/ac
Corn silage	18.0	6.0	1.4-2.0	168-240	0.22-0.47	26-57
Rye haylage	6.0	3.0	2.6-3.3	156-198	0.23-0.50	14-30
Bermudagrass hay	6.0	5.0	1.8-2.9	180-290	0.20-0.34	20-34

According to Van Horn et al (1998), the studied cropping system (bermudagrass-corn-rye) has great potential for Southern United States because a large part of the harvest is corn silage, a high-energy forage that fits the feed needs of high producing cows; the bermudagrass forms a sod base and forage for harvest in the warm season; and rye utilizes a large amount of N during the winter season. One of the major strengths of using flushed manure systems, along with irrigation, is that additional water can be applied along with fertilizer nutrients so that full response to added nutrients is possible.

Analysis with respect to quadrants (vertical comparison) in Table 3.3 shows that NO_3-N was significantly different for each application. The statistical difference in year 1 may be attributed to the initial lower NO_3-N concentrations in the west quadrant. Although years 2 and 3 reflect initial differences, treatment effects are evident. No other statistical differences were found for any other nutrient, NH_4-N and TKN. Analysis with respect to time (horizontal comparison) show that NO_3-N concentrations increase with time at all depths in the S and N quadrants. No significant differences were found over time and at any depth for the W quadrant. If NO_3-N concentrations at 2.0 m are assumed to be indicators of leaching below the root zone, it could be inferred that NO_3-N concentrations are depleted under the lower application rates, while NO_3-N concentrations at 2.0 m are being replenished under the two higher rates and potential contamination of shallow groundwater will increase (Vellidis et al., 1996).

Table 3.3. Mean annual concentrations (mg/L) in soil solution samples at 1.5 m for each quadrant. Statistical companions are made for each year between quadrants (vertical) and each quadrant between years (horizontal).

Quadrant	NO_3-N			NH_4-N			TKN		
	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
E	5.41	2.13	1.39	0.08	0.02	0.12	4.80	2.16	0.18
W	3.36	3.90	3.67	0.08	0.08	0.60	3.32	2.41	0.50
N	6.77	10.29	8.86	0.18	0.64	0.10	5.42	2.90	0.31
S	5.46	10.49	10.84	0.13	0.16	0.11	3.58	2.38	0.23

In a study completed by Lowrance et al. (1998) at the CPES site, samples were taken bimonthly before manure application (July 1990 – May 1991) and monthly after manure application began (June 1991- July 1993). Nitrate increased significantly in all quadrants. The largest increase occurred in the S quadrant since it had the highest manure application rate (800 kg N/ha). In general, increases were proportional to manure application; however, data was not significantly correlated with denitrification. Denitrification increased significantly after manure was applied; from 3 to 10 times the pre-application rate for year 1 and even greater for year 2.

Denitrification rates were not consistent with application rates; N quadrant > S quadrant and E quadrant > W quadrant. Peak denitrification rates, for all quadrants, occurred in January 1993 and April 1993. Denitrification rates, nitrate, and ammonium concentrations tended to be higher in the top than in the lower soil layers, while water filled pore space (WFPS) was highest in the deeper horizons. WFPS is an important factor because enhanced rates of denitrification were observed in soil cores with elevated soil moisture. Denitrification is thought to proceed at optimal rates with 60% or more WFPS (Lowrance et al., 1998). The study observed that the N and E quadrants had a higher percentage of WFPS than the S and W quadrants; thus, denitrification occurred at a higher rate in the N and E quadrants. It was concluded that WFPS drove the denitrification process, assuming abundant carbon available.

The volume of solution extracted from the samplers varied spatially as well as with sampling event. The volume of water collected depended on the amount of rainfall events, liquid manure and freshwater applications that occurred in between sampling periods, which took place every two weeks. Under good conditions, samples had volumes of 300 to 400 mL but under dry conditions, volumes decreased dramatically. Therefore, the nutrient analyses on samples of less than 20 mL were not included because under these circumstances nutrient concentrations were erratic and unreliable.

Chapter 4

GROUNDWATER LOADING EFFECTS OF AGRICULTURAL MANAGEMENT SYSTEMS (GLEAMS)

4.1 Model description

GLEAMS is a continuous hydrology and chemical transport model that simulates the transfer and transformation of nutrients and pesticides within the root zone and in surface runoff. It is a field scale model, where field can be defined as a management unit having single land use, homogenous soil, spatially uniform rainfall and a single management practice (Muller and Gregory, 2003). The model is based on a nonpoint source model called CREAMS (Knisel et al., 1993) and has added components to simulate water and chemical movement within the crop root zone. It runs on a daily step, using daily rainfall information.

In order to simulate the many processes that take place on a field, the model was subdivided in three separate components: hydrology, erosion, and plant nutrient. Each submodel requires a separate parameter file to input data and a specific output where results are written. The input parameters will be set up by the user to best represent the particular characteristics of the site. The model provides default values; however, it is important to stress the importance of using site-specific data for more accurate results.

GLEAMS uses daily rainfall and temperature records that were obtained from a rain gage and weather station near the site. The measured rainfall file was edited to include the irrigation water applied to the site for each quadrant.

4.2 GLEAMS Submodels

4.2.1 Hydrology Submodel

The hydrology submodel models runoff, soil water distribution, ET, and irrigation. Since irrigation was applied with a pivot, the depth was added into the precipitation data file. This component is based on the hydrology component used by its predecessor, CREAMS, and most of the routines are the same.

GLEAMS uses a modification of the SCS Curve Number method (Williams and La Seur, 1976) to predict runoff; the traditional 5-day antecedent rainfall was replaced with the available storage in the root zone on the day of the rainfall (Muller and Gregory, 2003). Soil water calculations are done on a daily basis to obtain the soil-water content and the available storage for each soil layer. Then, the curve number is adjusted to consider the current moisture conditions. The modification makes GLEAMS a more physically based model; hence, it does not need calibration before running in a continuous basis.

The potential ET was estimated running the Priestly-Taylor method for humid climates. This method uses daily temperature and radiation data. Actual soil evaporation and plant transpiration are simulated separately by the method developed by Ritchie (1972) for incomplete cover. Separate components of the ET are needed to partition chemical movement upward in the soil and into the transpiration stream for plant uptake. Plant transpiration is approximated from the active root zone using a decreasing exponential function.

Water redistribution is simulated within the plant root zone using the transmission and retention capacity of the computational soil layers (Muller and Gregory, 2003). Water movement from one soil layer to the next is characterized by a system of linked linear storages utilizing water content at field capacity (FC), water content at wilting point (BR15), and porosity

(POR). The travel time through each layer is estimated from the thickness and saturated conductivity for each layer (Knisel et al., 1991). The root zone may be specified with as many as 5 soil horizons with varying soil properties. The effective root zone can be divided into a minimum of 3 and a maximum of 12 computational layers, depending on the depth and thickness of the soil horizons. The surface layer has a thickness of 10 mm and the remaining layers in the topsoil are a maximum of 100 mm thick but divided into equal thicknesses. The other layers are a maximum of 150 mm thick, equally divided. The lower layers may be larger than 150 mm to meet the 12-layer limit (Knisel et al, 1989)

GLEAMS employs a capacity based approach to simulate one-dimensional, vertical movement of water and solutes in the unsaturated zone. The model will simulate the effect of a restrictive soil layer or horizon that impedes root growth and/or water movement (e.g. plinthic layer, or clay pan) by allowing the user to specify its saturated hydraulic conductivity of the layer (RC). The plinthite layer was not physically added as another layer in GLEAMS; instead, its saturated conductivity was specified as the Ks of the layer below the root depth that restricts water flow. The SATK of the horizon immediately below the effective root depth is used with a 30 cm thickness to calculate travel time in that horizon. If the SATK is less than the bottom horizon, characteristics of clay are assumed for FC, BR15, and POR. Percolation is assumed to occur though the layer but will not be allowed to move back up into the root zone since the depth of the water table is not specified (Leonard et al., 1987).

The field used in the GLEAMS simulation was 6.5 ha with an average 2.3 percent slope. The estimated mean sea level was 106.7 m and latitude was 31.48 degrees North. The characteristics of the simulation field corresponded to the Southeast Georgia climate, field conditions and soil characteristics. Average monthly values for maximum temperature, minimum temperature, dew point, wind speed, and radiation used by the model were obtained from the weather station approximately 0.5 km from the field research site.

Information gathered from the UGA Coastal Plain Experimental Station and the Abraham Baldwin Agricultural College research farm was used to specify soil properties as input to the hydrology and erosion components of GLEAMS. The properties of the soil at the field experiment site were used for the GLEAMS simulation. The soil was a Tifton loamy sand profile with 5 horizons described in Table 4.1.

Table 4.1. Means (n = 24) of measured soil and soil hydraulic properties of the major diagnostic horizons of Tifton loamy sand at the Abraham Baldwin Agricultural College research farm (Ma et al., 2000).

Depth	**Sand**	**Silt**	**Clay**	**OC**[1]	**OM**[2]	**θ_{sat}**[1]	**θ_{33}**[1]	**θ_{1500}**[1]	**ρ**[1]	**φ**	**K^g_s**[1]
m	**%**			**m^1/m^1**		**Mg/m^3**			**cm^3/cm^3**		**cm/hr**
0.0 –0.29	84.6	9.3	6.1	0.79	1.36	0.38	0.14	0.05	1.64	0.38	12.1
0.29-0.62	63.4	11.4	25.2	0.34	0.59	0.36	0.22	0.15	1.69	0.36	4.54
0.62-0.92	62.9	11.0	26.1	0.24	0.41	0.37	0.26	0.16	1.66	0.37	3.52
0.92-1.11	62.3	10.6	27.1	0.12	0.21	0.37	0.26	0.18	1.68	0.37	3.35
1.11-1.50	60.4	11.8	27.8	0.02	0.03	0.36	0.28	0.18	1.69	0.36	0.49

[1]organic carbon; θ_{sat} θ_{33}, θ_{1500} are volumetric soil water content at 0-, 33-, and 1500-kPa suction, respectively; ρ is soil bulk density; and K^a_s and K^g_s are arithmetic and geometric means of saturated hydraulic conductivity, respectively.
[2]OM = 1.724*OC.
[3]Porosity $\varphi = 1 - (\rho_b/\rho_s)$; ρ_s =1.65 g/cm^3

The typical rooting depths for the crops were 12 to 50 cm. It was assumed that below 50 cm percolated water and any dissolved nutrients would be lost to deep percolation and may enter the groundwater supply. Values for the parameters for which data were not available were selected based on information and recommendations in the GLEAMS User Manual (Knisel et al., 1992). Table B.1 shows the value, description, and justification for each entry within the hydrology component.

Implications of overestimating or underestimating runoff can be visualized when considering timing of simulated and measured runoff relative to nutrient applications. For example, small volumes of runoff within a few days of surface manure application may result in high concentrations in runoff (Knisel and Leonard, 1990). Therefore, imperfections in the hydrology component may have repercussions on other system responses depending on soil, climate and fertilizer characteristics.

4.2.2 Erosion Submodel

The erosion parameters are largely unchanged from CREAMS (Knisel, 1980). This component uses the Foster et al. (1977) modification of the Universal Soils Loss Equation (USLE) and the principle of continuity of mass to predict erosion and sediment yield and transport under topographic conditions and management practices. For GLEAMS, the change in soil loss ratio is a function of crop growth and canopy, which is a gradual and continuous change. Total sediment yield and the enrichment ratio are estimated at the edge of the field but there is not actual differentiation on its origin. Thus, there could be discrepancies between the simulated and observed nutrient concentrations based on the origin of the nutrients that were carried in sediment and runoff.

In this case, runoff on the field was designated as overland flow because of the small incline and lack of channelization. Computation begins at the upper end of the overland slope. Crop cover, management practice, and Manning's roughness factors are entered into the erosion component to simulate soil disturbance throughout the crop rotation. These factors are used in the Universal Soil Loss Equation and are updated during the year. The processes of detachment and deposition are both considered and each condition occurs based on the relationship between transport capacity of runoff and sediment load. Soil sediment load on sloping land is controlled by either the amount of sediment made available by detachment processes or by the transport capacity of the flow. Decreasing flow volume and velocity translates into sediment deposition due to a decrease in transport capacity. The soil erodibility factor (K) was calculated using the Tifton loamy sand soil data described in Table 4.1. Table C.1 extensively explains the values used to set up the erosion parameters.

4.2.3 Nutrient Submodel

The nutrient component is the most complex of the three components and considers the nitrogen and phosphorus cycles. It considers the different processes within the nutrient cycles (mineralization, immobilization, nitrification, denitrification, volatilization, crop N uptake, and N losses in runoff, sediment, and percolation below the root zone) as well as inorganic fertilizer and animal waste applications. Figure 4.1 shows a schematic of the nitrogen cycle considered in GLEAMS. The daily observed data for nutrient application was available from June 1991 to May 1994. The soil was tested for different forms of nitrogen and phosphorus using suction lysimeters; however, the phosphorous data was scarce and inaccurate for the most part.

The erosion component also considers tillage operations to account for incorporation of crop residue and fertilizers. Minimum tillage operation and equipment were used only to overseed and harvest corn. Finally, even though the initial soil total N and P are considered sensitive parameters, previous studies established that longer runs are more insensitive to nutrient initialization. Since the model runs were for a long period of time, the outputs were relatively insensitive to the initial values of the nitrogen and phosphorus pools; the observable period occurred approximately 6 months after the model started the run. Table D.1 explains in detail the values used and a brief justification and/or source.

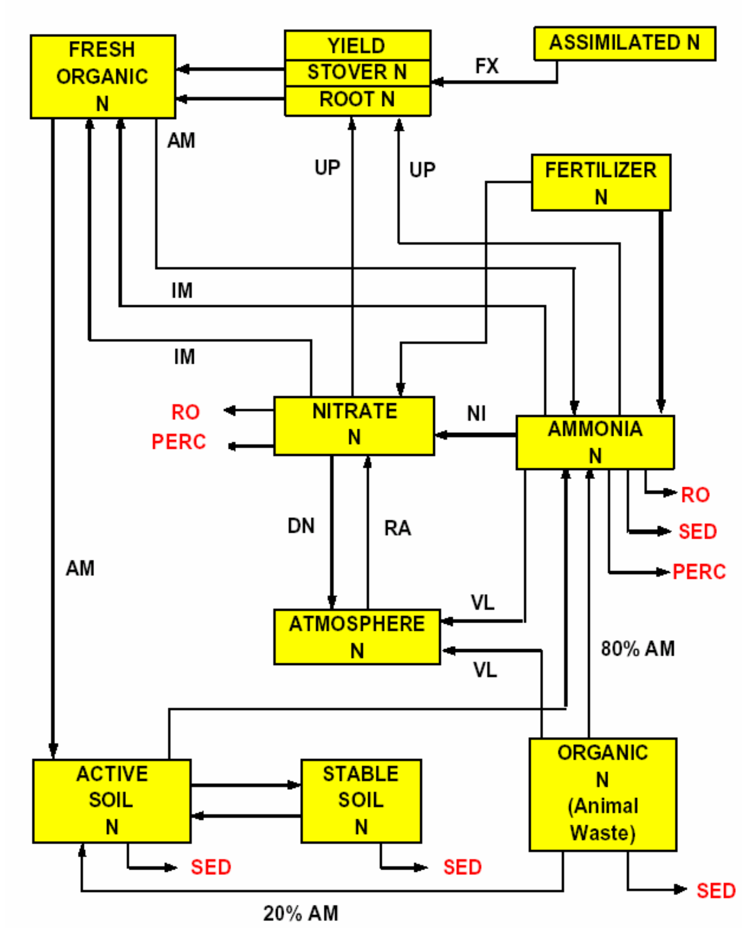

Figure 4.1. Representation of the GLEAMS nitrogen cycle. AM = ammonification; NI = nitrification; DN = denitrification; VL = volatilization; IM = immobilization; UP = uptake; FX=fixation; PERC = percolate; SED = sediment; RO = runoff (Shirmohammadi et al., 1999).

4.3 Verification and Validation

Solute transport models are increasingly being used in problem solving and to aid the decision-making process; therefore there is a justifiable concern with whether a model and its results are "correct." This concern is addressed through model verification, validation, and testing. Model verification corroborates that the model is transformed, with sufficient accuracy, from one form into another (Balci, 1998). Model validation proves that the model, within its domain of applicability, behaves with satisfactory accuracy consistent with the study objectives.

In other words, model verification deals with building the model *right* and model validation deals with building the *right* model (Balci, 1998). Model testing determines whether inaccuracies or errors exist in the model. The model is subjected to test data or test cases to determine if it functions properly.

The first step in the validation process was to review and evaluate the data. The base values of the input parameters represent average values calculated from field-measured properties for the site. Data analysis ensured that the assumptions regarding input data were correct or at least were sensible assumptions. Finally, results obtained from the model were compared with the field-measured data. The output variables from GLEAMS on the field sampling dates were considered for comparison with observed nutrient distribution in the root zone. Model calibration consists of changing values of model input parameters in an attempt to match field conditions within some acceptable criteria. This requires that field conditions at a site be properly characterized. Lack of proper site characterization may result in a model that is calibrated to a set of conditions, which are not representative of actual field conditions.

Validation was lengthy and convoluted and only partially successful. The model was set up to simulate the NO_3-N concentration in leachate at 1.5 m depth. Using the hydrology and erosion parameters previously calibrated the nutrient parameter was initialized using values for input parameters calculated from literature and from previous experiments that had taken place on the same area.

Simulation started on day 1 of 1991 and proceeded for 4 years. The first step towards validation is to validate the hydrology component since is the basis for chemical movement. The best way to verify it is to use runoff data. Figure 4.2 shows the water balance for the entire field; all four quadrants should have approximately the same water balance since all received the same amount of liquid during the experiment. Even if the waste application was lower for certain quadrants, freshwater was irrigated following waste application to equalize the depth of water applied; simulation data runs from 1991 to 1994. Since there was no runoff information available for the four quadrants, the water balance was analyzed in order to define if the model was producing realistic numbers.

