

WATER AND NITRATE MOVEMENT IN POULTRY LITTER AMENDED SOILS

By

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Jaime F. Sanchez

To the memory of my father

To Margarita

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Abstract of Dissertation Presented to the Graduate School
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Nitrate leaching from land application of animal wastes has been linked to increasing levels of nitrate in drinking water in the Suwannee River Basin over the past several years. The main focus of this research study was to describe nitrate movement in soils under long term poultry litter management. Pedo Transfer Functions (PTF) were developed to describe the water retention characteristics that are valued as low resource alternatives. The PTFs were found to be influenced by the clay content followed by the soil organic carbon content. Mineralization of poultry manure was determined in the laboratory columns during a 60-day incubation period. At the end of the 60-day period, 69, 51, 58, 47, 48, 43 and 39 % of the total nitrogen applied was mineralized for applications equivalent to 3, 6, 9, 12, 15, 18 and 21 Mg ha⁻¹ of poultry manure respectively.

LEACHM is a potential modeling tool for characterizing nitrate and water movement in the soils. A statistical procedure termed the Scenarios Technique was effectively combined with LEACHM to provide a predictive approach for nitrate losses

from the drainage zone for various nutrient management levels. Higher N rates produced higher cumulative nitrate values in the soils. An application of additional 50 kg ha⁻¹ N in the form of ammonium nitrate along with the standard litter application resulted in higher nitrate levels in the drainage indicating that the source of N was a critical factor when making nutrient management decisions. The scenarios established with a sequence of wet dry years had a strong effect on the nitrate leaching suggesting that the effect of adverse weather conditions on the nitrate leaching risk could be forecast with the help of the Scenarios Technique. The effect of textural changes in the soil profile on soil nitrate movement was less pronounced compared to the total rainfall received. The Scenarios Technique was found to be a reliable tool for evaluation of best nutrient management practices in Ultisols.

CHAPTER 1 INTRODUCTION

Agriculture has been found to be the primary source of non-point contamination of both surface and groundwater quality (USEPA, 1994). Farmers often apply higher rates of fertilizers as they perceive such a practice as a low cost insurance against crop failure. The effect of higher application rates is further complicated when organic amendments are applied where the nutrient contents are highly variable and where nutrient availabilities are difficult to establish using standard laboratory procedures (Mylavarapu, 2003).

In Florida where there are many eco-sensitive areas such as Everglades, Lake Okeechobee and the Suwannee, regulatory agencies are developing nutrient management programs to protect the water quality from contamination by agricultural nutrients (Mylavarapu, 2003).

Loamy sand or sandy soils (Entisols) overlying an eroded limestone (*karst*) topography inherently expose the vulnerability of the Suwannee River Basin in north central Florida to both surface and groundwater contamination (Mylavarapu, 2003).

The Suwannee River Water Management District (SRWMD) is responsible for both water quantity and water quality in the SRB. More than two decades of water quality data for the SRB have demonstrated a statistically significant (at the 95% confidence level), time-dependent increase in the concentration of nitrate-nitrogen in the river and several of its associated freshwater springs. The primary source of the nitrate-nitrogen is

groundwater entering the river's surface water system via a series of springs (Hornsby and Mattson, 1998).

The Suwannee River Basin

The Suwannee River flows 395 kilometers from its origin in the Okefenokee Swamp near Fargo in Charlton County, Georgia, up to its discharge into the Gulf of Mexico near the town of Suwannee on the border between Levy and Dixie counties in Florida (Crane, 1986) creating nearly 28,600 km² of river basin.

Five different sub-basins have been recognized in the basin: Upper basin above the Withlacoochee River Basin or upper Suwannee River Basin, the Withlacoochee River Basin, the Alapaha River Basin, the Santa Fe River Basin and the Lower Suwannee River basin below the Withlacoochee River (Figure 1.1).

Geographically, the Suwannee River Basin (SRB) encompasses twenty-one counties in Georgia and twelve counties in Florida. The Florida portion constitutes 39% of the total basin area. With a population of 290,000 people, it is one of the most sparsely populated areas of the state and with a projected growth rate of 1.6% between 2000 and 2020 (SRWMD, 2000).

Studies have shown that a continuous increase of the annual in-stream nitrogen load in seven rivers in Georgia and Florida, primarily from agricultural operations (Asbury and Oaksford, 1997). For example, in the Suwannee River at Branford, Florida, NO₃⁻ levels rose from 180 kg in 1986 to 220 kg year⁻¹ km⁻² in 1990 and they concluded that land application of animal wastes was one of the primary reasons for excess nitrate levels in the SRB. Additionally, they had also suggested that the above values detected for the SRB were higher than the observed values in other basins such as St. Johns and Withlacoochee rivers.