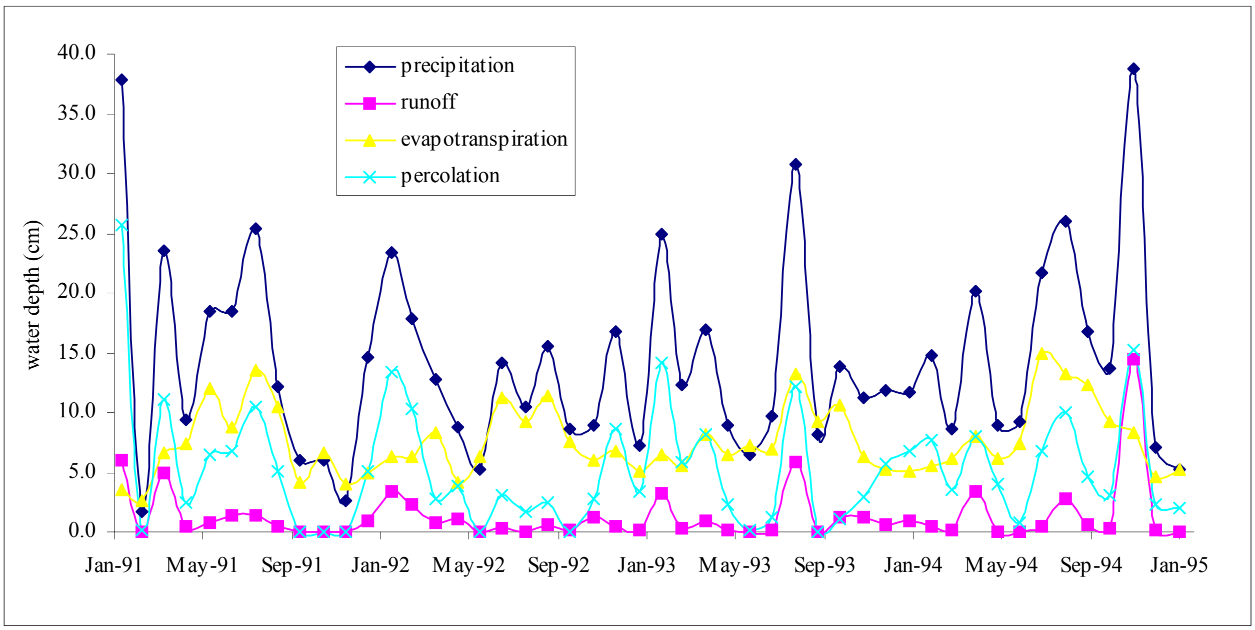

Figure 4.2. Water balance for all quadrants (East, West, North and East) calculated using GLEAMS.

Evapotranspiration, as expected, was high in the summer months and low in the winter months while percolation was very low or zero in the summer months and high in the winter as it correlates to the amount of precipitation. Muller and Gregory (2003) found that GLEAMS under predicts runoff volume because the model does not define the depth of the water table. Ignoring the water table will result in the model assuming that infiltration occurs even though on site the water table has risen closer to the surface; thus, limiting infiltration and generating large runoff volumes. On the other hand, dry weather could be a cause for over estimating runoff. After a drought, which is common in Georgia, the water table drops and takes longer for the soil in the field to respond to rainfall events due to the high infiltration potential. Since GLEAMS does not represent the variability of water table depth, input values for soil characteristics could be manipulated to obtain a smoother runoff curve.

Once the hydrology and erosion components were set, the nutrient component was adjusted using the land application data provided by Dr. Vellidis. The depth of manure applied was recorded accurately using the 48 in-field quantitative samplers located over the crop canopy. Moreover, the dairy manure applied was analyzed for its nitrogen content. Since this was the most accurate data available, it was used to parameterize the model so that simulated animal waste TKN was equivalent to the TKN recorded during the application. In order to modify the default values given to TN, NH_3-N, and organic N, the animal waste type entry (MTYPE = 15) was changed for the user to input the N and P percents. The percentage of ammonia and organic nitrogen for the dairy manure were further discussed with Dr. Newton. During the experimental period, mean TKN concentrations recorded were 99.1% of the mean TN concentrations (164mg/L) in the liquid manure, NO_3-N was 0.9% of TN, and NH_4-N was 79% of TN (Vellidis et al, 1996). Based on relative concentrations of the nitrogen forms (TKN, NO_3-N, and NH_4-N) in liquid manure, the concentration of organic nitrogen was approximately 20% of TN. Animal waste composition was set by trial and error using the nutrient concentrations in liquid manure samples collected by the 48 in-field quantitative samplers during application. This procedure was done for each year and for each quadrant. Table 4.2 shows the results of the trial and error procedure to set up the TKN loading rate.

Table 4.2. Actual and simulated TKN loading rate (kg/ha) for each quadrant.

Year	Actual TKN loading rate (kg/ha)				Simulated TKN loading rate (kg/ha)			
	E	W	N	S	E	W	N	S
1991	137.6	236.9	363.0	450.1	137.6	236.9	363.2	450.2
1992	213.9	370.6	542.5	691.0	213.9	370.5	542.5	691.4
1993	210.4	376.7	582.0	772.2	210.3	376.8	582.1	722.4
1991	177.6	319.0	445.5	565.4	177.6	319.1	445.4	565.4

Papers published by Johnson et al. (1995) and Newton et al. (1995) were used to estimate the potential yield (PY) for each crop. The remaining crop characteristics, dry matter ratio (DM), carbon-nitrogen ratio at harvest (CNR), ratio for N:P ratio (RNP), and coefficient (C1) and exponent (C2) on nitrogen content for the crop were left as defaults since data could not be obtained. Ultimately the purpose of the validation and verification was to run the model to obtain the NO_3-N leached at 1.5 m depth and compare it to the actual NO_3-N leached at the same depth. For the field experiment, the NO_3-N concentration at 1.5 m best characterized the observed trend; it decreased with time in the East quadrant, remained unchanged in the West quadrant and increased in the North and South quadrants. The model was first run for the West and North quadrants since they had moderate application rates of 400 and 600 kg N/ha, respectively. Figures 4.3 and 4.4 illustrate the NO_3-N concentrations leached for these two quadrants during the land application months, June 1991 through September 1994, and compare it to the actual data obtained from the suction lysimeters.

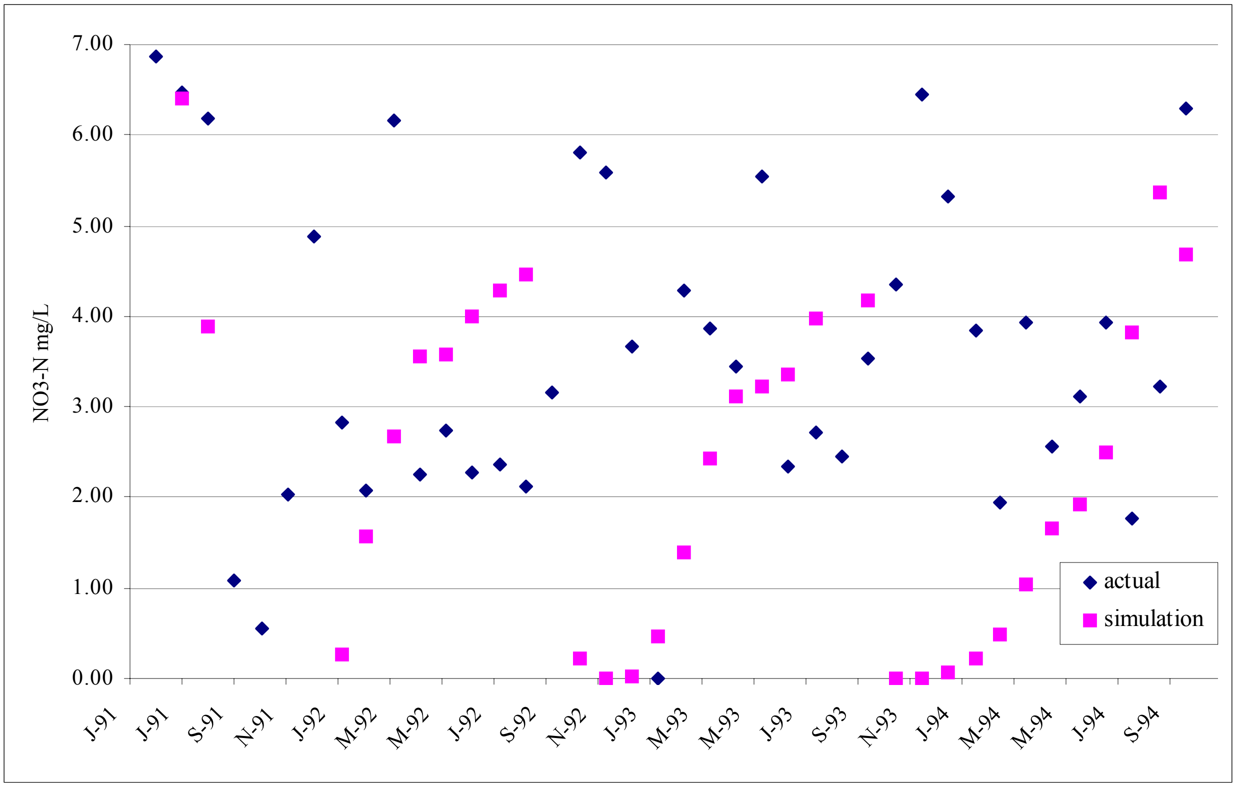

Figure 4.3. NO_3-N leached at 1.5 m depth for West Quadrant (400 kg N/ha).

In the case of the West quadrant the model seems to simulate the trend as well as the values obtained by the suction lysimeters. There are some points that underestimate leaching and that could be fixed manipulating potential yield (PY). On the other hand, the data for the North quadrant follows the trend for 1992 but then overestimated the NO_3-N leached by100% in the following years. This may be happen when PY is increased, which is the harvestable portion of the crops.

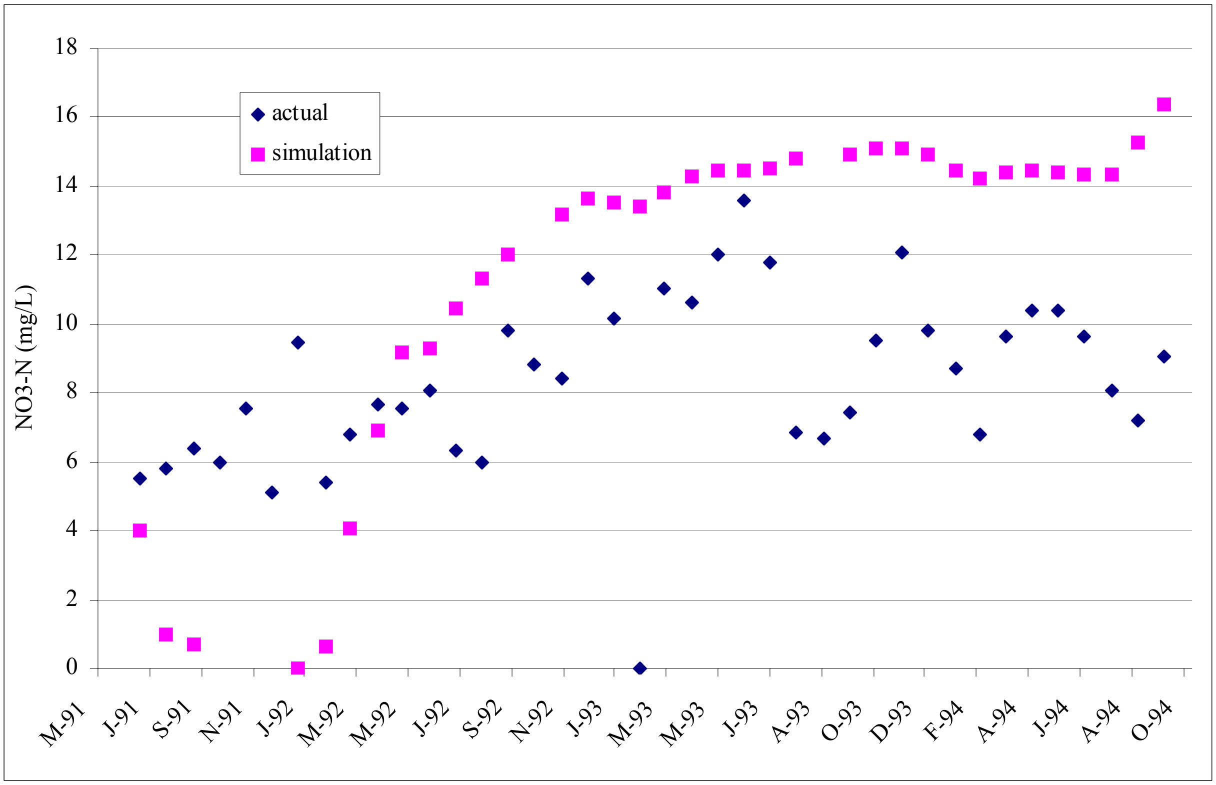

Figure 4.4. NO_3-N leached at 1.5 m depth for North Quadrant (600 kg N/ha).

After running the two quadrants with moderate loading rates (400 kg N/ha and 600 kg N/ha), the East and South with 200 and 800 kg N/ ha, which were the extreme loading rates were set. Figures 4.5 and 4.6 graph the NO_3-N leached results from the model and compares them to the actual NO_3-N leached at 1.5 m.

For the East quadrant, the model seemed to overestimate year 1 (1991) while the other three years seem to agree with the actual leachate data. No specific trend was followed between the modeled and the actual data. However, the modeled data shows a sigmodal curve in which at the beginning of the year leachate appears low and then it increases throughout the year, dropping again at the beginning of the winter months. The record for the South quadrant shows that the model is overestimating the NO_3-N leachate, approximately 300% more than the actual

NO_3-N sampled with the suction lysimeters. Further modifying the PY will be necessary to calibrate the model to match the given data.

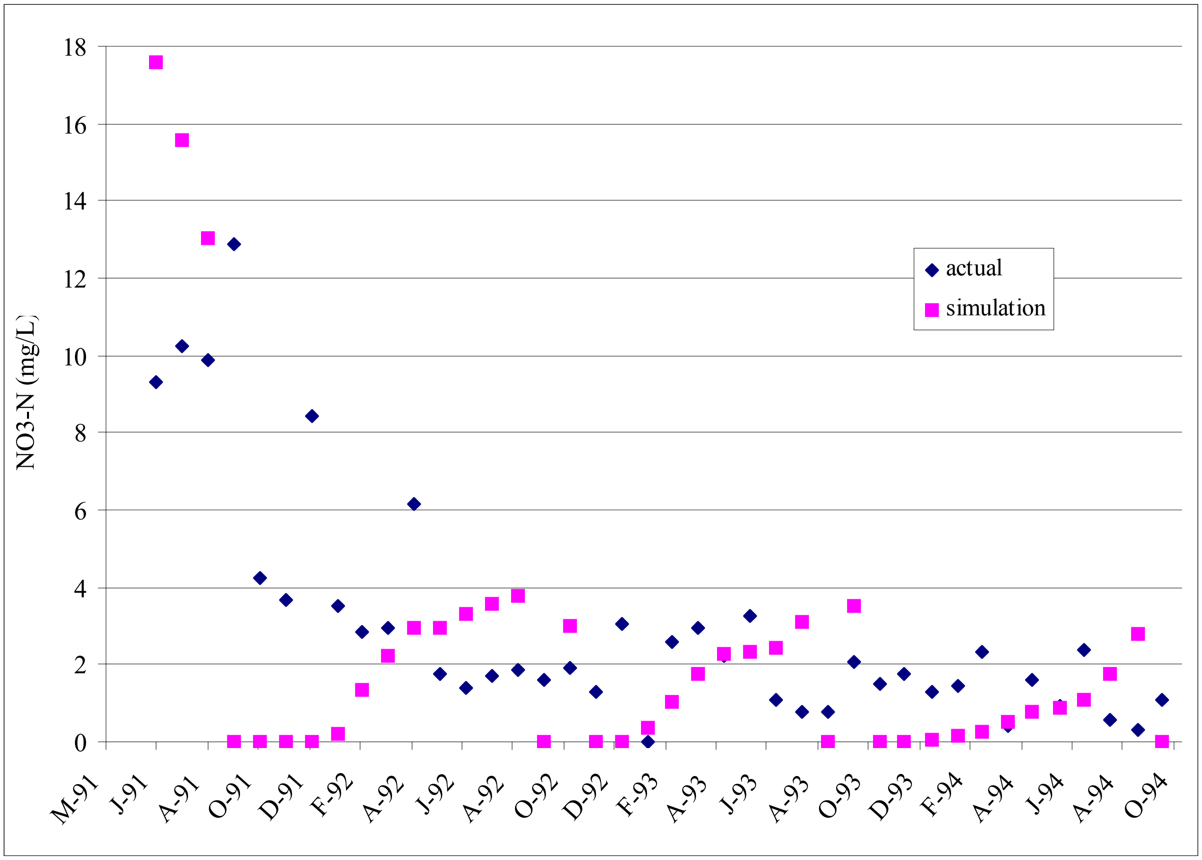

Figure 4.5. NO_3-N leached at 1.5 m depth for East Quadrant (200 kg N/ha).

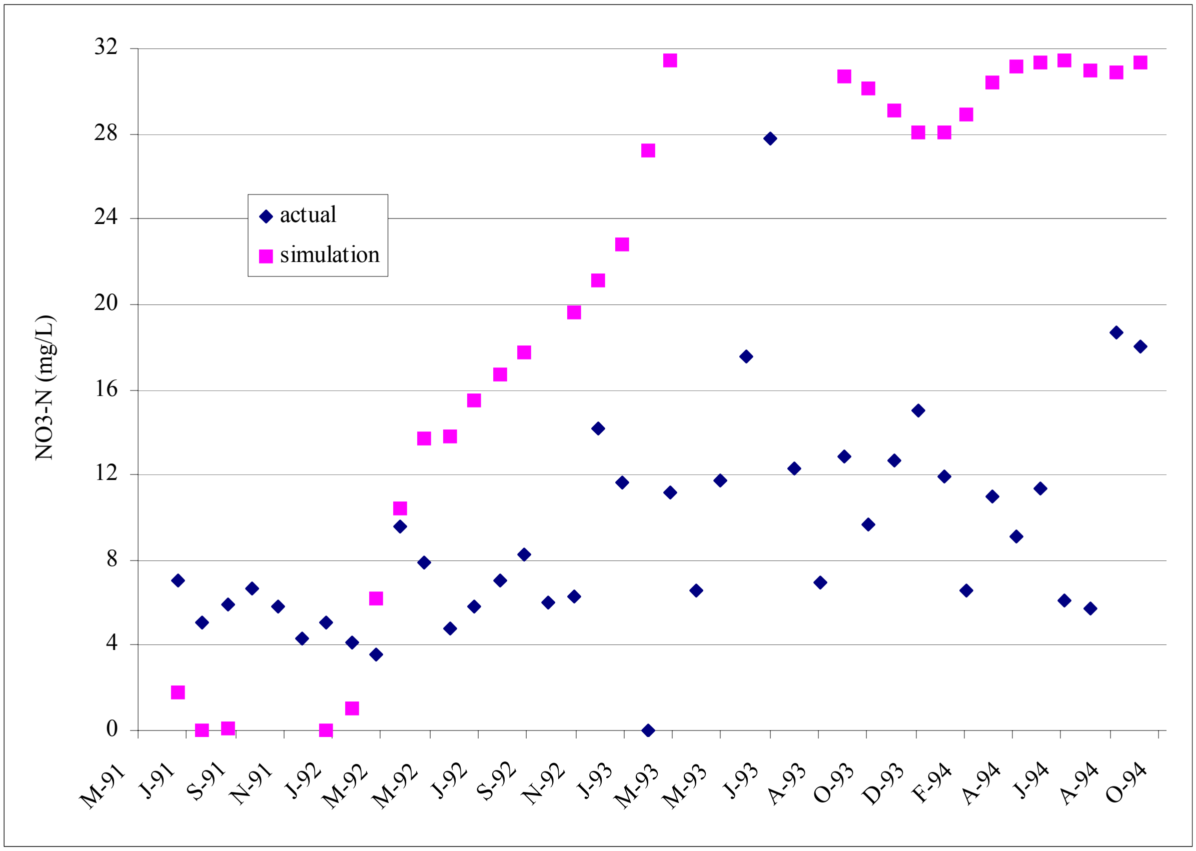

Figure 4.6. NO_3-N leached at 1.5 m depth for South Quadrant (800 kg N/ha).