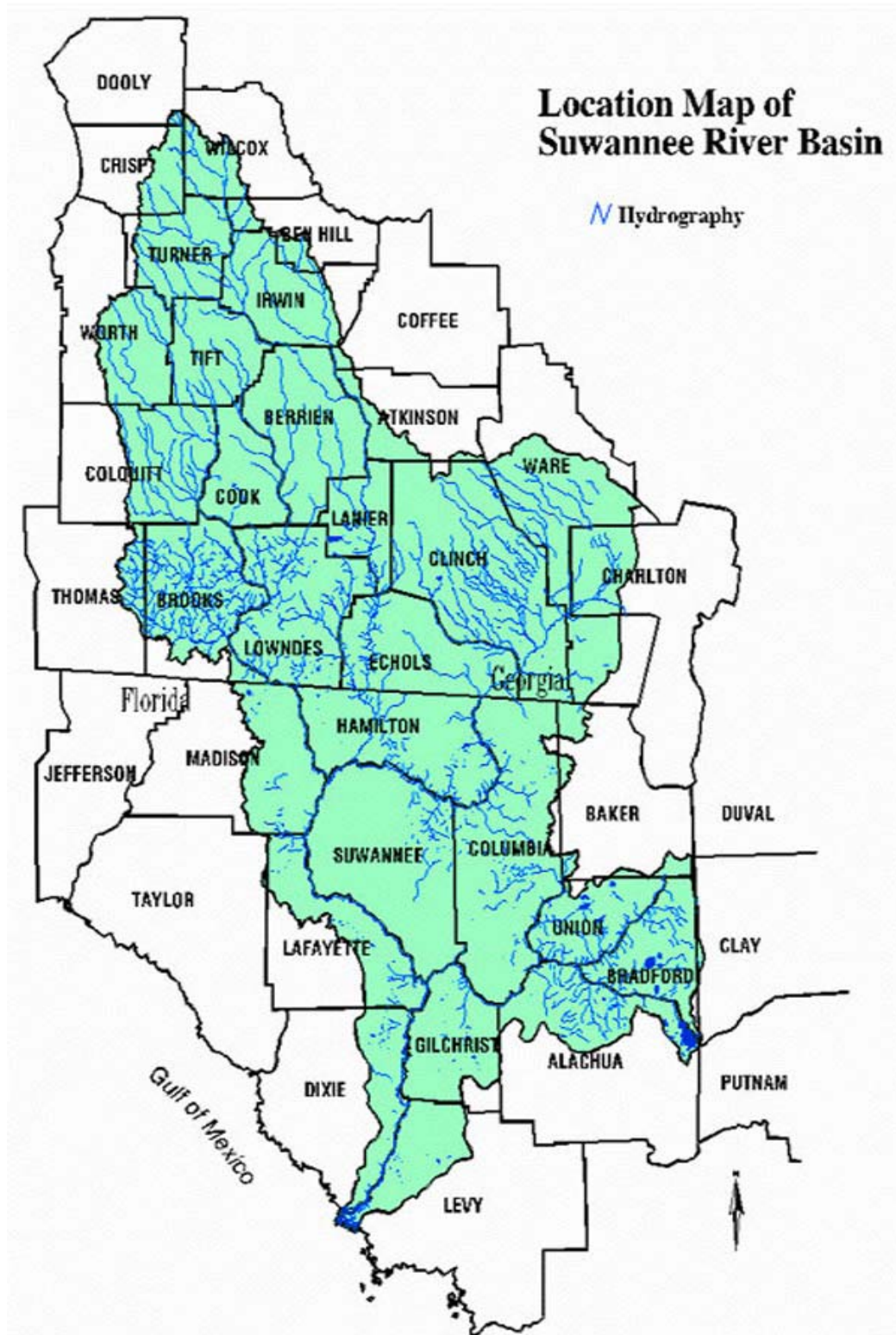


Figure 1.1 Suwannee River Basin.

The poultry industry is predominantly located in the SRB counties with a high degree of concentration in the Suwannee County. The poultry industry has recorded an increase of 17% in broiler meat production from 213,000 Mg produced in 1992 (FDACS, 2002) to 248,000 Mg produced in 2001 with an economic value of \$254 million for that period (USDA, 2003). The main technological change was the use of genetically improved broiler birds that caused a faster weight gain in a shorter amount of time. As a result, Suwannee County was classified as one of the 100 leading counties in the country in broiler production (USNASS, 1997).

Under intensive poultry production methods, one-square meter of area is able to support 13.7 birds (Deaton, 1995), produce 55 kg of meat and approximately 14 kg of poultry litter (Malone, 1992). If the majority of the poultry production units in Florida were to use intensive production practices, we could assume that the poultry industry could concentrate its efforts on only 841 hectares and produce 115,300,000 birds during 2002 (USDA, 2003) requiring the disposal of around 117,800 Mg of poultry litter. In many cases the litter production can exceed the nutrient requirement of the crops planted in the litter applied areas promoting surface and ground movement of nitrogen (Sharpley, et.al., 1993). Therefore, poultry operations concentrated in small areas with their considerable production of wastes can represent a potential pollution problem, depending on the disposal practices of those by-products.

Suwannee River Basin Nutrient Management Working Group

To find solution to the current and potential problem of agricultural impacts on groundwater in the SRB both the public and private entities form a coalition, the Suwannee River Basin Nutrient Management Working Group (SRBNMWG). The

primary focus of the RBNMWG is to implement, track and evaluate agricultural practices to control the environmental impact of the agricultural practices.

The research results presented in this dissertation were supported by the US EPA Sec 319 funds for demonstrating the effectiveness of Best Nutrient Management Practices (BMPs) at a poultry production site. The overall objective was to describe the problem of nitrate movement in soils in a grazed bahia pasture under a long term poultry litter application. The study also aims to test a statistical tool termed ‘Scenarios Technique’ to help predict the influence of different nutrient management regimes on nitrate losses in the soil.