Finally using information from Newton et al. (1995), the N uptake was compared using the uptake measured for the cropping season 1991 to 1992 and the average N uptake calculated by the model. Table 4.3 shows the results.

Table 4.3. Actual and simulated N uptake for each quadrant.

Quadrant	Actual N uptake kg/ha	Simulated N uptake kg/ha	Difference %
E	162	204	26
W	321	334	4
N	434	402	7
S	464	394	15

Uptake was overestimated for East and West and underestimated for North and South. However, the estimates for the North and Wets quadrants are very close to the actual values. The simulated uptake for the east quadrant had the largest margin of error.

The results were compared to data gathered from three years; thus, the differences noted between simulated an observed data values may not materialize in comparison with future data from this site. As the model runs for longer periods, the output becomes less sensitive to the initial default inputs. As shown in Figures 4.3, 4.4, 4.5 and 4.6, simulation for year 1 appears extremely high compared to the actual data in all four quadrants. This can be explained because the nutrient initialization within each soil horizon, which was estimated from literature not from site samples, might not reflect the state of the site. However, as the model continues to run the initialization data becomes a secondary element compared to the nutrient the input from the land application system. Therefore, in subsequent years, data stabilizes and starts to show escalating trends.

Once the water balance and nitrate values were obtained, GLEAMS was used to simulated denitrification and compare it with the data from the field gathered from July 1990 to June 1993 (Lowrance et al., 1998). Figures 4.7 and 4.8 show the denitrification rates for the E and W quadrant. Rates decreased for the first year of application to the second year (Table 4.4). As mentioned before, the simulated data for 1991, which shows extremely high denitrification values, is not reliable since the initialization parameters for nutrients were set up with default values. Contrary to the vales gathered at the site, the denitrification rates in the simulation were consistent with application rates; thus rates were higher for the W quadrant than for the E quadrant. There are two peaks in Figure 4.7 in July 1993 and in June 1994, which are also present in Figure 4.8.

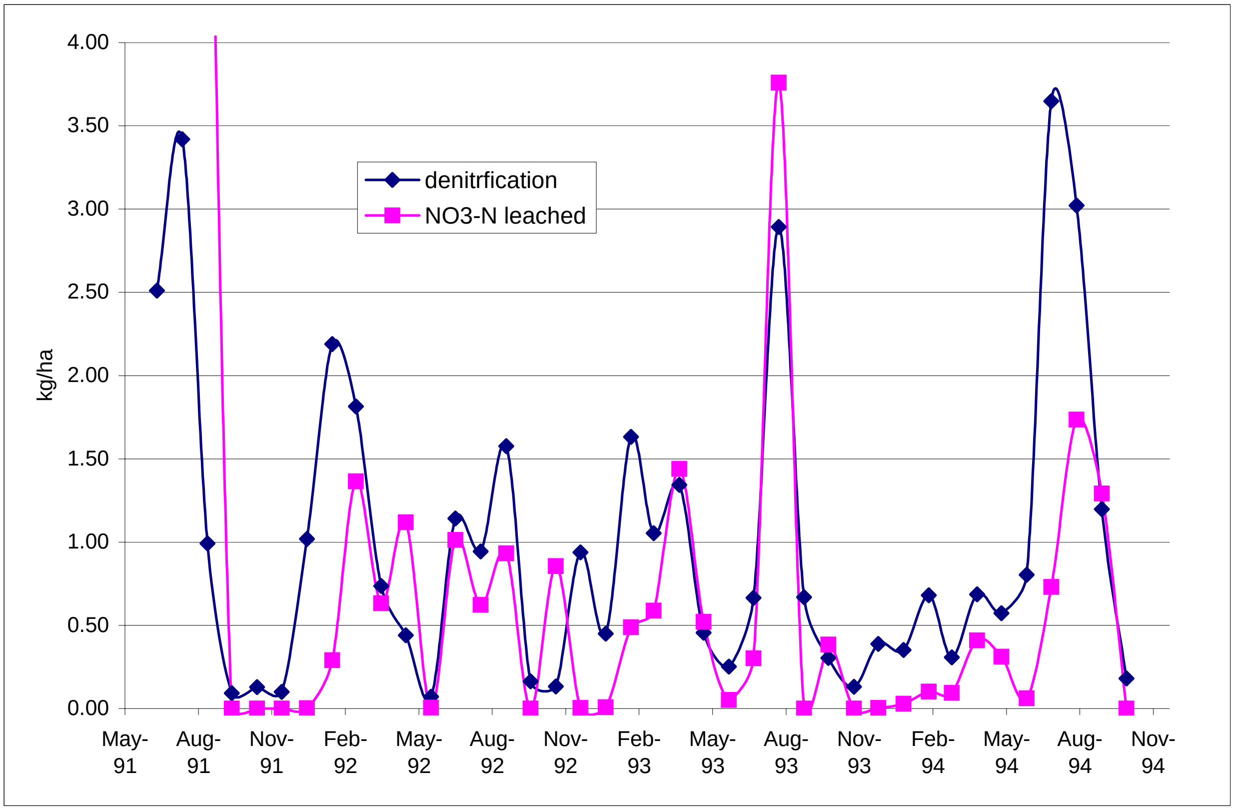

Figure 4.7. Monthly denitrification and NO_3-N leached for the East Quadrant.

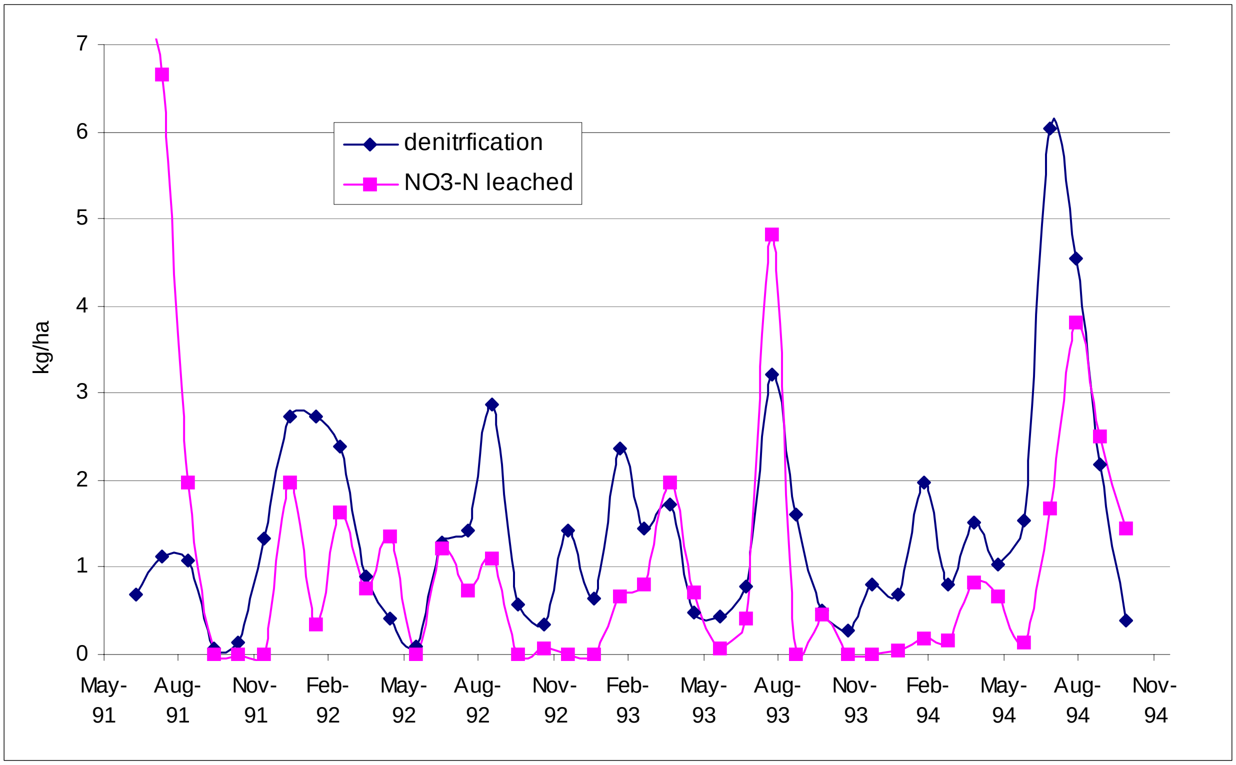

Figure 4.8. Monthly denitrification and NO_3-N leached for the West Quadrant.

Figure 4.9 illustrates the denitrification and nitrate concentrations for the N quadrant simulated by GLEAMS. Even though denitrification continues to rise it does not show high peaks as observed in the previous graphs. Nitrate leached displays various peaks in January 1993, July 1993 and July 1994. Compared to the previous graphs, nitrate leached doubles the amount of N denitrified; which might explain the increasing nitrate leached observer in Figure 4.4.

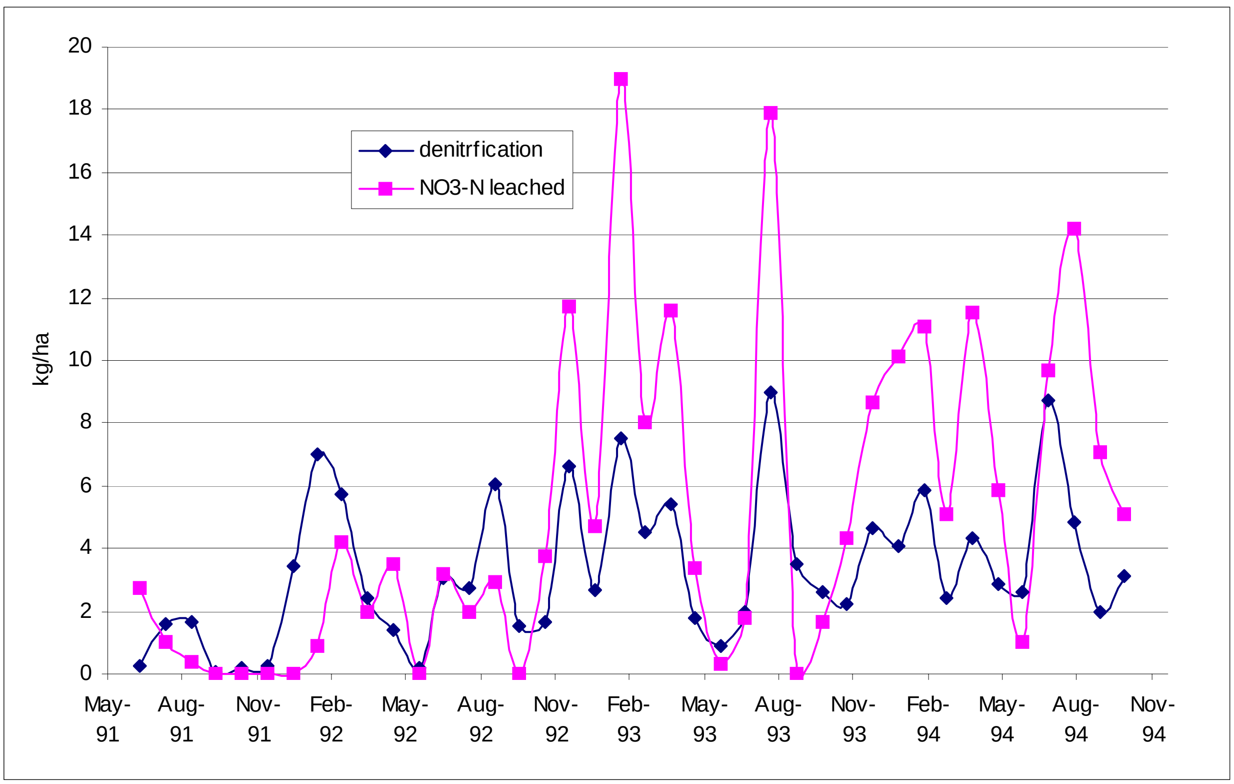

Figure 4.9. Monthly denitrification and NO_3-N leached for the North Quadrant.

Figure 4.10 shows the denitrification and nitrate concentrations for the S quadrant. Denitrification rates were consistent with application rates; rates are higher for the S quadrant than for the N quadrant. Nitrate leached also displays peaks on January 1993, July 1993 and July 1994. Nitrate concentrations increased significantly for the S quadrant while denitrification did not increase proportionally; therefore, explaining the jump in nitrate leached numbers shown in Figure 4.5.

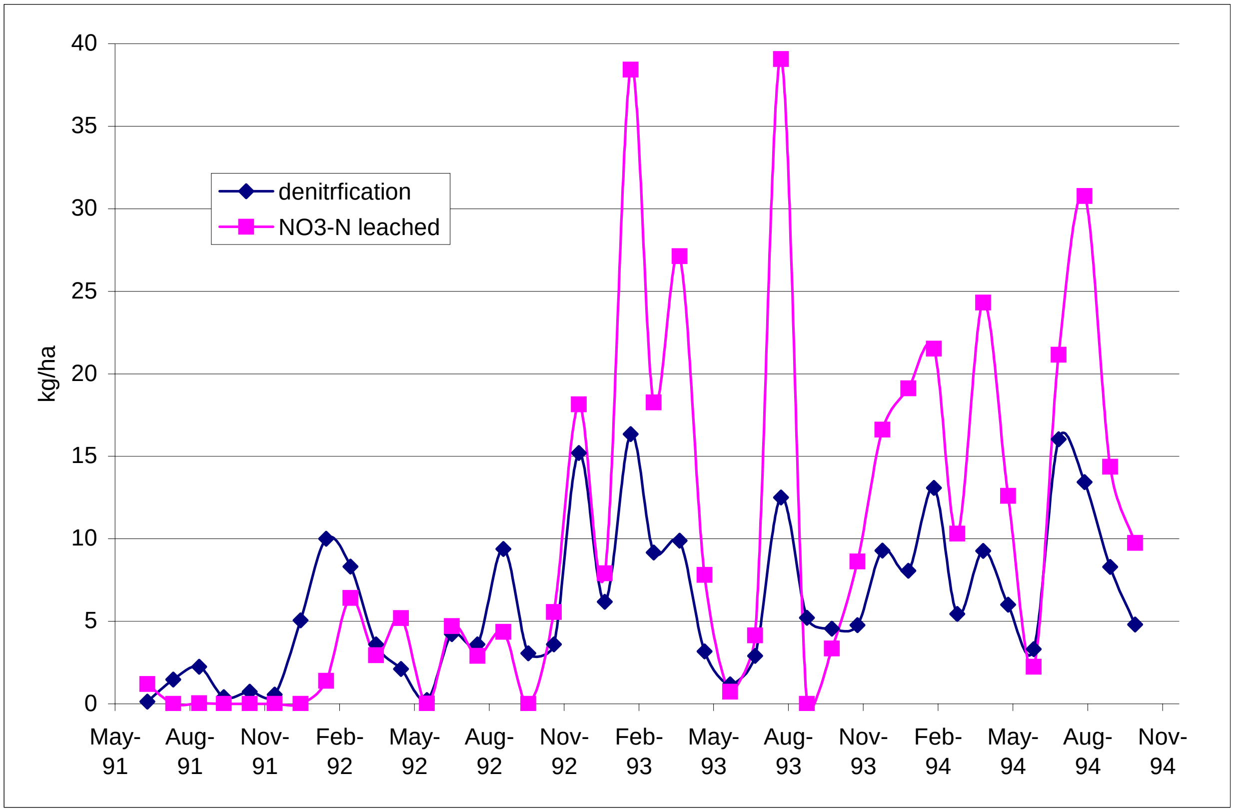

Figure 4.10. Monthly denitrification and NO_3-N leached for the South Quadrant.

Table 4.4 compares the simulated and actual mean denitrification rates. The pre-application numbers are overestimated significantly by the model which stresses the importance of having site-specific data to initialize the nutrient parameters. Also, the model underestimated denitrification rates for the E and W quadrants and overestimated the rates for the N and S quadrants.

Table 4.4. Simulated and actual mean denitrification rates for each application rate and time period.

Quadrant	Actual[1]			Simulated[2]		
	Pre-application	Year 1	Year 2	Pre-application	Year 1	Year 2
	$g\ N_2O\text{-}N\ ha^{-1}\ d^{-1}$			$g\ N_2O\text{-}N\ ha^{-1}\ d^{-1}$		
E	5.9	20.2	63.1	141	39	26
W	6.95	33.1	50.2	125	43	40
N	11.5	99.8	246	120	92	119
S	2.17	42.4	118	144	133	230

[1]Pre application = July 1990- May 1991; Year 1 = July 1991 – June 1992; Year 2 = July 1992 – June 1993.
[2]Pre application = = January 1991- May 1991; Year 1 = July 1991 – June 1992; Year 2 = July 1992 – June 1993.

Table 4.4 compares the simulated and actual mean nitrate concentrations. The model overestimated the nitrate concentrations for during pre-application formal quadrants except the S quadrant. During the first year of application, nitrate is overestimated in all quadrants. And during the second year of application, only the N and S quadrant are overestimated.

Table 4.5. Simulated and actual mean soil nitrate for each application rate and time period.

Quadrant	Actual[1]			Simulated[2]		
	Pre-application	Year 1	Year 2	Pre-application	Year 1	Year 2
	ppm $N_3O\text{-}N$			ppm $N_3O\text{-}N$		
E	0.51	0.62	1.18	19.8	3.78	1.87
W	0.35	1.12	2.39	7.31	2.46	2.01
N	0.50	1.55	3.72	1.91	8.25	14.4
S	0.49	2.52	5.56	0.62	12.34	30.76

[1]Pre application = July 1990- May 1991; Year 1 = July 1991 – June 1992; Year 2 = July 1992 – June 1993.
[2]Pre application = = January 1991- May 1991; Year 1 = July 1991 – June 1992; Year 2 = July 1992 – June 1993.