Organization of the dissertation

The dissertation has six chapters. The first chapter is a general introduction providing the background and justification for this study, the SRB and its features and the overall objectives of this research. The movement of nitrate in soils under a grazed bahia pasture system that received a long term poultry litter application is discussed in the second chapter. The third chapter focuses on description of water movement in selected soil profiles using two different pedotransfer functions. The fourth chapter estimates the mineralization of the poultry litter in laboratory columns. The fifth chapter introduces the scenarios technique, describes the elements of the technique, and then presents LEACHM, a simulation model of nutrient movement in soils, as a tool to describe the changes in soil nitrate levels. Fifteen scenarios were created, analyzed and discussed in this chapter. The sixth chapter provides the over-all conclusions of our research.

CHAPTER 2

WATER MOVEMENT

Soil water content is a critical factor for plant growth (Hillel, 1998). Water movement is directly related to soil water content and is a main factor for estimation of solute movement with potential for groundwater pollution. A common approach to describe soil water movement is by determining the soil moisture characteristic curve. This curve depicts the relationship between the water content in the soil and the soil suction or matric potential (Klute, 1986). The matric potential is defined as the tenacity with which water is retained by the soil matrix (Hillel, 1998).

Soil water retention is a complex phenomenon and therefore requires complex mathematical functions to completely describe it. These functions often require information that is not available or is too difficult to determine in the laboratory. Consequently, practitioners have agreed that an acceptable approximation of the retention function can be obtained by using the most important factors correlated with soil water retention (Hutson and Cass, 1987).

Different retention functions relating to water content θ and matric potential ψ have been proposed in the literature. Brooks and Corey (1966) suggested an exponential retentivity function:

$$S_e = (\theta - \theta_r) (\theta_s - \theta_r) = (\Psi_e / \Psi)^\lambda \quad 2.1$$

where θ is the volumetric water content, θ_r is the residual saturation defined as the value at which $d\theta/d\psi = 0$ or $K(\theta)=0$, θ_s is the volumetric water content at saturation; λ is the pore-size distribution index; Ψ is the water potential; Ψ_e is the air-entry pressure head

during desorption or absorption; $K(\theta)$ is the unsaturated hydraulic conductivity at θ moisture content.

Campbell (1974) modified the Brooks and Corey model removing the residual saturation:

$$\Psi = \Psi_e (\theta / \theta_s)^{-b} \quad 2.2$$

where b is a constant that has been related with textural classes (Clapp and Horberger, 1978). The main constraint of the exponential function is the discontinuity of the function at Ψ_e because at that point $\theta = \theta_s$ and $d\theta/d\Psi = 0$ over the potential range θ to Ψ_e .

To avoid the problem of discontinuity of the exponential retentivity function, Hutson and Cass (1987) introduced the concept of a two part retentivity function establishing an exponential portion:

$$\theta = \theta_s (\Psi/a)^{-b} \quad 2.3$$

where a and b are constants and a is the parabolic portion:

$$\theta = \theta_s - [(\theta_s \Psi^2 (1 - \theta_i / \theta_s)) / (a^2 (\theta_i / \theta_s)^{-2b})] \quad 2.4$$

where θ_i is the volumetric content at the inflection point. The inflection point is at:

$$\theta_i = (2b \theta_s) / (1+2b) \quad 2.5$$

Estimation of the a and b parameters can be obtained by iterative procedures using values obtained in the laboratory for θ and Ψ . This type of solution is however empirical.

Water retention curves can be obtained with information from specific samples obtained from the field and the subsequent laboratory determinations. The equipment used included pressure plate apparatus and/or tension plates and tempe cells that

determine soil moisture contents at different matric potentials. The procedures involved are however time consuming, expensive and labor intensive (Cornelis et al., 2001).

Bouma (1989) introduced the concept of pedotransfer functions (PTF). These functions relate readily available soil properties like particle-size distribution, organic matter content and bulk density with soil-water content to predict the water retention curve. The pedotransfer functions are a reasonable option to estimate indirectly the soil-water holding properties when direct determination of the soil-water retention curves cannot be performed because of resource constraints. The PTFs have gained popularity with the development of simulation programs that require water-retention characteristics to calculate soil water-retention, soil solute movement or plant growth (Gijssman et al., 2002).

The PTFs were classified by Cornelis et al. (2001) into three groups of models based on the purpose: 1) models that use multivariate regression analysis to relate water content to soil properties (Gupta and Larson, 1979; Rawls and Brakensiek, 1981); 2) models that estimate the retention function parameters (Rawls and Brakensiek, 1985); and 3) models that use physical conceptual functions of more complex relationships between soil characteristics to estimate soil moisture contents (Arya and Paris, 1981).

The PTFs of the first group have been developed for different regions around the world. Rawl and Brakensiek (1981) developed a PTF using 2,543 soil horizons from 18 states of the United States. The variables considered in that model were sand, silt, clay, organic matter, bulk density and two points of water content at 0.33 and 15 bars. Gupta and Larson (1979) used 10 soil samples from eastern and central United States and three soil-water contents at 0.04, 0.33 and 7 bars. Tomasella et al. (2003) developed a PTF for

838 soil profiles in Brazil using the same variables from the previous reports. Cornelis et al. (2001) evaluated 9 PTFs using 298 soil samples from Flanders, Belgium. Nemes et al. (2003) derived PTFs to estimate soil-water retention characteristics using 576 Hungarian soil profiles.

Kern (1995) using the USDA-SCS National Soil Survey Laboratory Pedon Database compared six PTFs using 3,666 soil samples for -10 kPa, 23,642 samples for -33 kPa and 23,333 samples for 1,500 kPa. He found that the simpler models represented by simple regression equations led to results similar to more complex PTFs. Tietje and Hennings (1996) reached a similar conclusion comparing 6 PTFs to determine hydraulic conductivity. Cornelis et al. (2001) found that simpler models like the Rawls and Brakensiek (1981) and Gupta and Larson (1979) showed an intermediate performance compared with more complex models. Those observations were confirmed by Tietje and Tapkenhinrichs (1993) who reported comparable results for water retention using Rawls and Brakensiek model (1981) and a more complex model from Vereecken et al. (1989).

The objective of this study was to determine the physical characteristics and organic carbon content of the soil in order to develop a PTF and to describe the water movement for selected profiles of a North Florida Ultisol receiving poultry manure amendments.

Materials and Methods

The experimental site is located on a poultry farm in the Suwannee County, Florida. We selected a field, 11 ha. in area that was land applied with poultry litter and planted to Bahia grass (*Paspalum notatum*). The study area was grazed by 55 cows for 40% of the time during a year. According to the producer records, the experimental area has been receiving the poultry manure for at least the last 20 years.

Although the field had negligible slope, at the field scale however it was possible to identify localized differences in elevation. In the lowland area of the selected lot, there was a permanent water reservoir used as a natural source of drinking water for the grazing animals. The grazing started each day early in the morning from the southwest corner of the area and lasted generally until 2 PM. The animals grazed from south to north (Figure 2.1) covering almost all the area before noon. During the summer, when temperature, humidity and sun light were too strong, the animals relocated under the shade on the west side of the lot. Trees formed natural fences on the north and west borders of the lot.

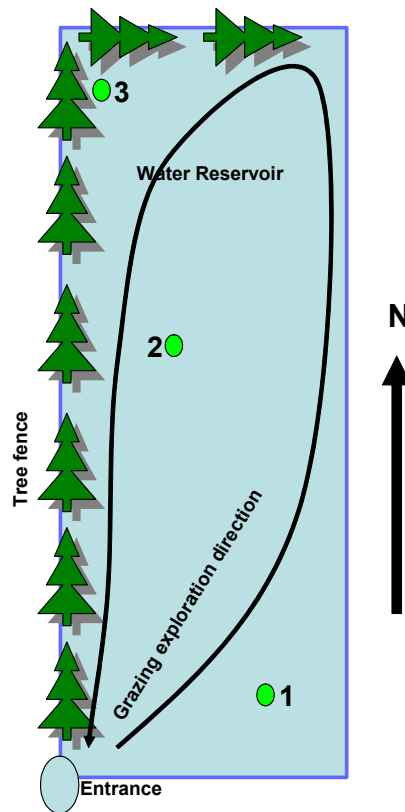


Figure 2.1 Grazing pattern and sampling points of the poultry litter spread area.

The application of poultry litter was restricted to spring and summer as per the conservation plan implemented by the NRCS under PL 566. The application was done with a mechanical spreader on the soil surface and was not incorporated. The applications were scheduled for early and late spring around March and August.

Three points were selected in a transect South-East North-West to cover the field variability.(Figure 2.1) Undisturbed samples were obtained in April 2002 with a soil core sampler, each 10 cm from the surface to 1.50 m depth. The soil sampler held two brass cylinders of 3-cm height each and three small rings of 1-cm height each called dividers. Two of the dividers were located at the extreme ends of the cylinders and the third in the center separating the two larger cylinders. The height of the cylinders-holder was 10-cm. The brass cylinders were 5.4 cm diameter and the total volume of the cylinder was 68.64 cm³. A total of 30 soil cores were obtained at each point.

The brass cylinders were removed carefully from the soil core sampler and divided properly to leave soil sample slightly beyond (0.5 -cm) the edges of the cylinders. Each sample was covered with a plastic bag and wrapped tightly with a rubber band to avoid any soil spillage from the cylinder. The samples were stored in the refrigerator to maintain the original soil water content until it could be processed at the laboratory, to avoid the deterioration due to weed growth and microbiological activity.

In the laboratory, soil at both ends of each cylinder was trimmed carefully, flush with the cylinder walls, leaving a flat surface at both ends. To determine the moisture characteristic curve between 0 and 0.3 kPa, the soil cores were placed in the base cap of a tempe cell containing a 0.5 bar porous ceramic plate. The soil sample was covered with the top cap assembly of the tempe cell. The tempe cell was placed in a trough with

appropriate water level to saturate the soil sample from bottom up. Typically sandy soil samples were saturated for 1 hour; samples with higher clay content however required longer periods.

After the samples reached saturation tempe cells were removed from the water trough and excess water was carefully wiped from around the outside of each tempe cell wall. The tempe cells were set up on a rack to connect the pressure line to the top inlet of each cell. Excess water was allowed to be drained from the saturated samples under gravity, to mimic reaching of the conceptual field capacity. The tempe cells were then weighed and the initial weights were recorded. At that time the sample was deemed to be in equilibrium with the atmospheric (ambient) pressure.

After this first point of equilibrium, the pressure line was connected to the top inlet of the tempe cell. Each time the tempe cell reached equilibrium with the corresponding pressure applied, the weights were recorded and the next level of pressure was applied until a new equilibrium was reached. The tempe cells were subjected to 10 levels of pressure: 0.3, 2.0, 2.9, 4.4, 5.9, 7.8, 9.8, 14.7, 19.6 and 33.8 kPa. After the last pressure was applied and equilibrium was reached, the tempe cell was removed from the rack and was opened to carefully remove the soil core. The weight of the core was then recorded.