Given the uncertainty assoiciated with models and the parameters required there are concerns about the lack of a standardized validation range that represents how close a model must match field observations to be considered properly validated (Smith et al. 1991). Leonard and Knisel (1990) indicated that no standard criteria exist for model validation. Since spatial distribution of the various inputs is usually unknown, it would be unreasonably to expect any model to exactly match a specific number measured at any point in a field experiment. During the Predictive Exposure Assessment Workshop, sponsored by EPA in Atlanta (1982), two criteria were agreed on for model validation. For applications that were not calibrated to previous data from the site and limited site-specific data were utilized, the model should be able to replicate measured field data within an order of magnitude. For site-specific applications where parameters have been reported on-site and the model calibrated to the site, it should be able to match filed observations within a factor of two (Smith et al., 1991). Even though the site-specific level criterion is ideal, the screening level criteria seem reasonable when all sources of error and uncertainty are considered. In addition, the site-specific criteria may be difficult to meet even after thoroughly gathering site-specific parameters.

The fact that models cannot exactly replicate field data does not mean they cannot be verified and validated. In the case of this study, trials run using the best available measurements for the parameters applied to the experimental site. In the absence of data, estimates were determined consulting the user manual or other supplements.

4.4 Parameter Sensitivity

It was observed that interactions are very important in estimating parameter sensitivity; hence, blanket statements about sensitivity cannot be made with absolute certainty (Knisel et al., 1993). Studies preformed by Zacharias (1998) and Knisel et al. (1991), state that the parameters controlling water flow, RD, POR, FC, and BR15 are important to determine the movement of water and chemicals within the soil layers of the root zone. Flow was sensitive to saturated hydraulic conductivity of the plinthite layer and other heavy textures soils.

Leonard et al. (1987) established that the main differences relative to rooting depth are the partitioning of water between surface runoff and percolation through the root zone. Even though the surface layer is fixed (1 cm), the computational layers are thicker at the bottom of the root zone. The thicker layers are less sensitive to small changes in total water content and runoff response increases as soil water increases. Since ET is virtually the same for all rooting depths and runoff increases with rooting depth, the water balance is achieved is by decreasing percolation and/or changing soil water storage. A sensitivity analysis performed for Watkinsville, Georgia (Knisel et al., 1991), showed that temperature and radiation are not sensitive parameters to determine runoff and percolation. In the Coastal Plain, mean daily temperatures rarely fall below freezing for more than two days; hence it can be assumed that temperature and radiation would not be sensitive parameters in water balance calculations at Tifton.

Initialization of N and P pools in GLEAMS could be very sensitive depending on the duration of the simulation. When model results are compared with observed data and the compared data occurs shortly after the beginning of simulation, the initial values may be very sensitive for those storms. This is particularly true for NO_3-N (CNIT) and liable P (CLABP). During long-term simulation, these parameters are not sensitive (Knisel et al., 1993). CNIT is very dynamic because it changes rapidly due to mineralization, immobilization, leaching, uptake, and denitrification. However, the default values should be used as a last resource if initial data is available.

Crop characteristics may also be sensitive depending upon climate and management. Potential yield (PY) and leaf area index (LAI) mare sensitive with respect to different climatic regions and irrigation where water stress is not significant. Current crop rooting depth (CCRD) is sensitive under water stress conditions. Nutrient uptake may be sensitive to the crop coefficient and exponent (C1 and C2, respectively) for intensive, high-fertilization management systems.

Animal waste characteristics (ATN, APORGN, ANH, APHOS, APORGP, and AOM) and the application method are sensitive parameters. Model default vales represent “as excreted” (Knisel et al., 1993) values; however, the waste applied has lost nitrogen due to ammonia volatilization during storage and handling. The default values are not representative and might overestimate nitrogen input unto the system; site-specific values should be used to replace them.

Chapter 5

SUMMARY AND CONCLUSIONS

Methods to predict the fate of agrochemicals and nutrients can range from simple indices to very complex models. Models, such as GLEAMS, that are able to represent the management practices within a site are useful tools that enable the simulation of various scenarios in order to apply the best management practices that would fit a particular site. Most of the management models are designed to mathematically represent processes within the soil profile, the crop root zone and some within the water table. As expected, there are many sources of uncertainty and error, especially due to the lack of sufficient information concerning the field being studied. It was clear the model was overestimating nitrate leached, even though denitrification values seem to be over estimated there is a decrease of nutrient uptake for the quadrants with the highest application rates in the N and S quadrants.

The model tended to over predict nitrate leaching in the upper application rates, 600 and 800 kg N/ha. When nitrogen balance was simulated, it was observed that denitrification values continued to increase for the increasing application rates; however, nitrate values increased more than ten times for the E to the S quadrants, explaining the excess nitrate. Moreover, when the simulated N uptake values are compared to the field samples, the model tended to over estimate uptake for E and W quadrants, with 200 and 400 kg N ha^{-1} yr^{-1} respectively, and underestimate N uptake for the N and S quadrants, 600 and 800 kg N ha^{-1} yr^{-1} respectively. The model would simulate uptake up to a plateau and would not be able to imitate luxury consumption as it occurs in the field. Therefore, uptake values would decrease after uptake has reached its maximum and the N in excess would be simulated as leached nitrate.

As described above, models should not be expected to provide mirror images of the real data but to simulate the overall process that occurs within the study area. In order to gain confidence in the modeling method, new studies are needed. Results from simulations using GLEAMS were closely related to the data recorded during the on-site study. In most cases, the measured and predicted concentrations agreed within an order of magnitude. Taking into consideration that many of the modeling parameters were obtained from historical data and reference papers and that the model itself was not calibrated to produce a best fit, GLEAMS was able to model the trend of NO_3-N movement successfully.

Model validation results must be viewed considering the assumptions applied in the modeling process and the limitations of the observed data. Assuming one-dimensional movement as the unique hydraulic phenomenon may be incorrect in areas of heterogeneous field characteristics where lateral flow might exist. This is particularly interesting in this case because the experimental field was divided in quadrants that were very close together. Water movement from a quadrant treated with a higher application rate could have traveled laterally to another quadrant, therefore affecting their nutrient content within the root zone.

In addition, comparisons with observed data must consider that there was only limited number of sampling points available and that the observed data on each of these dates were based on sample volume; therefore if the volume gathered for a specific date was not enough, the data sample was thrown out. On the other hand the volume collected was subject to the soil water content and therefore the concentration of nutrients within the samples could be diluted when more water is present.

5.1 Limitations of GLEAMS

The complexity and expensive nature of experimental procedures lead to the use of mathematical models for evaluating hydrologic and water quality response of watersheds to different events and scenarios. Variation in soils, climate, and management practices make the experimental evaluation and movement of agricultural chemicals impractical through soil and plant systems. Moreover, available experimental data are usually site-specific and may not be used to describe processes for a condition outside the one, which has been studied. Simulation models have been developed to resolve this difficulty (Shirmohammadi et al, 1999).

The accuracy of the model predicting average conditions as well as spatial variability of output variables is dependent on the amount and the quality of the data available to characterize the input parameters of the model. Capacity based models require less soil water parameters that tend to be less variable and require fewer samples than are necessary to describe spatial variability. The use of these types of models over rate-based models will lead to a significant reduction in time gathering data and running the model during long-tern and multiple simulations (Zacharias, 1998).

Reyes et al. (1994) developed the GLEAMS with Subsurface drainage and Water Table (GLEAMS-SWT) model. It is a modified version of GLEAMS designed for poorly drained or subsurface drained conditions. However, GLEAMS-SWT is considered to be incomplete since it only has hydrology and erosion submodels. A study conducted by Reyes et al. (1994) evaluated the reliability of GLEAMS and GLEAMS-SWT by comparing their nutrient predictions with observed data from a shallow water table and subsurface drained experiment. This version contains the GLEAMS nutrient component and additional routines to predict nitrogen loss from subsurface drainage. The model was been tested and compared with GLEAMS to predict nitrogen and phosphorus loss with six years of measured data gathered at Ben Hur Research Farm in Baton Rouge, Louisiana. The study showed that: GLEAMS-SWT over predicted total (ammonia and nitrate both in solution and solids) surface nitrogen (TSN) loss by 10%; while GLEAMS under predicted TSN loss by 38% for the non-subsurface drained plot. Also, GLEAMS-SWT over predicted TSN loss by 31%, and GLEAMS over predicted it by 7% for the subsurface drained plot. GLEAMS-SWT over predicted total nitrogen loss in subsurface drainage nearly 7-fold.

As GLEAM-SWT, the model allows the addition and or/modification of routines to simulate spatial variability and other features that the original GLEAMS lacks; however, models are not able to perfectly imitate field phenomena only to describe their general processes that can be described mathematically. Understanding the imitations of the model is as important as setting it up so outcome can be interpreted appropriately.

5.2 Future research

The main benefit of having a valid model representation of any system is the ability to evaluate various scenarios varying crop rotations, tillage operation, and land applications animal waste. Comparing different management practices using a model might be cost effective compared to testing on site.

Spatial heterogeneity within a site has a profound influence on the flow of water and the chemical moment in the unsaturated zone. Incorporation the variability in solute leaching models could lead to more accurate and realistic results and provide better prediction to assess risks. Eventually it would enhance the credibility of models to be used as regulatory and management tools.

In order to improve the results that the model will provide, future studies should consider the extensive and detailed data needed for modeling. Even though most of the input data was not hard to gather, being historical, data it was difficult to come about the exact values for the field at the time the study took place.

REFERENCES

1. Addiscot, T.M., and R.J. Wagenet. 1985. Concepts of Solute Leaching in Soils: A review of Modeling Approaches. *J. Soil Sci.* 36:411-424.

2. American Society for Tenting Materials. 1984. Standard Practice for Evaluating Environmental Fate Models of Chemicals. E978-84.

3. Chinkuyu, A.J. and R.S. Kanwar. 2001. Predicting Soil Nitrate-Nitrogen Losses from Incorporated Poultry Manure Using the GLEAMS Model. American Society of Agricultural Engineers. 44 (6): 1643-1650.

4. Edwards, D.R. and T.C. Daniel. 1992. Environmental Impact of On-Farm Waste Disposal – A Review. Bioresource Technology. 41: 9-33.

5. Fiez, T. E., W. L. Pan, and B. C. Miller. 1995. Nitrogen efficiency analysis of winter wheat among landscape positions. Soil Sci. Soc. Am. J. 59:1666-1671.

6. Hargrove, W.L. and G.D. Hoyt. 1986. Legume Cover Crops for Improving Crop and Soil Management in the Southern United States. Interplanting in Horticultural Cropping Systems: Proceedings of the Symposium held at the 81st ASHS Annual Meeting. Vancouver, B.B. HortScience. 21(3):397- 401.

7. Hermanson, Ronald, William Pan, Cathy Perillo, Robert Stevens, and Claudio Stockle. 2000. Nitrogen Use by Crops and the Fate of Nitrogen in Soil and Vadose Zone – A Literature Search. Publication No. 00-10-015. Washington State University Department of Ecology.

8. Hollister, Steven. Year. NRCS Nutrient management Planning. U.S. Department of Agriculture. http://www.age.uiuc.edu/bee/Outreach/lwmc/lwm21.htm.

9. Huang Keng Liang and Jaime F. Sanchez. 2001. GLEAMS. Simulation of Agricultural Watershed Systems. University of Florida. http://www.agen.ufl.edu/%7Eklc/abe6254/modelinfo/models.htm.

10. Jackson, W. A., W. L. Pan, R. H. Moll, and E. J. Kamprath. l986. Uptake, Translocation, and Reduction of Nitrate. In C. A. Neyra, ed., Biochemical Basis of Plant Breeding. CRC Press, Boca Raton, Florida.

11. Johnson, J.C., G.L. Newton, J.G. Davis, and P.R. Utley. 1995. Forage Production from Two Minimum-Till Cropping System Utilizing Liquid Dairy Manure. Annual Report. UGA Animal and Dairy Science.

12. Johnson, J. C., G. L. Newton, and J. L. Butler. 1991. Recycling liquid dairy waste to sustain annual triple crop production of forages. Proc. Florida Dairy Production Conf., Dairy Science Dept., Univ. Fl. Coop. Ex, Gainesville, FL. 32611.

13. Knisel, W. G., R. A. Leonard, F.M. Davis, and J.M. Sheridan. 1991. Water Balance Components in the Georgia Coastal Plain: A GLEAMS Model Validation and Simulation. Journal of Soil and Water Conservation. 46(6): 450-456.

14. Knisel, W. G., R.A. Leonard, and F. M. Davis. 1993. Groundwater Loading Effects of Agricultural Management Systems. Version 2.10. Part II. Model Validation.

15. Knisel, Walter G. and Frank M. Davis. 2000. Groundwater Loading Effects of Agricultural Management Systems. Version 3.0. User Manual

16. Leonard, R.A., W.G. Knisel, and D.A. Still. 1987. GLEAMS: Groundwater Loading Effects of Agricultural Management Systems. ASAE. 30(8): 1403-1418.

17. Leonard R.A. and W.G. Knisel. 1990. Can Pesticides Transport Models be Validated Using Field data: Now and In the Future? Departmental Publication No.3. Agricultural Engineering Department. University of Georgia, Coastal Plain Experiment Station

18. Lewis, D.R. and M.B. McGechan. 2000. A Review of Field Scale Phosphorous Dynamics Models. Biosystems Engineering, 82 (4): 359-380.

19. Lowrance, Richard, G Vellidis, and R. K. Hubbard. 1995. Denitrification in a Restored Riparian Forest Wetland. J. Environ. Qual. 17(1):158-162.

20. Lowrance, R., J.C. Johnson, Jr., G.L. Newton, and R.G. Williams. 1998. Denitrification from Soils of a Year-Round Forage Production System fertilized with Liquid Dairy Manure. J. Environ. Qual. 27:1504-1511.

21. Lowrance, Richard and Robert K. Hubbard. 2001. Denitrification from a Swine Lagoon overland Flow Treatment System at a Pasture-Riparian Zone Interface. Environmental Quality, 30: 617-624.

22. Ma, Qingli, James E. Hook, R. Don Wauchope, Clyde C. Dowler, A.W. Johnson, Jessica G. Davis, Gary J. Gascho, Clint C. Truman, Haronls R. Sumner, and Lawrence D. Chandler. 2000. GLEAMS, Opus, PRZM2B, and PRZM3 Simulations Compared with Measured Antrazine Runoff. Soil Sci. Soc. Am. J. 64: 2070-2079.

23. Newton, G.L. 2004. Personal communication.

24. Newton, G.L., J.C. Johnson, Jr., J.G. Davis, G. Vellidis, R. Lowrance, A.W. Johnson, and R.N. Williams. 1995. Nutrient Recovery and Movement Associated with a Year-Round Forage System Fertilized with Liquid Manure. Annual Report. UGA Animal and Dairy Science. http://www.ads.uga.edu/annret/1995/95 192.htm

25. Newton, G.L. 1998. Cropping Systems and Nutrient Recovery for Dairy Manure Utilization. Annual Report. UGA Animal and Dairy Science.

26. Newton, G.L., J.K. Hubbard, J.R. Allison, R.R. Lowrance, G.J. Gascho, R.N. and G. Vellidis. 2003. Managing Manure Nutrients through Multi-crop Forage Production. Journal of Dairy Science. 86 (6): 1-10.

27. Nordstedt R.A., A.V. Bottcher, E.A. Hanlon, and C.G. Chamblis. 1996. Dairy Manure Management: Strategies for Recycling Nutrient Recover Fertilizer and Avoid Environmental Pollution. Virginia Tech. Feed & Nutritional Management.

28. Novotny, V., and H. Olem. 1993. Water Quality: Prevention, Identification, and Management of Diffuse Pollution. Van Nostrand Reinhold, New York.

29. Michael Schmitt and George Rehm. 2002. Fertilizing Cropland with Dairy Manure. University of Minnesota Extension Service. http://www.extension.umn.edu/distribution/cropsystems/DC5880.html

30. Muller, Stuart and Justin Gregory. 2003. Calibration and Verification of the GLEAMS Model for Buck Island Ranch. Department of Agricultural and Biological Engineering. University of Florida.

31. Pettygrove, G.S., T.A. Doane1, W. R. Horwath, J.J. Wu1, M.C. Mathews, and D.M. Meyer. 2003. Mineralization of Nitrogen in Dairy Manure Water. Western Nutrient Management Conference. 2003. 5.

32. Reyes, Manuel R., Richard W. Skaggs, and Richard L. Bengtson. 2004. GLEAMS-SWT with Nutrients. Transactions of the ASAE. 47(1): 129-132

33. Sainju, Upendra M. and Bharat P. Singh. 2001. Tillage, Cover Crop and Kill-Planting Date Effect on Corn Yield and Soil Nitrogen. Agronomy Journal. 93: 878-886.

34. Shaffer. M.J. 2002. Nitrogen Modeling for Soil Management. Soil and Water Conservation. 417 (57) 6.

35. Shirmohammadi, A., W.G. Knisel, R. Bengtson, A. Ward, M. Reyes, H. Manguera, K. King. 1999. GLEAMS Model. Southern Cooperative Series Bulletin.

36. Smith, M.C., A.B. Bottcher, K.L. Campbell and D.L. Thomas. 1991. Field Testing and Comparison of the PRZM and GLEAMS Models. American Society of Agricultural Engineers. 34 (3): 838-847.

37. Stichler, Charles, and David Bade. 1997. Forage Bermudagrass: Selection, Establishment, and Management. Texas A& M University.

38. Tollner, Ernest W. 2002. Natural Resources Engineering. Iowa State Press. Ames, IA.

39. United States Department of Agriculture (USDA). 1996. Agricultural Waste Management Field Handbook. Chapter 11: Waste Utilization. 210-VI-NEH-651.11.

40. USDA-NRCS Soil Survey Division. Official Soil Series Description. http://ortho.ftw.nrcs.usda.gov/cgi-bin/osd/osdname.cgi

41. Urbanowicz, Bill. 2001. Manure and Soil Organic Matter. Penn State Filed Crop News. 1:11

42. Vellidis, G., R.K. Hubbard, J.G. Davis, R. Lowrance, R.G. Williams, J.C. Johnson Jr., G.L. Newton. 1996. Nutrient Concentration in the Soil Solution and Shallow Groundwater of a Liquid Dairy Manure Land Application Site. American Society of Agricultural Engineers. 39 (4): 1357-1365.

43. Van Horn, H.H., G.L. Newton, R.A. Nordstedt, E.C. French, G. Kidder, D.A. Graetz, and C.F. Chambliss. 1998. Dairy Manure Management: Strategies for Recycling Nutrient to Recover Fertilizer Value and Avoid Environmental Pollution. Circular 1016. Dairy and Poultry Science Department, Florida Cooperative Extension Services.