Saturated hydraulic conductivity was determined by constant head method. To determine saturated hydraulic conductivity, the bottom of the soil core was covered with cheesecloth. On top of the soil core, another brass ring of 3-cm height was attached and sealed airtight with a duct tape. The surface of the soil sample in the cylinder was carefully covered with a filter paper to avoid any disturbance during water application. The soil sample in the core-assembly was rewetted in a water trough. The core-assembly

was then transferred to the hydraulic conductivity apparatus where water was applied to the top cylinder and the water level was maintained constant. Once a steady flow was established, the drainage water under the soil sample was collected for a known (constant) period of time for each of the sample. Volume of the drained water and time were recorded.

To determine the bulk density, the samples were removed from the hydraulic conductivity rack after carefully removing the cheesecloth, the top ring and the paper filter. The soil core was oven dried during 48 hours at 105°C. Finally, the dry weights of core and soil were recorded.

Water retention values at higher pressures of 490.4 kPa and 1471.3 kPa were determined using pressure plate apparatus. Soil samples were carefully packed into PVC rings 5.2 cm diameter and 1 cm height were distributed over 15 bar ceramic plates previously saturated with water. Each ceramic plate could accommodate up to 12 rings. The samples were wetted along with the ceramic plates until saturation. After all the samples were saturated the pressure plates were assembled in the pressure plate extractor and the lower pressure of 490.4 kPa was applied as the initial point. The end equilibrium point at a given pressure was determined by the cessation of all draining water. At this point the extractor was opened and the pressure plates were removed. Soil samples were weighed and oven dried for 48 hours. Wet and dried weights were recorded. Due to high variability in the experimental procedure water retention determinations at 490.4 kPa and 1471.3 kPa was replicated.

The bulk density was calculated using the following formula:

$$\text{Bulk Density} = M_s / V_{sc} \quad 2.6$$

where M_s is the soil mass oven dried and V_{sc} is the volume of the soil (Campbell and Henshall, 2000).

The saturated hydraulic conductivity K_s was calculated by:

$$K_s = [Q * L] / [A * \Delta h] \quad 2.7$$

where Q is the volume of water collected per unit time, L is the height or thickness of the column, A is the cross-sectional area of the soil core, and Δh is the hydraulic differential (Youngs, 2000).

The soil water content, w , as a mass fraction of soil is:

$$w = [M_w / M_s] \quad 2.8$$

where M_w is the water mass in grams and M_s is the soil mass oven dried in grams.

To convert the water content to volumetric θ content we used,

$$\theta = w * [\rho_s / \rho_w] \quad 2.9$$

Where w is the water content as mass fraction of the soil, ρ_s is the soil bulk density and ρ_w is the density of free water (Gardner et al., 2000).

Particle size analysis was performed using the Pipet method (Gee and Bauder, 1986). Organic matter in the soil sample was destroyed using H_2O_2 . A solution of Na-hexamethaphosphate was used as a soil dispersing agent. The sample was shaken for 3 minutes with water and the dispersing agent. The solution was transferred to the cylinder and the volume was brought to 1 L. An aliquot of 20 ml was obtained with the pipet after 20 minutes at 5 cm depth at 20 °C. The aliquot sample was oven then dried and weighed to determine the clay content. The sand remained in the cylinder was recovered and oven-dried. Sands were divided into four subclasses: very coarse (2 - 1 mm), coarse (1.0 - 0.5 mm), medium (0.5 - 0.25), fine (0.25 - 0.10 mm) and very fine sands (0.10 - 0.05 mm).

Soil weight was corrected to express the results in terms of oven-dry soil and zero organic matter content. Also the organic carbon content in the soil samples was determined by Walkley-Black method (Mylavarapu and Kennelly, 2002).

Pedotransfer functions (PTF) were developed for 2.9, 9.8, 33.8, 490.4, and 1,471.3 kPa suction pressures. Bulk density, carbon content and particle size classes were used in multivariate regression analysis to describe water content at each pressure point (SAS, 1999).

RETFIT software (Hutson, 2001) was used to estimate the parameters **a** and **b** of the Hutson and Cass (1987) modification of the Campbells's water retention equation.

The model's performance was evaluated using three different statistics. 1) The coefficient of determination R^2 :

$$R^2 = SS_r / SS_t \quad 2.10$$

Where SS_r is the square sum due to the regression and SS_t is the total sum of squares; R^2 measures the proportion of the total variation about the mean; and, Y is explained by the regression (Draper and Smith, 1981).

2) The mean absolute error MAE:

$$MAE = [1/N] \sum_{i=1}^N |P_i - O_i| \quad 2.11$$

Where N is the number of samples, P_i is the predicted value for the i^{th} member of the group and O_i is the observed value for the i^{th} member of the group.

3) The root mean square error:

$$RMSE = [1/N \sum_{i=1}^N (P_i - O_i)^2]^{1/2} \quad 2.12$$

Results and Discussion

Bulk density is depicted for the three profiles under study in Figure 2.2. Bulk density increased with depth from an average of 1.45 Mg m^{-3} in the surface to 1.69 Mg

m^{-3} at the bottom layer. Sodek et al. (1990) noted similar increase in bulk densities in the deeper layers in other Ultisols in Florida under pine plantations. The increase in percentage of clay with depth naturally showed corresponding decrease in the bulk density (Figure 2.3). Soil bulk density is related to natural soil characteristics such as texture, soil structure and organic matter (Cassel 1982; Hamblin, 1985). Management factors that modify the structure of the soil affect also the soil bulk density. The bulk density modifications due to agricultural practices are more evident in the surface layers. Tillage (Ahuja et al., 1998), grazing (Willat and Pullar, 1983) and the use of organic amendments (Barzegar et al., 2002) are examples of management factors affecting the soil structure. Applications of organic materials to the soil for crop production or for waste disposal have a strong effect on the surface soil structure. Due to the low bulk density of organic materials and the tendency to increase soil aggregate stability, the applications of organic materials result in lower soil bulk density (Dexter, 1988).

The saturated hydraulic conductivity (SHC) at each 10 cm increments up to 150 cm depth for each of the three observation points is shown in Figure 2.4. The SHC decreased gradually with depth evidently due to the increase of the clay content in the profile with depth. Soils with higher clay contents typically have lower SHC than sandy soils, even though the total porosity of the clay soils is higher (Hillel, 1998). Compared with similar arenic sandy soils of Florida, the SHC values obtained were in the range reported by Carlisle et al., 1989. The variability in the SHC observed in our study was also reported previously. SHC is one of the most variable and uncertain soil properties (Poulsen et al., 1999) because changes in water content can produce changes over several orders of magnitude in SHC.

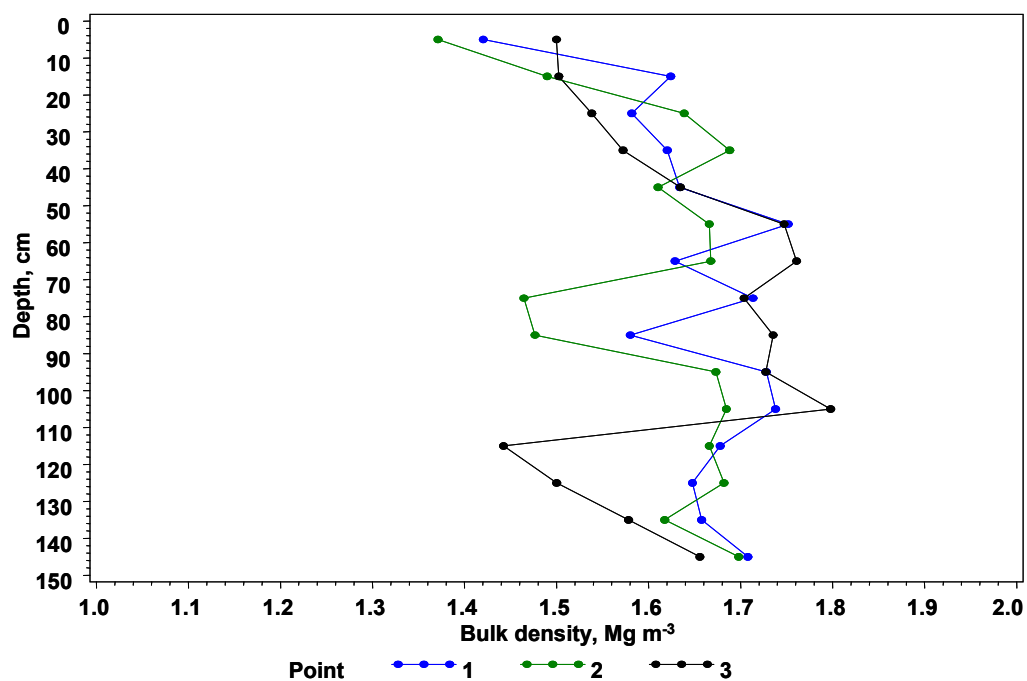


Figure 2.2 Bulk density (Mg m⁻³) in three soil profiles of a North Florida Ultisol under long term poultry litter application.

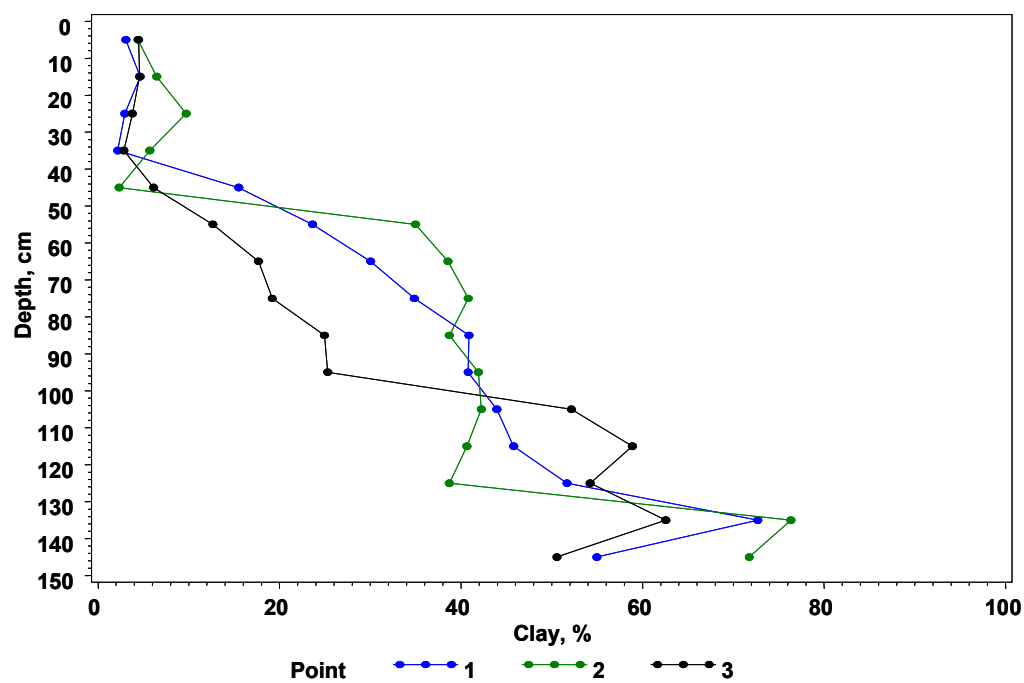


Figure 2.3 Clay content in three soil profiles of a North Florida Ultisol under long term poultry litter application.