44. Wagenet, R.J., and P.S.C. Rao. 1990. Modeling Pesticide Fate in Soils. In Pesticides in the Soil Environment: Processes, Impacts, and Modeling. Soil Science Society of America, Madison, Wisconsin.

45. Webb, T.H. L.R. Lilburne, and G.S Francis. 2001. Validation of the GLEAMS Simulation Model for Estimating Net Nitrogen Mineralization and Nitrate Leaching Under Cropping in Canterbury, New Zealand. Aust.J.Soil.Res. 39: 1015-1025

46. Wewick, S., B. Lakhani, J. Stone, P. Waller, and J. Artiola. 2001. Development and sensitivity Analysis of the GLEAMS-IR Model. American Society of Agricultural Engineers. 44 (5): 1095-1104.

47. Woodard, K. R. the late E. C. French, D. A. Graetz, L. E. Sollenberger, L. A. Sweat, B. L. Wade, S. J. Rymph, B. Macoon, G. M. Prine, and H. H. Van Horn. 2000. Utilization of Dairy Waste Effluent in Year-Round Cropping Systems for Nutrient Recovery and Water Quality Enhancement. Final Report. Florida Department of Environmental Protection.

48. Zacharias, Sebastian. 1998. Modeling Spatial Variability of Field-Scale Solute Transport in the Vadose Zone. PhD Dissertation. Biological Systems Engineering. Virginia Polytechnic Institute and State University.

APPENDICES

Appendix A

GLOSSARY

Ammonia Volatilization: although nitrogen is quite stable in the atmosphere, the form of nitrogen in the soil can change very easily. Some forms of nitrogen can be changed to ammonia gas (NH_3), which is volatile. The process of ammonia volatilization commonly takes place when nitrogen is in organic form, such urea. Ammonia volatilization is most likely to take place when soils are moist and warm and the source of urea is on or near the soil surface. Ammonia volatilization will also take place on alkaline soils (pH greater than 8). The process of ammonia volatilization does not directly impact water quality. Ammonia volatilization results in a net loss of nitrogen from the soil system. Therefore, indirectly it will result in less soil nitrogen being converted into the nitrate form. In this form, and when soils are excessively wet, nitrate is very mobile and easily moves with water. Nitrate is the form of nitrogen most likely to be lost to groundwater (http://muextension.missouri.edu/explore/envqual/wq0257.htm).

Denitrification: process in which oxidized forms of nitrogen, such as nitrate (NO_3^-), are reduced to form nitrites, nitrogen oxides (N_2O), ammonia, and ultimately free nitrogen (N_2). Commonly brought about by the action of denitrifying bacteria and usually resulting in the escape of nitrogen to the air. This process reduces desirable fertility of an agricultural field or the extent of undesirable aquatic weed production in aquatic environments (http://water.usgs.gov/pubs/circ/circ1157/nawqa91.e.html).

Field capacity (FC): amount of water in the soil after all free gravitational water has been removed (drained via gravity) and no additional water can be held in the soil. For most crop plants, this moisture level is ideal for growth because both water and air are available in soil pores.

Forage: food of any kind for animals, especially for horses and cattle, as grass, pasture, hay, corn, and oats.

Mineralization: general process by which elements present in organic compounds are eventually converted into inorganic forms, ultimately to become available for a new cycle of plant growth. The mineralizable nitrogen pool is the soil's nitrogen bank.

Model Calibration: process involving iterative adjustments of selected parameters values in effort to obtain a "best fit" comparison between simulated results and actual data. Some models do not require calibration, such as CREAMS; while others are highly dependent upon calibration. For successful operation without calibration, models must be completely physically based or be written to use parameters that can be obtained from prior experience or other observations.

Model Validation: process of substantiating that the model, within its domain of applicability, behaves with satisfactory accuracy consistent with the study objectives. The process reflects the ability of the model to accurately represent real-world systems response. Validation involves a comparison of models output with actual observations, using data sets different from those used in model development or calibration. Criteria do not exist for acceptable validation. A commonly used procedure is to graphically compare simulated versus observed values over some time period. Statistical comparisons of simulated and observed values may include correlation coefficients, relative errors and comparing means for a predetermined time (Knisel and Leonard, 1990).

Model Verification: process that substantiates the model is transformed, with sufficient accuracy, from one form to another (for example, the transformation of a model representation in a flow chart into an executable computer program). It also includes program debugging and testing through expected ranges of parameters value to insure computational stability (American Society for Testing Materials, 1984)

Nitrification: process in which organic nitrogen is transformed to NO^{-3} (nitrate) is one component of mineralization, the other major product being ammonium (NH^{-4}). Nitrate is the most useful form of nitrogen used by plants, but it is also easily leached into groundwater where it becomes a pollutant.

Nitrogen fixation: conversion of elemental nitrogen in the atmosphere (N_2) to a reduced form (e.g., ammonia and amino groups of amino acids) that can be used as a nitrogen source by organisms. The process is important because all organisms require a source of nitrogen for nutrition and the majority of the biota cannot use N_2. Certain species are responsible for most of fixations are: bluegreen algae, the soil bacterium *Azotobacter*, and the symbiotic association of legumes and the *Rhizobium* bacterium.

Nitrogen Leaching: nitrogen in the form of nitrate is negatively charged and is not attracted to negatively charged clay and humus. Negatively charged clay repels negatively charged nitrite (NO_2^-) and nitrate (NO_3^-) so they will not be absorbed by the clay and are left to move down through the soil and into the groundwater, where streams and drinking water can become contaminated.

Root zone: depth of soil in which most (about 90 per cent) of the roots of a plant occur.

Soil saturated hydraulic conductivity (Ksat): measure of a soil's ability to transmit water in a water-saturated state. Hydraulic conductivity is a key variable describing soil water fluxes. The entry of water into soil, the movement of water to plant roots, the flow of water to drains and wells and its evaporation are some of the examples in which hydraulic conductivity plays a decisive role (http://www.fao.org/gtos/tems).

Plow layer: Ap horizon (Knisel and Davis, 2000). The greatest depth of soil exhibiting mixing or inversion by surface tillage operations (http://www.soils.org/sssagloss/).

Vadose zone: (a.k.a. unsaturated zone): subsurface zone above the water table and the capillary fringe in which pores within the geologic matrix are partially filled with air and partially filled with water, and fluid pressure is less than atmospheric.

Witling point: amount of water held in the soil that plants are unable to remove. Soil may still contain water but it is inaccessible to plants.

Appendix B

HYDROLOGY PARAMETERS

Table B.1. Hydrology parameters listing.

Card	Parameter	Description	Value	Notes
1-3	TITLE			
4	HBDATE	Beginning date for hydrology simulation (year and Julian day)	1991000	If the rainfall record begins on Jan 1, 1991, and it is not known if rainfall occurs that day HBDATE should be 1991000 to initialize water before 1991001
	HYDOUT	Code to designate level of printed hydrology output 0 Annual summary output 1 Storm-by-storm output	0	Annual summary output
	FLGPEN	Code to designate method for simulation of potential ET 0 Priestly-Taylor 1 Penman-Monteith	0	Priestly-Taylor Method is an energy-based method for calculating evapotraspiration. It is simply the energy portion of the Penman-Monteith equation, modified with an empirical constant accounting for the wind-humidity component. It is appropriate for more humid Easter US, where humidity is generally higher and wind run lower. (Tollner, 2002, pg 86)
	FLGNUT	Code to designate simulation of nutrients 0 Nutrients are not simulated 1 Nutrients are simulated	1	
	FLGPST	Code to designate simulation of pesticides 0 Pesticides are not simulated 1 Pesticides are simulated	0	
	FLGGEN	Code to designate temperature data generation 0 Temperature data are to be read from hydrology parameter file 1 Climate generator is used	0	
	FLGMET	Code to designate units 0 English units 1 Metric units	1	
	FLGTMP	Code to indicate if daily temperature is to be read	1	Daily temperature data for the site provided by Dr. Vellidis

		0 Mean daily temperature file is not read 1 Mean daily temperature file is read		
	BCKEND	Code to indicate selection of variables for output 0 No selected variables are wanted 1 Selected variables are desired	1	
	FOREST	Code to indicate agricultural or forestry site (field) 0 Agricultural field application 1 Long leaf conifer forest 2 Short leaf conifer and cedar forest 3 Mixed pine-hardwood forest 4 Hardwood forest	0	
5	IBACK( )	Codes for selected variables	2003 2920 2927	Monthly Percolation (cm) Monthly NO3-N leached (kg/ha) Monthly Nitrogen uptake (kg/ha)
6	DAREA	Total drainage area (ha)	E 1.87 W 1.09 N 2.43 S 1.12	Total area of each quadrant calculated using the topographic map and AutoCAD.
	RC	Effective saturated hydraulic conductivity (Ksat) of the soil horizon immediately below the root zone (cm/hr)	.19	Ksat of the restricting layer (Ma et al, 200). A restricting layer such as a clay pan, argillic or spodic layer may determine the effective rooting depth and control drainage from above (Knisel and Davis, 2000)
	BST	Fraction of available plant water in soil. A full wet condition (field capacity) BST = 1.0; for completely dry (wilting point) BST = 0.0.	.80	If overestimated, runoffs will be high, underestimating infiltration. This will continue until the simulated soil water approaches the actual as rainfall values are factored into the model. There is little sensitivity for long-tern simulations. BST is not a sensitive parameter except if a rainfall event of interest occurs right after the beginning of simulation.
	CONA	Soil evaporation parameter, dependent upon soil texture.	3.3	Used value for loamy sand in Table H.3 Mean physical properties of soils by textural classification (Knisel and Davis, 2000). CONA is not a sensitive parameter in the water balance computation.
	CN2	SCS curve number (CN) for moisture condition II	85	In a study performed by Ma et al (2000), a CN of 85 was found to give acceptable runoff predictions. This value for Tifton loamy sand on the experimental site is complicated by surface crusting, sealing and transient perched water conditions at surface horizons.

				This is a sensitive parameter for runoff volume simulation. The higher CN is, the more sensitive it becomes because the maximum available storage is relatively small.
	CHS	Hydraulic slope of the field (m/m)	E .019 W .028 N .021 S .024	Calculated using the topographic map and AutoCAD.
	WLW	Ratio of field length to field width	E 2.29 W 1.90 N 0.81 S 1.84	Calculated using the topographic map and AutoCAD.
	RD	Effective rooting depth (cm)	C 12.0 R 20.0 BG 60.0	RD was determined from soil and crop data (Ma et al., 2000) and after conversations with Dr. Newton and Dr. Knisel
	ELEV	Mean sea level elevation (m) of the field outlet	106.7	Looked at a topographic map during a meeting with Dr. Smith and Dr. Vellidis (Nov. 2003)
	LAT	Latitude (°)	31.48	Looked at a topographic map during a meeting with Dr. Smith and Dr. Vellidis (Nov. 2003)
7	ISOIL	Code to designate soil phosphorus sorption 0 nutrients are not to be simulated 1 calcareous 2 slightly weathered 3 highly weathered	3	Assumed worse case scenario since the soil type is highly erodibile.
	NOSOHZ	Number of soil horizons in the root zone	4	Data observed from Ma et al., 2000
	BOTHOR( )	Depth to bottom of each soil horizon (cm)	29.0 62.0 92.0 111.0 150.0	First layer (Ma et al, 2000) First sampling depth
8	POR( )	Porosity for each soil horizon (cm^3/ cm^3)	.38 .36 .37 .37 .36	(Ma et al, 2000) Sensitive parameter in water balance calculations; it affects runoff, percolation, ET and evaporation. These components are sensitive in when simulating nutrient fate. Runoff would affect the erosion parameter when calculating sediment yield.
9	FC( )	Field capacity (FC) for each soil horizon (cm/cm)	.14 .22 .26 .26 .28	(Ma et al, 2000) Sensitive parameter in water balance calculations; it affects runoff, percolation, ET and evaporation. These components are sensitive in when simulating nutrient fate. Runoff would affect the erosion parameter when calculating sediment yield. As water enters a layer, it first fills the layer to field capacity, if enough water is available. Once the layer is at field capacity, the incoming water begins to replace the existing water (excluding bypassed volume) and the existing water is moved out of the layer. The incoming water continues to replace the existing water until all the existing water is replaced and then the incoming water begins to move out of the layer.

10	BR15( )	Wilting point (WP) for each soil horizon (cm/cm)	.05 .15 .16 .18 .19	I immobile soil water content of each soil horizon (Ma et al, 2000)
11	SATK( )	Saturated conductivity (KSAT) in each soil horizon (cm/hr)	12.1 4.5 3.51 3.35 .49	(Ma et al, 2000)
12	OM( )	Organic matter content of each soil horizon (%)	1.36 .59 .41 .21 .03	(Ma et al, 2000) OM = OC * 1.724
13	CLAY( )	Clay content of each soil horizon (%)	6.1 25.2 26.1 27.1 27.8	(Ma et al, 2000)
14	SILT( )	Silt content of each soil horizon (%)	9.3 11.4 11.0 10.6 11.8	(Ma et al, 2000)
15	PH( )	pH in each soil horizon	-	
16	BSAT( )	Base saturation in each soil horizon (%)	-	
17	CACO3( )	Calcium Carbonate content in each soil horizon (%)	-	
18-19	TEMPX( )	Mean monthly maximum temperature (ºC)	V	Mean maximum monthly temperature for the site provided by Dr. Vellidis
20-21	TEMPN( )	Mean monthly minimum temperature (ºC)	V	Mean minimum monthly temperature for the site provided by Dr. Vellidis
22-23	RAD( )	Mean monthly solar radiation (Langleys or MJ/cm²)	V	Mean monthly radiation for the site provided by Dr. Vellidis
24-25	WIND( )	Mean monthly wind movement (km/day)	V	Mean monthly wind velocity for the site provided by Dr. Vellidis
26-27	DEWPT( )	Mean monthly dew point temperature (ºC)	V	Mean monthly dew point for the site provided by Dr. Vellidis
28	HBYR	Beginning year of hydrology simulation	1991	
	HEYR	Ending year of hydrology simulation	1994	
	IROT	Number of years in rotation cycle	4	
29	ICROP	Crop identification code	R[1] 52 C[2] 22 BG[3] 10	Table N-2. Crop characteristics in GLEAMS database (Knisel and Davis, 2000)
	DPLANT	Date of planting for each crop	V	Cropping system developed with data provided by Dr. Newton
	DHRVST	Date of harvesting for each crop	V	Cropping system developed with data provided by Dr. Newton

	DTRUNC	Date of truncation of each crop	V	Cropping system developed with data provided by Dr. Newton
	CCRD	Rooting depth for each crop (cm)	R 20 C 12 BG 50	Estimated by communicating with Dr. Knisel and Dr. Newton.
	CRPHTX	Maximum height of each crop (m)	R C BG	Used default values
	PERNNL	Code to designate perennial crops 0 annual crop 1 perennial crop	R 0 C 0 BG 1	BG was over seeded with R during winter and the field is then planted with C during summer; however, BG is used as a cover crop and is considered perennial, it becomes dormant during winter.
	BEGGRO	Julian day for beginning of growth of perennial crops	BG 066	Cropping system developed with data provided by Dr. Newton
	ENDGRO	Julian day for end of growth of perennial crops	BG 311	Cropping system developed with data provided by Dr. Newton
30	IROPT	Code for model to consider irrigation date and amount 0 irrigation is not applied 1 irrigation is applied on demand	0	Irrigation should not be modeled but is specified.
	DBIRR	Date model is to begin considering soil moisture for automatic irrigation	-	
	DEIRR	Date model is to quit considering automatic irrigation	-	
	DPREIR	Date pre-planting irrigation is to be applied to leach salt from the root zone	-	
	PREIRR	Equivalent depth of pre-planting irrigation to be applied (cm)	-	
	BASEI	Fraction of plant available water content in the root-zone when the model is to apply irrigation	-	
	TOPI	Fraction of plant available water content in the root-zone desired after irrigation	-	
31	ICROP	Crop identification code	-	
	NOLAI	Number of data points to describe the leaf area index	-	
32	USRFRC	Fraction of the growing season for which LAI is specified	-	
	USRPHT	Leaf area index at the specified fraction	-	
	CROPHT	Crop height (m)	-	

33	NEWT	Code for reading new mean monthly temperature data 0 Do not read new temperature data 1 Read new temperature data -1End simulation	0 -1	
	NEWR	Code for reading new mean monthly radiation data 0 Do not read new radiation data 1 Read new radiation data	0	
	NEWW	Code for reading new mean monthly wind movement data 0 Do not read new wind movement data 1 Read new wind movement data	0	
	NEWD	Code for reading new mean monthly dew point temperature data 0 Do not read new dew point temperature data 1 Read new dew point temperature data	0	

[1] R = abruzzi rye
[2] C = corn
[3] BG = bermuda grass

Table B.2. Sample GLEAMS 3.0 hydrology parameter file for corn-bermudagrass-rye rotation for the South quadrant.

```
UGA CPES - SI
Tifton, GA continuous T44BG, rye, corn, min. tillage
Tifton loamy sand
 1991000    0    0    1    0    0    1    1    1    0
   2003   2920   2927

   1.12    .49    .8    3.3    85   .024   1.84   150.0   106.7   31.48
     3      5   29.0   62.0   92.0  111.0  150.0
    .38    .36    .37    .37    .36
    .14    .22    .26    .26    .28
    .05    .15    .16    .18    .19
   12.1   4.54   3.52   3.35    .49
   1.36    .59    .41    .21    .03
    6.1   25.2   26.1   27.1   27.8
    9.3   11.4   11.0   10.6   11.8
   14.4   17.5   20.5   21.2   27.7   30.3   32.1   31.0   29.7   24.7
   19.9   15.9
    4.1    5.8    7.9   11.7   16.1   19.9   21.5   20.7   18.5   12.6
    8.1    4.9
    8.4   13.2   16.8   19.9   21.1   20.6   21.7   18.9   17.7   13.9
   10.9    8.9
  167.1  175.6  190.7  168.5  153.9  165.4  155.6  157.1  170.1  188.6
  207.8  204.1
    2.9    3.5    5.5   11.0   17.2   21.0   22.3   21.2   19.2   13.7
    7.7    2.9
   1991   1994    4
    10   1001   1090   1079   50.0          1    066    311
     0
    22   1080   1209   1196   12.0

    10   1197   1223   1215   50.0          1    066    311
     0
    10   1216   1241   1233   50.0          1    066    311
     0
    10   1234   1258   1251   50.0          1    066    311
     0
    10   1252   1277   1269   50.0          1    066    311
     0
    10   1270   1297   1288   50.0          1    066    311
     0
    52   1289   1348   1341   20.0          0
     0
    52   1342   2035   2029   20.0          0
     0
    52   2030   2090   2079   20.0          0
     0
    22   2080   2209   2196   12.0          0
     0
    10   2197   2223   2215   50.0          1    066    311
     0
    10   2216   2241   2233   50.0          1    066    311
     0
```

```
10   2234   2258   2251   50.0          1   066    311
0
10   2252   2277   2269   50.0          1   066    311
0
10   2270   2297   2288   50.0          1   066    311
0
52   2289   2348   2341   20.0          0
0
52   2342   3035   3029   20.0          0
0
52   3030   3090   3079   20.0          0
0
22   3080   3209   3196   12.0          0
0
10   3197   3223   3215   50.0          1   066    311
0
10   3216   3241   3233   50.0          1   066    311
0
10   3234   3258   3251   50.0          1   066    311
0
10   3252   3277   3269   50.0          1   066    311
0
10   3270   3297   3288   50.0          1   066    311
0
52   3289   3348   3341   20.0          0
0
52   3342   4035   4029   20.0          0
0
52   4030   4090   4079   20.0          0
0
22   4080   4209   4196   12.0          0
0
10   4197   4223   4215   50.0          1   066    311
0
10   4216   4241   4233   50.0          1   066    311
0
10   4234   4258   4251   50.0          1   066    311
0
10   4252   4277   4269   50.0          1   066    311
0
10   4270   4297   4288   50.0          1   066    311
0
52   4289   4348   4341   20.0          0
0
52   4342   5035   5029   20.0          0
0
0
0    0    0    0
0    0    0    0
0    0    0    0
-1    0    0    0
```

Appendix C

EROSION PARAMETERS

Table C.1. Erosion parameter listing.