Higher organic carbon contents were detected in the surface layers up to 35-cm depth in all the three profiles observed at the study site (Fig 2.5). These observations support our previous finding that showed reduced bulk densities in the surface layers which was a direct result of poultry litter applications. Kingery et al. (1994) reported a significant increase in organic carbon content in the surface 15 cm of Alabama soils that received long term poultry litter application when compared with soils without poultry litter applications. Below 35-cm depth, the organic carbon reached more or less a consistent low value between 0.2 to 0.7 %. Soil samples at Points 2 and 3 had higher organic carbon values probably due to the grazing pattern of cows observed in the field, with Point 2 being nearer to the water reservoir and Point 3 being closer to the north-west tree fence with shade (Figure 2.1)

Water retention curves are presented in Figures 2.6 and 2.7. At each depth from surface to 150 cm, the graphs depict volumetric water content (θ) on the y-axes and the pressure applied in kPa on the x-axes. As the pressure increased, the water content decreased as a result of higher pressure head. The three points evaluated are shown simultaneously at each depth in Figures 2.6 and 2.7. Water retention reduced rapidly in the first five soil layers with the application of additional suction pressure (Figure 2.6) due to the high sand content of around 80% in the first three soil layers. Sandy soils normally cannot retain water at higher or even at intermediate suction pressures (Hillel, 1998). At pressures higher than 100 kPa, water content in the first three soil layers was around $0.1 \text{ m}^3 \text{ m}^{-3}$. The increase in clay content explained the increased water retention observed in the soil layers below 55-cm depth (Figure 2.7). At Point 2, a different behavior was observed that could be the result of natural variability and possible

occurrence of preferential flow patterns. However our study did not include determination of features that could indirectly affect the water retention in that profile.

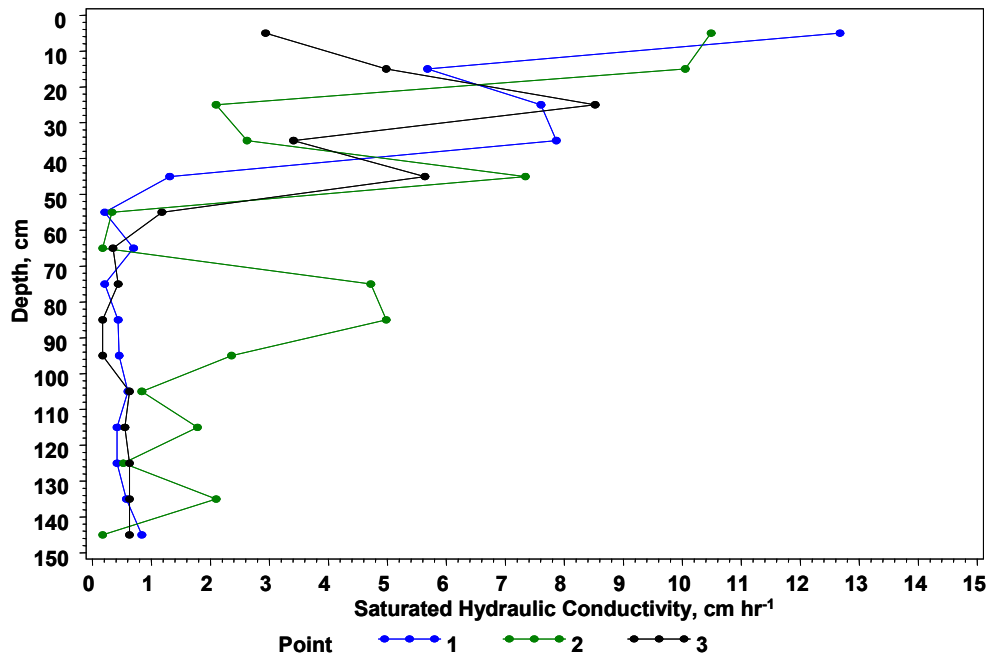


Figure 2.4 Saturated hydraulic conductivity in three profiles of a North Florida Ultisol under long term poultry application.