Card	Parameter	Description	Value	Notes
1-3	TITLE			
4	BYEAR	Year when simulation begins	1991	
	EYEAR	Year when simulation ends	1994	
	EROOUT	Code for output 0 abbreviated annual summary output 1 detailed annual summary output 2 abbreviated monthly and annual summary output 3 detailed monthly and annual summary output 4 abbreviated storm-by-storm and summary output 5 detailed storm-by-storm and summary output	0	
	FLGSEQ	Code to indicate execution sequence of erosion-sediment submodules 1 overland 2 overland-impoundment 3 overland-channel 4 overland-channel-channel 5 overland-channel-impoundment 6 overland-channel-channel-impoundment	1	
	METFLG	Code for metrification 0 English units 1 Metric units	1	
5	SSCLY	Specific surface area	15	Used to estimate enrichment ratio (ER) for

		for clay particles (m^2/g)		sediment delivered to the edge of the field. Phosphorous and ammonia are absorbed onto the clay fraction of the soil. Transport capacity determines which particles will be carried and which will be deposed. The specific surface area of clay is dependent on the mineralogy.
6	NPTSO	Number of points for overland flow profile slope	1	
	DAOVR	Drainage area represented by the overland flow profile (ha)	E 1.87 W 1.09 N 2.43 S 1.12	The entire area of the field is usually considered contributing to the overland flow.
7	XOV( )	Distance from upper end of overland flow profile to the point where slope is given (m)	E 206.9 W 143.8 N 140.1 S 143.8	Calculated from topographic map information
	SLOV( )	Slope of the overland profile (m/m)	E .019 W .028 N .021 S .024	Calculated from topographic map information
8	NXK	Number of slope segments differentiated by changes in soil erodibility factor	1	
	XSOIL( )	Relative horizontal distance from the top of the slope to the bottom of the segment	1.0	Calculated from topographic map information
	KSOIL( )	Soil erodibility factor for the slope segment	.0302	Erodibility change within a soil series just as water retention characteristics. Soil erodibility was calculated using the average relative size distribution data from the textural classification. KSOIL equation and data were obtained from Tollner (2002), Ma et al (2000), and http://soilphysics.okstate.edu/S257/book/mlra133a/tables.html
9	NSC	Number of channel segments differentiated by changes in slope	-	
	CTLO	Channel outlet control condition that affects flow depth	-	
	RA	Coefficient in the rating equation	-	
	RN	Exponent in the rating equation	-	
	DACHL	Total drainage area at the lower end of the	-	

		channel (ha)		
	DACHU	Drainage area at the upper end of the channel (ha)	-	
	Z	Side slope of field channel cross-section (m/m)	-	
10	XLSP( )	Distance from upper end of the channel to the bottom of segment (m)	-	
	SSLP( )	Slope of segment directly above (m/m)	-	
11	CTLZ	Side slope of a cross-section of the outlet control channel	-	
	CTLN	Manning's "n" for the outlet control channel	-	
	CTLSL	Slope of the outlet control channel (m/m)	-	
12	DAPND	Total drainage area above the impoundment (ha)	-	
	INTAKE	Saturated soil-water intake rate or saturated conductivity within the impoundment (cm/hr)	-	
	FRONT	Embankment front slope	-	
	DRAW	Slope along channel draining into the impoundment	-	
	SIDE	Side slope of land at impoundment	-	
	CTL	Code for type of impoundment outlet 0 pipe control is typical of impoundment-type terraces 1 if an orifice coefficient is to be entered	-	
	DIAO	Diameter of orifice in outlet pipe (cm)	-	
	C	Orifice coefficient	-	
13	NYEARS	Number of years in this rotation	1 4	Only one year since the four years of rotation are the same, suggested by Dr. Knisel. However according to the manual, NYEARS should be the same as IROT in

				the hydrology parameter file so I have both files. Infiltration and percolation change but the overall result is the same.
14	CDATE( )	Julian dates on which these parameters take effect	001	Jan 1st of each year.
15	NXF	Number of overland flow profile segments differentiated by changes in the overland flow parameters	1	Parameters are assumed to be uniform along the entire profile.
	XFACT( )	Relative horizontal distance from the top of the overland flow profile to the bottom of segment	1	
16	CFACT( )	Soil loss ratio for overland flow profile segment	.15	Also called the crop factor for the USLE. It is a step function CFACT is a sensitive parameter in the model depending upon overland flow profile and the flow sequence (Knisel and Davis, 2000). If the FLGSEQ is 1 (overland flow only) and the profile ahs uniform slope or is convex (steeping along the slope), CFACT is very sensitive. Value obtained from Tollner (2000) for a 4-yr crop rotation in N GA (pg 156). Not very sensitive when changed from 0.05 to .15.
17	PFACT( )	Contouring factor for overland flow profile segment	0.6	Explains how management affects soil loss ratio. Obtained fro Table E-4. Contour factor values (PFACT) and slope length limits for contouring (Wischmeier and Smith, 1978; Knisel and Davis, 2000). Not very sensitive when changed from 1 to 0.6.
18	NFACT( )	Manning's "n" for overland flow profile segment	.05	Soil cover and hydraulic roughness slow overland flow and reduce sediment transport capacity. The reduction in velocity depends upon depth of flow, the type of material on the surface and its density. NFACT is a sensitive parameter for sediment yield from uniform or convex slopes. Used Table E-3. Manning's n values for overland flow element (forstr st at, 1980a; Knisel and Davis, 2000)
19	NXC	Number of channel profile segments differentiated by changes in the channel parameters	-	
	XCHAN( )	Relative horizontal distance from top of	-	

		channel to bottom of segment		
20	NCHAN( )	Manning's "n" for channel segment	-	
21	DCHAN( )	Depth to nonerodable layer in middle of channel for segment (m)	-	
22	WCHAN( )	Top width of channel for segment (m)	-	

Table C.2. Sample GLEAMS 3.0 erosion parameter file for an overland flow and conservation tillage system in the South quadrant.

```
UGA CPES - SI
Tifton, GA continuous T44BG, rye, corn, min tillage
Tifton loamy sand
   1991    1994       0       1       1
   15.0
     1    1.12
  143.8   0.024
     1     1.0   .0302
     1
    001
     1     1.0
    .05
    1.0
    .05
```

Appendix D

PLANT NUTRIENTS PARAMETERS

Table D.1. Plant nutrient parameters listing.

Card	Parameter	Description	Value	Notes
1-3	TITLE			
4	NYBR	Beginning year of plant nutrient simulation	1991	
	NEYR	Ending year of plant nutrient simulation	1994	
	NUTOUT	Code to designate level of printed nutrient output 0 for annual summaries only 1 for monthly and annual summaries 2 for storm output, and monthly and annual summaries 3 for storm output with concentrations by layer, and monthly and annual summaries	1	
	FLGROT	Number of years in a rotation cycle	4	
	FLGBAL	Code for output of N and P balance at the end of each year of simulation 0 No N & P balance output 1 Output N & P balance each year	1	The beginning and ending total mass in each pool, such as soil nitrate, potentiality mineralizable nitrogen, and liable phosphorous, in the root zone and on the surface will be printed.
5	RESDW	Crop residue (kg/ha)	9000	Crop residue on the soil surface has tow effects: a) serves as an insulator on soil temperature; and b) source of nitrogen and phosphorous mineralization. The value was a selected for a no-till system with corn harvested in the fall (Knisel and Davis, 2000).
	RCN	Nitrogen concentration in rainfall (ppm)	.8	Rainfall might be a significant source of nitrogen insole locations. Rainfall nitrogen is mainly in the nitrate form but could also include ammonia. Value obtained from Figure N-1. Nitrogen (NO_3-N and NH_3-N), kg/ha/yr, contributions fro rainfall though the USA (Chapin, and Uttormark, 1973; Knisel and Davis, 2000). RCN is not a sensitive parameter.

	CNI	Concentration of nitrate-nitrogen in irrigation (ppm)	-	If blank additions will not be simulated. Irrigation amounts are included in the precipitation file for validation purposes, IROPT = 0 in hydrology file.
	CPI	Concentration of labile-phosphorus in irrigation (ppm)	-	If blank additions will not be simulated. Irrigation amounts are included in the precipitation file for validation purposes, IROPT = 0 in hydrology file.
INITIALIZATION OF N AND P POOLS Initial values of different conceptualized pool are every site specific and generally management dependent. This is especially true for systems with animal waste application and conservation tillage with heavy residue left on the soils surface such as the site being modeled.				
6	TN( )	Total nitrogen in each horizon (%)	0.050	Expressed as TKN (all N forms but NO_3-N). Selected Ultisol from Table N-1. Mineralizable nitrogen, total nitrogen, and organic carbon in surface soils of various orders (Stanford and Smith, 1978; Knisel and Davis, 2000). Talk with Julia Gaskin (Apr, 2004) and UDA-NRCS Soil Survey Division. http://ortho.ftw.nrcs.usda.gov/cgi-bin/sc/scname.cgi Then calculated TN( ) using the formula in pg 140.
7	CNIT( )	Nitrate-nitrogen concentration in each horizon (μg/g)	35.0	Very dynamic and not very sensitive in long term simulations. If left blank, the model estimates concentration of 10 μg NO_3-N/g of soil in all horizons. Due to its dynamic nature, transformations will rather quickly modify the values to represent actual conditions.
8	POTMN( )	Potentially mineralizable nitrogen in each horizon (kg/ha)	150.0	Used Table N-1. Mineralizable nitrogen, total nitrogen, and organic carbon in surface soils of various orders (Stanford and Smith, 1978; Knisel and Davis, 2000).
9	ORGNW	Organic nitrogen content from animal waste in the plow horizon (%)	0.0	Organic nitrogen from animal waste application is highly significant in long-term simulations and there might be considerable carry over from year-to-year. Animal waste is only incorporated in the plow layer (Ap horizon); hence, ORGNW has to be estimated for the top layer. In warm most climatic regions, such as the SE, only ¼ of annual application might be carried over (Knisel and Davis, 2000). ORGNW is a sensitive parameter since mineralization occurs as a first order process. Organic-N is not available to crops (mineralized) until it has been decomposed to NH_4. Organic-N is lost from the soil only by erosion (http://hubcap.clemson.edu). Frequently, TN nitrogen in dairy lagoons effluent is composed of 2/3 NH_3-N and 1/3 organic-N. Any value other than 0.0 gives out ERROR N1: Underflow in Nitrogen Initialization.
10	TP( )	Total phosphorus in each horizon (%)	D	Phosphorus sorption is a function of soil type and varies with each horizon.
11	CLAB( )	Labile phosphorus concentration in each horizon (μg/g)	D	
12	ORGPW	Organic phosphorus content from animal waste in the plow horizon (%)	D	Must be estimated for the plow layer
13	PDATE	Date that the parameters are valid	1001	

14	NF	Number of fertilizer and animal waste applications	V	Varies for each crop rotation
	NTIL	Number of tillage operations	1 0	Only for C. BG and R are cut for hay but not tilled.
	DHRVST	Julian date of crop harvest	V	Varies for each crop rotation. Signals model to transform nutrients and residue into yield and biomass.
15	ICROP	Identification number of the crop grown during this cropping period	R 52 C 22 BG 10	Table N-2. Crop characteristics in GLEAMS database (Knisel and Davis, 2000)
	LEG	Code for legume crop 0 not a legume 1 legume	0	None of the crops are considered legumes.
	PY	Potential yield for the harvestable portion of the crop (kg/ha)	V	Varied for each crop rotation and quadrant. Harvestable portion of the crop. Allows dry matter to be taken out of the system at harvest time. PY tends to decrease for each cutting. Obtained from Newton et al., 1995.
	DMY	Dry matter ratio	D	
	CNR	Carbon:Nitrogen ratio for the crop	D	
	RNP	Ratio of crop nitrogen to phosphorus	D	
	C1	Coefficient in the exponential relation to estimate nitrogen content of the crop	D	
	C2	Exponent in the exponential relation to estimate nitrogen content of the crop	D	
16	DF	Date of fertilizer application	V	Dr. Vellidis provided the dates for fertilizer application.
	MFERT	Code for method of fertilization 0 for inorganic fertilizer 1 for organic fertilizer	1	
	METHAP	Code for method of application 0 for surface application of manure solids or slurry, or inorganic fertilizer 1 for incorporated fertilizer or animal waste 2 for injected 3 fertigation 4 liquid animal waste	4	

	MTYPE	Code for animal waste type 0 inorganic fertilizer 1 beef cattle, solid 2 dairy cattle, solid 3 horse, solid 4 municipal sludge 5 poultry, solid 6 sheep, solid 7 swine, solid 8 beef, slurry 9 dairy, slurry 10 swine, slurry 11 beef, liquid 12 dairy, liquid 13 poultry, liquid 14 swine, liquid 15 if user supplies N and P levels	15	N and P levels will be calibrated to match the TKN and P (kg/ha) applied for a year for each quadrant data provided by Dr. Vellidis. The default N and P levels estimated very high input TKN and TP balances producing excess nitrate leachate.
17	FN	Fertilizer nitrate (kg/ha)	-	
	FNH	Fertilizer ammonia (kg/ha)	-	
	FP	Fertilizer phosphorus (kg/ha)	-	
	DEPIN	Depth of incorporation (cm)	-	
	FRTWAT	Depth of water applied for fertigation (cm)	-	
18	RATE	Application rate for animal waste (cm)	V	Dr. Vellidis provided the dates for fertilizer application and the amount of fertilizer applied
	DEPIN	Depth of animal waste injection (cm)	0.0	
	ATN	Total nitrogen in animal waste (%)	V	Varied for each crop rotation, year, and quadrant. Set up by trial and error using the analysis from on-site samples.
	APORGN	Organic nitrogen content in animal waste (%)	V	According to the analysis of the irrigated manure, organic nitrogen was 2% of TN (Vellidis et al., 1996)
	ANH	Ammonia content in animal waste (%)	V	According to the analysis of the irrigated manure, organic nitrogen was 79% of TN (Vellidis et al., 1996).
	APHOS	Total phosphorus content in animal waste (%)	.013	Used default values.
	APORGP	Organic phosphorus content in animal waste (%)	.0042	Used default values.
	AOM	Organic matter content in animal waste (%)	0.5	Urbanowicz (2001) wrote that most dairy farmers use liquid manure, which does not contain any bedding material. Liquid manure contains less than 5% matter compared to 13% dry matter in solid manure.
	WASTYP	Waste type 1 solid	3	

		2 slurry 3 liquid		
19	NTDAY	Date of tillage	V	Varies for each crop rotation
	LTIL	Code to designate type of tillage implement	5	See GLEAMS manual, pg 214, for types
	DTIL	Depth of tillage (cm)	5.0	
	EFFINC	Efficiency of incorporation of surface residue	.1	
	FMIX	Tillage mixing efficiency	.1	

[1] D = default value, value given by the model.

Table D.2. Sample GLEAMS 3.0 plant nutrient parameters for liquid dairy manure land application system over a corn-bermudagrass-rye rotation, East quadrant (200 kg N/ha).

```
Tifton, GA continuous T44BG, rye, corn, min tillage
Tifton loamy sand
  1991   1994     1     4     1
 9000.0    .8
  .050   .050   .030   .010   .010
   3.8    3.8    3.8    3.8    3.8
  150.0  150.0  260.0  260.0  120.0
   0.0


  1001
    0     0   1079
   10       1700.0
  1080
    2     1   1196
   22       6000.0
  1177     1     4     15
   .63   0.0  .01780  .00356  .01406   .013   .0042    .05     3
  1182     1     4     15
   .52   0.0  .01780  .00356  .01406   .013   .0042    .05     3
  1196     5    5.0
  1197
    2     0   1215
   10       1700.0
  1206     1     4     15
   .42   0.0  .01780  .00356  .01406   .013   .0042    .05     3
  1211     1     4     15
   .54   0.0  .01780  .00356  .01406   .013   .0042    .05     3
  1216
    2     0   1233
   10       1700.0
  1218     1     4     15
   .45   0.0  .01780  .00356  .01406   .013   .0042    .05     3
  1225     1     4     15
  0.53    0.0  .01780  .00356  .01406   .013   .0042    .05     3
  1234
    1     0   1251
   10       1700.0
  1246     1     4     15
  0.50    0.0  .01780  .00356  .01406   .013   .0042    .05     3
  1252
    1     0   1269
   10       1700.0
  1255     1     4     15
  0.57    0.0  .01780  .00356  .01406   .013   .0042    .05     3
  1270
    2     0   1288
   10       1700.0
  1273     1     4     15
   .65   0.0  .01780  .00356  .01406   .013   .0042    .05     3
  1287     1     4     15
```

```
0.55     0.0  .01780  .00356  .01406    .013   .0042     .05       3
1289
  3      0    1341
 52         1400.0
1301      1       4       15
 .56    0.0  .01780  .00356  .01406    .013   .0042     .05       3
1317      1       4       15
 .53    0.0  .01780  .00356  .01406    .013   .0042     .05       3
1336      1       4       15
0.75     0.0  .01780  .00356  .01406    .013   .0042     .05       3
1342
  3      0    2029
 52         1400.0
1348      1       4       15
0.61     0.0  .01780  .00356  .01406    .013   .0042     .05       3
2007      1       4       15
 .51    0.0  .01912  .00382  .01511    .013   .0042     .05       3
2021      1       4       15
 .59    0.0  .01912  .00382  .01511    .013   .0042     .05       3
2030
  3      0    2079
 52         1400.0
2034      1       4       15
 .55    0.0  .01912  .00382  .01511    .013   .0042     .05       3
2050      1       4       15
 .55    0.0  .01912  .00382  .01511    .013   .0042     .05       3
2062      1       4       15
 .55    0.0  .01912  .00382  .01511    .013   .0042     .05       3
2080
  7      1    2196
 22         6000.0
2113      1       4       15
 .52    0.0  .01912  .00382  .01511    .013   .0042     .05       3
2120      1       4       15
 .56    0.0  .01912  .00382  .01511    .013   .0042     .05       3
2132      1       4       15
 .59    0.0  .01912  .00382  .01511    .013   .0042     .05       3
2146      1       4       15
 .59    0.0  .01912  .00382  .01511    .013   .0042     .05       3
2160      1       4       15
 .56    0.0  .01912  .00382  .01511    .013   .0042     .05       3
2175      1       4       15
 .52    0.0  .01912  .00382  .01511    .013   .0042     .05       3
2195      1       4       15
 .54    0.0  .01912  .00382  .01511    .013   .0042     .05       3
2196      5     5.0
2197
  0      0    2215
 10         1700.0
2216
  2      0    2233
 10         1700.0
2223      1       4       15
0.55     0.0  .01912  .00382  .01511    .013   .0042     .05       3
2231      1       4       15
 .61    0.0  .01912  .00382  .01511    .013   .0042     .05       3
```

```
2234
  1      0    2251
 10          1700.0
2240      1       4       15
 .51    0.0  .01912  .00382  .01511    .013   .0042     .05       3
2252
  1      0    2269
 10          1700.0
2253      1       4       15
 .53    0.0  .01912  .00382  .01511    .013    .042     .05       3
2270
  0      0    2288
 10          1700.0
2289
  3      0    2341
 52          1400.0
2301      1       4       15
 .59    0.0  .01912  .00382  .01511    .013   .0042     .05       3
2315      1       4       15
 .65    0.0  .01912  .00382  .01511    .013   .0042     .05       3
2323      1       4       15
 .59    0.0  .01912  .00382  .01511    .013    .042     .05       3
2342
  3      0    3029
 52          1400.0
2349      1       4       15
 .64    0.0  .01912  .00382  .01511    .013   .0042     .05       3
3004      1       4       15
 .70    0.0  .01542  .00308  .01218    .013   .0042     .05       3
3019      1       4       15
 .68    0.0  .01542  .00308  .01218    .013   .0042     .05       3
3030
  3      0    3079
 52          1400.0
3032      1       4       15
 .60    0.0  .01542  .00308  .01218    .013   .0042     .05       3
3053      1       4       15
 .62    0.0  .01542  .00308  .01218    .013   .0042     .05       3
3061      1       4       15
 .62    0.0  .01542  .00308  .01218    .013   .0042     .05       3
3080
  9      1    3196
 22          6000.0
3103      1       4       15
 .51    0.0  .01542  .00308  .01218    .013   .0042     .05       3
3110      1       4       15
 .55    0.0  .01542  .00308  .01218    .013   .0042     .05       3
3117      1       4       15
 .58    0.0  .01542  .00308  .01218    .013   .0042     .05       3
3131      1       4       15
 .56    0.0  .01542  .00308  .01218    .013   .0042     .05       3
3146      1       4       15
 .54    0.0  .01542  .00308  .01218    .013   .0042     .05       3
3158      1       4       15
 .61    0.0  .01542  .00308  .01218    .013   .0042     .05       3
3173      1       4       15
```

```
 .59    0.0  .01542  .00308  .01218   .013   .0042    .05     3
3188     1      4      15
 .65    0.0  .01542  .00308  .01218   .013   .0042    .05     3
3195     1      4      15
 .60    0.0  .01542  .00308  .01218   .013   .0042    .05     3
3196     5     5.0
3197
  1      0    3215
 10        1700.0
3202     1      4      15
 .62    0.0  .01542  .00308  .01218   .013   .0042    .05     3
3216
  1      0    3233
 10        1700.0
3222     1      4      15
 .63    0.0  .01542  .00308  .01218   .013   .0042    .05     3
3234
  1      0    3251
 10        1700.0
3237     1      4      15
 .49    0.0  .01542  .00308  .01218   .013   .0042    .05     3
3252
  1      0    3269
 10        1700.0
3257     1      4      15
 .60    0.0  .01542  .00308  .01218   .013   .0042    .05     3
3270
  1      0    3288
 10        1700.0
3271     1      4      15
 .50    0.0  .01542  .00308  .01218   .013   .0042    .05     3
3289
  3      0    3341
 52        1400.0
3298     1      4      15
 .55    0.0  .01542  .00308  .01218   .013   .0042    .05     3
3312     1      4      15
 .54    0.0  .01542  .00308  .01218   .013   .0042    .05     3
3334     1      4      15
 .53    0.0  .01542  .00308  .01218   .013   .0042    .05     3
3342
  2      0    4029
 52        1400.0
3354     1      4      15
 .91    0.0  .01542  .00308  .01218   .013   .0042    .05     3
4011     1      4      15
 .61    0.0  .01533  .00307  .01211   .013   .0042    .05     3
4030
  3      0    4079
 52        1400.0
4032     1      4      15
 .74    0.0  .01533  .00307  .01211   .013   .0042    .05     3
4046     1      4      15
 .60    0.0  .01533  .00307  .01211   .013   .0042    .05     3
4067     1      4      15
 .68    0.0  .01533  .00307  .01211   .013   .0042    .05     3
```

```
4080
  6      1    4196
 22        6000.0
4095     1       4       15
 .63    0.0  .01533  .00307  .01211    .013   .0042     .05      3
4109     1       4       15
 .58    0.0  .01533  .00307  .01211    .013   .0042     .05      3
4123     1       4       15
 .67    0.0  .01533  .00307  .01211    .013   .0042     .05      3
4143     1       4       15
 .54    0.0  .01533  .00307  .01211    .013   .0042     .05      3
4150     1       4       15
 .61    0.0  .01533  .00307  .01211    .013   .0042     .05      3
4189     1       4       15
 .53    0.0  .01533  .00307  .01211    .013   .0042     .05      3
4196     5     5.0
4197
  2      0    4215
 10        1700.0
4202     1       4       15
 .60    0.0  .01533  .00307  .01211    .013   .0042     .05      3
4209     1       4       15
 .54    0.0  .01533  .00307  .01211    .013   .0042     .05      3
4216
  1      0    4233
 10        1700.0
4222     1       4       15
 .56    0.0  .01533  .00307  .01211    .013   .0042     .05      3
4234
  1      0    4251
 10        1700.0
4237     1       4       15
 .60    0.0  .01533  .00307  .01211    .013   .0042     .05      3
4252
  1      0    4269
 10        1700.0
4263     1       4       15
 .60    0.0  .01533  .00307  .01211    .013   .0042     .05      3
4270
  2      0    4288
 10        1700.0
4270     1       4       15
 .72    0.0  .01533  .00307  .01211    .013   .0042     .05      3
4279     1       4       15
 .66    0.0  .01533  .00307  .01211    .013   .0042     .05      3
4289
  2      0    4341
 52        1400.0
4291     1       4       15
 .63    0.0  .01533  .00307  .01211    .013   .0042     .05      3
4299     1       4       15
 .60    0.0  .01533  .00307  .01211    .013   .0042     .05      3
4342
  0      0    5029
 52        1400.0
  0
```

Table D.3. Sample GLEAMS 3.0 plant nutrient parameters for liquid dairy manure land application system over a corn-bermudagrass-rye rotation, West quadrant (400 kg N/ha).

```
Tifton, GA continuous T44BG, rye, corn, min tillage
Tifton loamy sand
  1991   1994     1     4     1
 9000.0     .8
  .050   .050   .030   .010   .010
   3.8    3.8    3.8    3.8    3.8
  150.0  150.0  260.0  260.0  120.0
   0.0


  1001
    0     0   1079
   10       2200.0
  1080
    2     1   1196
   22      15500.0
  1177    1     4     15
  1.11    0.0  .01593  .00319  .01259   .013   .0042    .05     3
  1182    1     4     15
  1.20    0.0  .01593  .00319  .01259   .013   .0042    .05     3
  1196    5    5.0
  1197
    2     0   1215
   10       2200.0
  1206    1     4     15
  1.43    0.0  .01593  .00319  .01259   .013   .0042    .05     3
  1211    1     4     15
  1.97    0.0  .01593  .00319  .01259   .013   .0042    .05     3
  1216
    2     0   1233
   10       2200.0
  1218    1     4     15
  1.13    0.0  .01593  .00319  .01259   .013   .0042    .05     3
  1225    1     4     15
  0.92    0.0  .01593  .00319  .01259   .013   .0042    .05     3
  1234
    1     0   1251
   10       2200.0
  1246    1     4     15
  0.55    0.0  .01593  .00319  .01259   .013   .0042    .05     3
  1252
    1     0   1269
   10       2200.0
  1255    1     4     15
  0.83    0.0  .01593  .00319  .01259   .013   .0042    .05     3
  1270
    2     0   1288
   10       2200.0
  1273    1     4     15
  1.00    0.0  .01593  .00319  .01259   .013   .0042    .05     3
  1287    1     4     15
```

```
0.90    0.0  .01593  .00319  .01259   .013   .0042    .05      3
1289
  3     0    1341
 52       2500.0
1301     1      4      15
1.14    0.0  .01593  .00319  .01259   .013   .0042    .05      3
1317     1      4      15
0.99    0.0  .01593  .00319  .01259   .013   .0042    .05      3
1336     1      4      15
0.89    0.0  .01593  .00319  .01259   .013   .0042    .05      3
1342
  3     0    2029
 52       2500.0
1348     1      4      15
0.95    0.0  .01593  .00319  .01259   .013   .0042    .05      3
2007     1      4      15
1.12    0.0  .01768  .00354  .01397   .013   .0042    .05      3
2021     1      4      15
1.26    0.0  .01768  .00354  .01397   .013   .0042    .05      3
2030
  3     0    2079
 52       2500.0
2034     1      4      15
0.88    0.0  .01768  .00354  .01397   .013   .0042    .05      3
2050     1      4      15
0.99    0.0  .01768  .00354  .01397   .013   .0042    .05      3
2062     1      4      15
0.87    0.0  .01768  .00354  .01397   .013   .0042    .05      3
2080
  7     1    2196
 22      15500.0
2113     1      4      15
0.98    0.0  .01768  .00354  .01397   .013   .0042    .05      3
2120     1      4      15
0.86    0.0  .01768  .00354  .01397   .013   .0042    .05      3
2132     1      4      15
1.18    0.0  .01768  .00354  .01397   .013   .0042    .05      3
2146     1      4      15
0.92    0.0  .01768  .00354  .01397   .013   .0042    .05      3
2160     1      4      15
2.42    0.0  .01768  .00354  .01397   .013   .0042    .05      3
2175     1      4      15
0.86    0.0  .01768  .00354  .01397   .013   .0042    .05      3
2195     1      4      15
0.99    0.0  .01768  .00354  .01397   .013   .0042    .05      3
2196     5    5.0
2197
  0     0    2215
 10       2200.0
2216
  2     0    2233
 10       2200.0
2223     1      4      15
0.95    0.0  .01768  .00354  .01397   .013   .0042    .05      3
2231     1      4      15
1.02    0.0  .01768  .00354  .01397   .013   .0042    .05      3
```

```
2234
  1     0    2251
 10        2200.0
2240     1       4       15
0.72     0.0  .01768  .00354  .01397    .013   .0042     .05       3
2252
  1     0    2269
 10        2200.0
2253     1       4       15
0.71     0.0  .01768  .00354  .01397    .013    .042     .05       3
2270
  0     0    2288
 10        2200.0
2289
  3     0    2341
 52        2500.0
2301     1       4       15
1.14     0.0  .01768  .00354  .01397    .013   .0042     .05       3
2315     1       4       15
1.05     0.0  .01768  .00354  .01397    .013   .0042     .05       3
2323     1       4       15
1.11     0.0  .01768  .00354  .01397    .013    .042     .05       3
2342
  3     0    3029
 52        2500.0
2349     1       4       15
1.13     0.0  .01768  .00354  .01397    .013   .0042     .05       3
3004     1       4       15
1.30     0.0  .01535  .00307  .01213    .013   .0042     .05       3
3019     1       4       15
1.18     0.0  .01535  .00307  .01213    .013   .0042     .05       3
3030
  3     0    3079
 52        2500.0
3032     1       4       15
0.89     0.0  .01535  .00307  .01213    .013   .0042     .05       3
3053     1       4       15
0.88     0.0  .01535  .00307  .01213    .013   .0042     .05       3
3061     1       4       15
1.09     0.0  .01535  .00307  .01213    .013   .0042     .05       3
3080
  9     1    3196
 22       15500.0
3103     1       4       15
1.14     0.0  .01535  .00307  .01213    .013   .0042     .05       3
3110     1       4       15
0.91     0.0  .01535  .00307  .01213    .013   .0042     .05       3
3117     1       4       15
0.91     0.0  .01535  .00307  .01213    .013   .0042     .05       3
3131     1       4       15
1.02     0.0  .01535  .00307  .01213    .013   .0042     .05       3
3146     1       4       15
1.09     0.0  .01535  .00307  .01213    .013   .0042     .05       3
3158     1       4       15
0.92     0.0  .01535  .00307  .01213    .013   .0042     .05       3
3173     1       4       15
```

```
0.99    0.0  .01535  .00307  .01213   .013   .0042    .05     3
3188     1      4      15
1.15    0.0  .01535  .00307  .01213   .013   .0042    .05     3
3195     1      4      15
1.04    0.0  .01535  .00307  .01213   .013   .0042    .05     3
3196     5     5.0
3197
  1     0    3215
 10         2200.0
3202     1      4      15
1.09    0.0  .01535  .00307  .01213   .013   .0042    .05     3
3216
  1     0    3233
 10         2200.0
3222     1      4      15
0.88    0.0  .01535  .00307  .01213   .013   .0042    .05     3
3234
  1     0    3251
 10         2200.0
3237     1      4      15
0.82    0.0  .01535  .00307  .01213   .013   .0042    .05     3
3252
  1     0    3269
 10         2200.0
3257     1      4      15
0.99    0.0  .01535  .00307  .01213   .013   .0042    .05     3
3270
  1     0    3288
 10         2200.0
3271     1      4      15
0.94    0.0  .01535  .00307  .01213   .013   .0042    .05     3
3289
  3     0    3341
 52         2500.0
3298     1      4      15
1.08    0.0  .01535  .00307  .01213   .013   .0042    .05     3
3312     1      4      15
1.09    0.0  .01535  .00307  .01213   .013   .0042    .05     3
3334     1      4      15
1.18    0.0  .01535  .00307  .01213   .013   .0042    .05     3
3342
  2     0    4029
 52         2500.0
3354     1      4      15
2.21    0.0  .01535  .00307  .01213   .013   .0042    .05     3
4011     1      4      15
1.34    0.0  .01575  .00315  .01244   .013   .0042    .05     3
4030
  3     0    4079
 52         2500.0
4032     1      4      15
0.98    0.0  .01575  .00315  .01244   .013   .0042    .05     3
4046     1      4      15
1.11    0.0  .01575  .00315  .01244   .013   .0042    .05     3
4067     1      4      15
1.05    0.0  .01575  .00315  .01244   .013   .0042    .05     3
```

```
4080
  6    1   4196
 22      15500.0
4095    1      4      15
0.84    0.0  .01575  .00315  .01244    .013   .0042     .05      3
4109    1      4      15
1.18    0.0  .01575  .00315  .01244    .013   .0042     .05      3
4123    1      4      15
1.13    0.0  .01575  .00315  .01244    .013   .0042     .05      3
4143    1      4      15
0.96    0.0  .01575  .00315  .01244    .013   .0042     .05      3
4150    1      4      15
1.01    0.0  .01575  .00315  .01244    .013   .0042     .05      3
4189    1      4      15
1.08    0.0  .01575  .00315  .01244    .013   .0042     .05      3
4196    5    5.0
4197
  2    0   4215
 10       2200.0
4202    1      4      15
1.11    0.0  .01575  .00315  .01244    .013   .0042     .05      3
4209    1      4      15
0.84    0.0  .01575  .00315  .01244    .013   .0042     .05      3
4216
  1    0   4233
 10       2200.0
4222    1      4      15
1.02    0.0  .01575  .00315  .01244    .013   .0042     .05      3
4234
  1    0   4251
 10       2200.0
4237    1      4      15
1.08    0.0  .01575  .00315  .01244    .013   .0042     .05      3
4252
  1    0   4269
 10       2200.0
4263    1      4      15
1.17    0.0  .01575  .00315  .01244    .013   .0042     .05      3
4270
  2    0   4288
 10       2200.0
4270    1      4      15
0.79    0.0  .01575  .00315  .01244    .013   .0042     .05      3
4279    1      4      15
1.61    0.0  .01575  .00315  .01244    .013   .0042     .05      3
4289
  2    0   4341
 52       2500.0
4291    1      4      15
1.21    0.0  .01575  .00315  .01244    .013   .0042     .05      3
4299    1      4      15
0.96    0.0  .01575  .00315  .01244    .013   .0042     .05      3
4342
  0    0   5029
 52       2500.0
  0
```

Table D.4. Sample GLEAMS 3.0 plant nutrient parameters for liquid dairy manure land application system over a corn-bermudagrass-rye rotation, North quadrant (600 kg N/ha).

```
Tifton, GA continuous T44BG, rye, corn, min tillage
Tifton loamy sand
   1991   1994      1      4      1
 9000.0     .8
  .050   .050   .030   .010   .010
   3.8    3.8    3.8    3.8    3.8
  150.0  150.0  260.0  260.0  120.0
   0.0


   1001
     0      0   1079
    10        2600.0
   1080
     2      1   1196
    22       19000.0
   1177     1      4     15
   2.30    0.0  .01452  .00290  .01147   .013   .0042    .05     3
   1182     1      4     15
   1.89    0.0  .01452  .00290  .01147   .013   .0042    .05     3
   1196     5    5.0
   1197
     2      0   1215
    10        2600.0
   1206     1      4     15
   1.98    0.0  .01452  .00290  .01147   .013   .0042    .05     3
   1211     1      4     15
   2.65    0.0  .01452  .00290  .01147   .013   .0042    .05     3
   1216
     2      0   1233
    10        2600.0
   1218     1      4     15
   1.45    0.0  .01452  .00290  .01147   .013   .0042    .05     3
   1225     1      4     15
   0.73    0.0  .01452  .00290  .01147   .013   .0042    .05     3
   1234
     1      0   1251
    10        2600.0
   1246     1      4     15
   0.86    0.0  .01452  .00290  .01147   .013   .0042    .05     3
   1252
     1      0   1269
    10        2600.0
   1255     1      4     15
   1.46    0.0  .01452  .00290  .01147   .013   .0042    .05     3
   1270
     2      0   1288
    10        2600.0
   1273     1      4     15
   1.19    0.0  .01452  .00290  .01147   .013   .0042    .05     3
   1287     1      4     15
```

```
2.53    0.0  .01452  .00290  .01147    .013   .0042     .05      3
1289
  3     0    1341
 52        2700.0
1301     1      4      15
1.24    0.0  .01452  .00290  .01147    .013   .0042     .05      3
1317     1      4      15
1.36    0.0  .01452  .00290  .01147    .013   .0042     .05      3
1336     1      4      15
4.44    0.0  .01452  .00290  .01147    .013   .0042     .05      3
1342
  3     0    2029
 52        2700.0
1348     1      4      15
1.19    0.0  .01452  .00290  .01147    .013   .0042     .05      3
2007     1      4      15
1.55    0.0  .01809  .00362  .01429    .013   .0042     .05      3
2021     1      4      15
1.51    0.0  .01809  .00362  .01429    .013   .0042     .05      3
2030
  3     0    2079
 52        2700.0
2034     1      4      15
1.43    0.0  .01809  .00362  .01429    .013   .0042     .05      3
2050     1      4      15
1.28    0.0  .01809  .00362  .01429    .013   .0042     .05      3
2062     1      4      15
1.50    0.0  .01809  .00362  .01429    .013   .0042     .05      3
2080
  7     1    2196
 22       19000.0
2113     1      4      15
1.63    0.0  .01809  .00362  .01429    .013   .0042     .05      3
2120     1      4      15
1.46    0.0  .01809  .00362  .01429    .013   .0042     .05      3
2132     1      4      15
1.53    0.0  .01809  .00362  .01429    .013   .0042     .05      3
2146     1      4      15
1.25    0.0  .01809  .00362  .01429    .013   .0042     .05      3
2160     1      4      15
1.58    0.0  .01809  .00362  .01429    .013   .0042     .05      3
2175     1      4      15
2.14    0.0  .01809  .00362  .01429    .013   .0042     .05      3
2195     1      4      15
1.44    0.0  .01809  .00362  .01429    .013   .0042     .05      3
2196     5    5.0
2197
  0     0    2215
 10        2600.0
2216
  2     0    2233
 10        2600.0
2223     1      4      15
1.59    0.0  .01809  .00362  .01429    .013   .0042     .05      3
2231     1      4      15
1.42    0.0  .01809  .00362  .01429    .013   .0042     .05      3
```

```
2234
  1     0   2251
 10       2600.0
2240    1     4     15
1.44    0.0  .01809  .00362  .01429   .013   .0042    .05    3
2252
  1     0   2269
 10       2600.0
2253    1     4     15
1.38    0.0  .01809  .00362  .01429   .013   .042    .05    3
2270
  0     0   2288
 10       2600.0
2289
  3     0   2341
 52       2700.0
2301    1     4     15
1.70    0.0  .01809  .00362  .01429   .013   .0042    .05    3
2315    1     4     15
1.72    0.0  .01809  .00362  .01429   .013   .0042    .05    3
2323    1     4     15
1.22    0.0  .01809  .00362  .01429   .013   .042    .05    3
2342
  3     0   3029
 52       2700.0
2349    1     4     15
1.52    0.0  .01809  .00362  .01429   .013   .0042    .05    3
3004    1     4     15
2.04    0.0  .01658  .00332  .01310   .013   .0042    .05    3
3019    1     4     15
1.76    0.0  .01658  .00332  .01310   .013   .0042    .05    3
3030
  3     0   3079
 52       2700.0
3032    1     4     15
1.26    0.0  .01658  .00332  .01310   .013   .0042    .05    3
3053    1     4     15
1.63    0.0  .01658  .00332  .01310   .013   .0042    .05    3
3061    1     4     15
1.40    0.0  .01658  .00332  .01310   .013   .0042    .05    3
3080
  9     1   3196
 22      19000.0
3103    1     4     15
1.34    0.0  .01658  .00332  .01310   .013   .0042    .05    3
3110    1     4     15
1.63    0.0  .01658  .00332  .01310   .013   .0042    .05    3
3117    1     4     15
1.15    0.0  .01658  .00332  .01310   .013   .0042    .05    3
3131    1     4     15
1.21    0.0  .01658  .00332  .01310   .013   .0042    .05    3
3146    1     4     15
1.36    0.0  .01658  .00332  .01310   .013   .0042    .05    3
3158    1     4     15
1.54    0.0  .01658  .00332  .01310   .013   .0042    .05    3
3173    1     4     15
```

```
1.64    0.0  .01658  .00332  .01310    .013   .0042     .05       3
3188      1       4      15
2.26    0.0  .01658  .00332  .01310    .013   .0042     .05       3
3195      1       4      15
1.86    0.0  .01658  .00332  .01310    .013   .0042     .05       3
3196      5     5.0
3197
  1     0    3215
 10       2600.0
3202      1       4      15
1.78    0.0  .01658  .00332  .01310    .013   .0042     .05       3
3216
  1     0    3233
 10       2600.0
3222      1       4      15
1.59    0.0  .01658  .00332  .01310    .013   .0042     .05       3
3234
  1     0    3251
 10       2600.0
3237      1       4      15
1.35    0.0  .01658  .00332  .01310    .013   .0042     .05       3
3252
  1     0    3269
 10       2600.0
3257      1       4      15
1.65    0.0  .01658  .00332  .01310    .013   .0042     .05       3
3270
  1     0    3288
 10       2600.0
3271      1       4      15
1.08    0.0  .01658  .00332  .01310    .013   .0042     .05       3
3289
  3     0    3341
 52       2700.0
3298      1       4      15
1.34    0.0  .01658  .00332  .01310    .013   .0042     .05       3
3312      1       4      15
1.95    0.0  .01658  .00332  .01310    .013   .0042     .05       3
3334      1       4      15
1.13    0.0  .01658  .00332  .01310    .013   .0042     .05       3
3342
  2     0    4029
 52       2700.0
3354      1       4      15
1.50    0.0  .01658  .00332  .01310    .013   .0042     .05       3
4011      1       4      15
1.67    0.0  .01499  .00299  .01184    .013   .0042     .05       3
4030
  3     0    4079
 52       2700.0
4032      1       4      15
1.47    0.0  .01499  .00299  .01184    .013   .0042     .05       3
4046      1       4      15
1.69    0.0  .01499  .00299  .01184    .013   .0042     .05       3
4067      1       4      15
1.41    0.0  .01499  .00299  .01184    .013   .0042     .05       3
```

```
4080
  6     1    4196
 22       19000.0
4095    1      4      15
1.61    0.0  .01499  .00299  .01184    .013   .0042     .05      3
4109    1      4      15
1.89    0.0  .01499  .00299  .01184    .013   .0042     .05      3
4123    1      4      15
1.64    0.0  .01499  .00299  .01184    .013   .0042     .05      3
4143    1      4      15
1.31    0.0  .01499  .00299  .01184    .013   .0042     .05      3
4150    1      4      15
1.76    0.0  .01499  .00299  .01184    .013   .0042     .05      3
4189    1      4      15
1.55    0.0  .01499  .00299  .01184    .013   .0042     .05      3
4196    5    5.0
4197
  2     0    4215
 10        2600.0
4202    1      4      15
1.53    0.0  .01499  .00299  .01184    .013   .0042     .05      3
4209    1      4      15
1.81    0.0  .01499  .00299  .01184    .013   .0042     .05      3
4216
  1     0    4233
 10        2600.0
4222    1      4      15
1.39    0.0  .01499  .00299  .01184    .013   .0042     .05      3
4234
  1     0    4251
 10        2600.0
4237    1      4      15
1.50    0.0  .01499  .00299  .01184    .013   .0042     .05      3
4252
  1     0    4269
 10        2600.0
4263    1      4      15
1.84    0.0  .01499  .00299  .01184    .013   .0042     .05      3
4270
  2     0    4288
 10        2600.0
4270    1      4      15
1.58    0.0  .01499  .00299  .01184    .013   .0042     .05      3
4279    1      4      15
1.29    0.0  .01499  .00299  .01184    .013   .0042     .05      3
4289
  2     0    4341
 52        2700.0
4291    1      4      15
2.01    0.0  .01499  .00299  .01184    .013   .0042     .05      3
4299    1      4      15
1.08    0.0  .01499  .00299  .01184    .013   .0042     .05      3
4342
  0     0    5029
 52        2700.0
  0
```

Table D.5. Sample GLEAMS 3.0 plant nutrient parameters for liquid dairy manure land application system over a corn-bermudagrass-rye rotation, South quadrant (800 kg N/ha).

```
Tifton, GA continuous T44BG, rye, corn, min tillage
Tifton loamy sand
  1991   1994     1      4      1
 9000.0     .8
  .050   .050   .030   .010   .010
   3.8     3.8     3.8     3.8     3.8
 150.0  150.0   260.0  260.0  120.0
   0.0


  1001
    0      0    1079
   10        1900.0
  1080
    2      1    1196
   22       24000.0
  1177     1      4      15
  1.72    0.0  .01803  .00361  .01424   .013   .0042    .05     3
  1182     1      4      15
  1.65    0.0  .01803  .00361  .01424   .013   .0042    .05     3
  1196     5     5.0
  1197
    2      0    1215
   10        1900.0
  1206     1      4      15
  2.79    0.0  .01803  .00361  .01424   .013   .0042    .05     3
  1211     1      4      15
  1.65    0.0  .01803  .00361  .01424   .013   .0042    .05     3
  1216
    2      0    1233
   10        1900.0
  1218     1      4      15
  1.53    0.0  .01803  .00361  .01424   .013   .0042    .05     3
  1225     1      4      15
  1.52    0.0  .01803  .00361  .01424   .013   .0042    .05     3
  1234
    1      0    1251
   10        1900.0
  1246     1      4      15
  1.18    0.0  .01803  .00361  .01424   .013   .0042    .05     3
  1252
    1      0    1269
   10        1900.0
  1255     1      4      15
  1.63    0.0  .01803  .00361  .01424   .013   .0042    .05     3
  1270
    2      0    1288
   10        1900.0
  1273     1      4      15
  1.83    0.0  .01803  .00361  .01424   .013   .0042    .05     3
  1287     1      4      15
```

```
2.12   0.0  .01803  .00361  .01424   .013   .0042    .05     3
1289
  3    0    1341
 52       3000.0
1301     1      4      15
1.77   0.0  .01803  .00361  .01424   .013   .0042    .05     3
1317     1      4      15
2.04   0.0  .01803  .00361  .01424   .013   .0042    .05     3
1336     1      4      15
1.91   0.0  .01803  .00361  .01424   .013   .0042    .05     3
1342
  3    0    2029
 52       3000.0
1348     1      4      15
1.88   0.0  .01803  .00361  .01424   .013   .0042    .05     3
2007     1      4      15
1.92   0.0  .01910  .00382  .01509   .013   .0042    .05     3
2021     1      4      15
1.85   0.0  .01910  .00382  .01509   .013   .0042    .05     3
2030
  3    0    2079
 52       3000.0
2034     1      4      15
1.67   0.0  .01910  .00382  .01509   .013   .0042    .05     3
2050     1      4      15
1.89   0.0  .01910  .00382  .01509   .013   .0042    .05     3
2062     1      4      15
1.59   0.0  .01910  .00382  .01509   .013   .0042    .05     3
2080
  7    1    2196
 22      24000.0
2113     1      4      15
1.77   0.0  .01910  .00382  .01509   .013   .0042    .05     3
2120     1      4      15
1.83   0.0  .01910  .00382  .01509   .013   .0042    .05     3
2132     1      4      15
1.69   0.0  .01910  .00382  .01509   .013   .0042    .05     3
2146     1      4      15
1.79   0.0  .01910  .00382  .01509   .013   .0042    .05     3
2160     1      4      15
1.91   0.0  .01910  .00382  .01509   .013   .0042    .05     3
2175     1      4      15
1.83   0.0  .01910  .00382  .01509   .013   .0042    .05     3
2195     1      4      15
1.85   0.0  .01910  .00382  .01509   .013   .0042    .05     3
2196     5    5.0
2197
  0    0    2215
 10       1900.0
2216
  2    0    2233
 10       1900.0
2223     1      4      15
1.72   0.0  .01910  .00382  .01509   .013   .0042    .05     3
2231     1      4      15
1.97   0.0  .01910  .00382  .01509   .013   .0042    .05     3
```

```
2234
  1     0    2251
 10        1900.0
2240     1      4      15
1.69     0.0  .01910  .00382  .01509    .013   .0042     .05       3
2252
  1     0    2269
 10        1900.0
2253     1      4      15
1.56     0.0  .01910  .00382  .01509    .013    .042     .05       3
2270
  0     0    2288
 10        1900.0
2289
  3     0    2341
 52        3000.0
2301     1      4      15
1.97     0.0  .01910  .00382  .01509    .013   .0042     .05       3
2315     1      4      15
2.14     0.0  .01910  .00382  .01509    .013   .0042     .05       3
2323     1      4      15
1.72     0.0  .01910  .00382  .01509    .013    .042     .05       3
2342
  3     0    3029
 52        3000.0
2349     1      4      15
2.20     0.0  .01910  .00382  .01509    .013   .0042     .05       3
3004     1      4      15
2.35     0.0  .01543  .00309  .01219    .013   .0042     .05       3
3019     1      4      15
2.24     0.0  .01543  .00309  .01219    .013   .0042     .05       3
3030
  3     0    3079
 52        3000.0
3032     1      4      15
1.73     0.0  .01543  .00309  .01219    .013   .0042     .05       3
3053     1      4      15
1.82     0.0  .01543  .00309  .01219    .013   .0042     .05       3
3061     1      4      15
1.90     0.0  .01543  .00309  .01219    .013   .0042     .05       3
3080
  9     1    3196
 22       24000.0
3103     1      4      15
1.87     0.0  .01543  .00309  .01219    .013   .0042     .05       3
3110     1      4      15
1.97     0.0  .01543  .00309  .01219    .013   .0042     .05       3
3117     1      4      15
2.02     0.0  .01543  .00309  .01219    .013   .0042     .05       3
3131     1      4      15
1.73     0.0  .01543  .00309  .01219    .013   .0042     .05       3
3146     1      4      15
2.00     0.0  .01543  .00309  .01219    .013   .0042     .05       3
3158     1      4      15
1.96     0.0  .01543  .00309  .01219    .013   .0042     .05       3
3173     1      4      15
```

```
2.09     0.0  .01543  .00309  .01219    .013   .0042     .05       3
3188      1       4       15
2.02     0.0  .01543  .00309  .01219    .013   .0042     .05       3
3195      1       4       15
2.13     0.0  .01543  .00309  .01219    .013   .0042     .05       3
3196      5     5.0
3197
  1      0    3215
 10         1900.0
3202      1       4       15
2.14     0.0  .01543  .00309  .01219    .013   .0042     .05       3
3216
  1      0    3233
 10         1900.0
3222      1       4       15
1.97     0.0  .01543  .00309  .01219    .013   .0042     .05       3
3234
  1      0    3251
 10         1900.0
3237      1       4       15
1.57     0.0  .01543  .00309  .01219    .013   .0042     .05       3
3252
  1      0    3269
 10         1900.0
3257      1       4       15
1.72     0.0  .01543  .00309  .01219    .013   .0042     .05       3
3270
  1      0    3288
 10         1900.0
3271      1       4       15
1.94     0.0  .01543  .00309  .01219    .013   .0042     .05       3
3289
  3      0    3341
 52         3000.0
3298      1       4       15
2.17     0.0  .01543  .00309  .01219    .013   .0042     .05       3
3312      1       4       15
1.91     0.0  .01543  .00309  .01219    .013   .0042     .05       3
3334      1       4       15
2.07     0.0  .01543  .00309  .01219    .013   .0042     .05       3
3342
  2      0    4029
 52         3000.0
3354      1       4       15
3.96     0.0  .01543  .00309  .01219    .013   .0042     .05       3
4011      1       4       15
2.09     0.0  .01482  .00296  .01171    .013   .0042     .05       3
4030
  3      0    4079
 52         3000.0
4032      1       4       15
2.12     0.0  .01482  .00296  .01171    .013   .0042     .05       3
4046      1       4       15
2.24     0.0  .01482  .00296  .01171    .013   .0042     .05       3
4067      1       4       15
1.74     0.0  .01482  .00296  .01171    .013   .0042     .05       3
```

```
4080
  6     1    4196
 22       24000.0
4095     1      4      15
1.88    0.0  .01482  .00296  .01171    .013   .0042     .05      3
4109     1      4      15
2.03    0.0  .01482  .00296  .01171    .013   .0042     .05      3
4123     1      4      15
2.16    0.0  .01482  .00296  .01171    .013   .0042     .05      3
4143     1      4      15
1.78    0.0  .01482  .00296  .01171    .013   .0042     .05      3
4150     1      4      15
2.13    0.0  .01482  .00296  .01171    .013   .0042     .05      3
4189     1      4      15
1.92    0.0  .01482  .00296  .01171    .013   .0042     .05      3
4196     5     5.0
4197
  2     0    4215
 10        1900.0
4202     1      4      15
2.66    0.0  .01482  .00296  .01171    .013   .0042     .05      3
4209     1      4      15
1.87    0.0  .01482  .00296  .01171    .013   .0042     .05      3
4216
  1     0    4233
 10        1900.0
4222     1      4      15
1.79    0.0  .01482  .00296  .01171    .013   .0042     .05      3
4234
  1     0    4251
 10        1900.0
4237     1      4      15
1.97    0.0  .01482  .00296  .01171    .013   .0042     .05      3
4252
  1     0    4269
 10        1900.0
4263     1      4      15
1.82    0.0  .01482  .00296  .01171    .013   .0042     .05      3
4270
  2     0    4288
 10        1900.0
4270     1      4      15
1.90    0.0  .01482  .00296  .01171    .013   .0042     .05      3
4279     1      4      15
1.96    0.0  .01482  .00296  .01171    .013   .0042     .05      3
4289
  2     0    4341
 52        3000.0
4291     1      4      15
2.17    0.0  .01482  .00296  .01171    .013   .0042     .05      3
4299     1      4      15
2.31    0.0  .01482  .00296  .01171    .013   .0042     .05      3
4342
  0     0    5029
 52        3000.0
  0
```