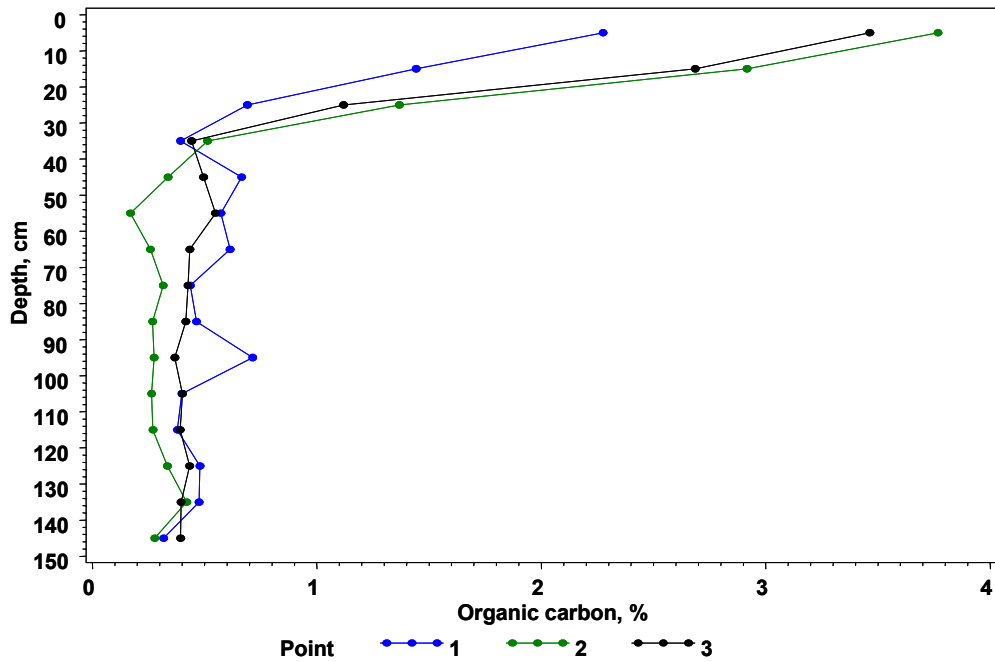


Figure 2.5 Soil organic carbon content in three profiles of a North Florida Ultisol under long term poultry litter application.

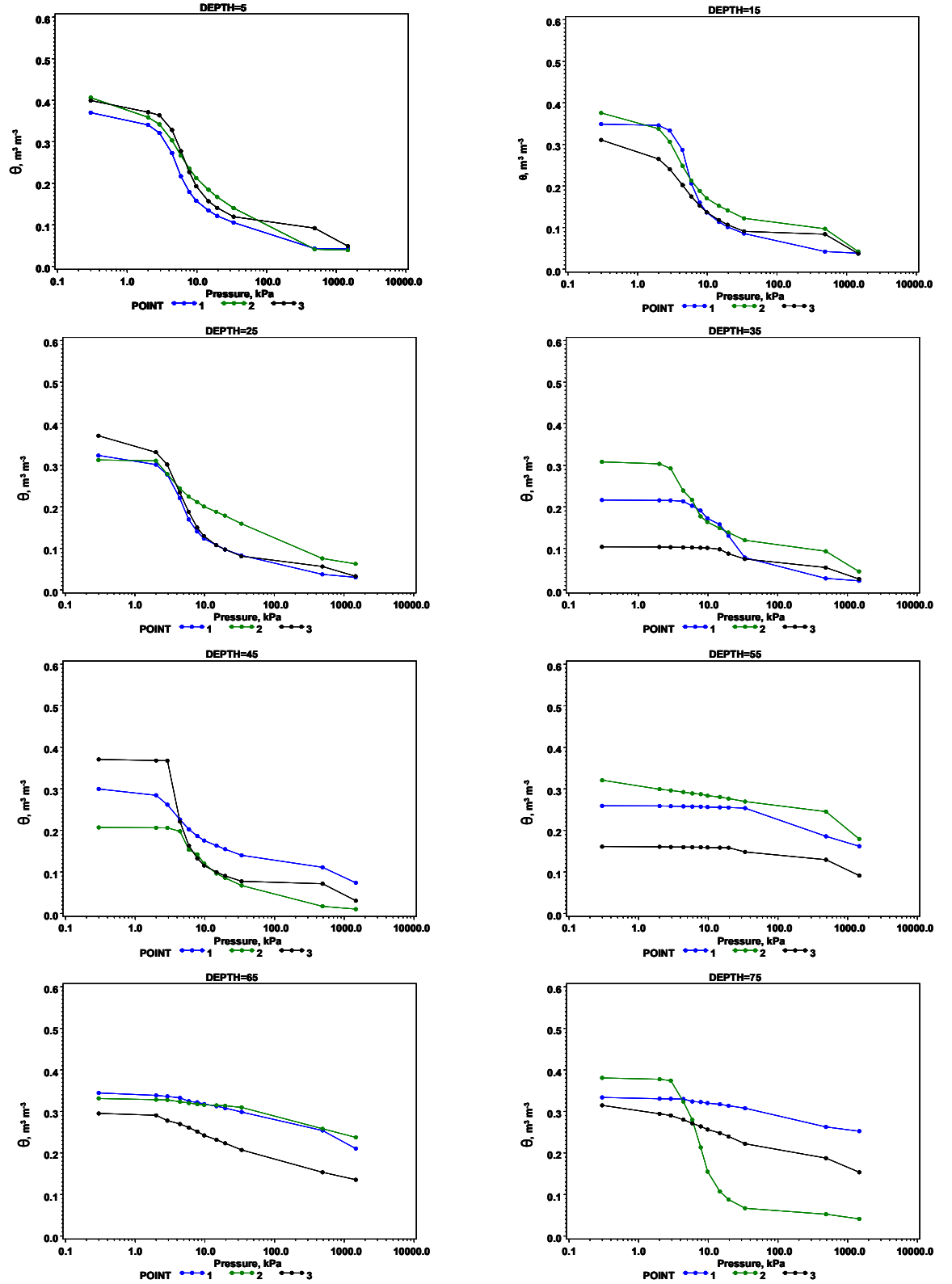


Figure 2.6 Water retention curves for three soil profiles in a North Florida Ultisol under long term poultry litter application at 8 depths from 5 cm to 75 cm.

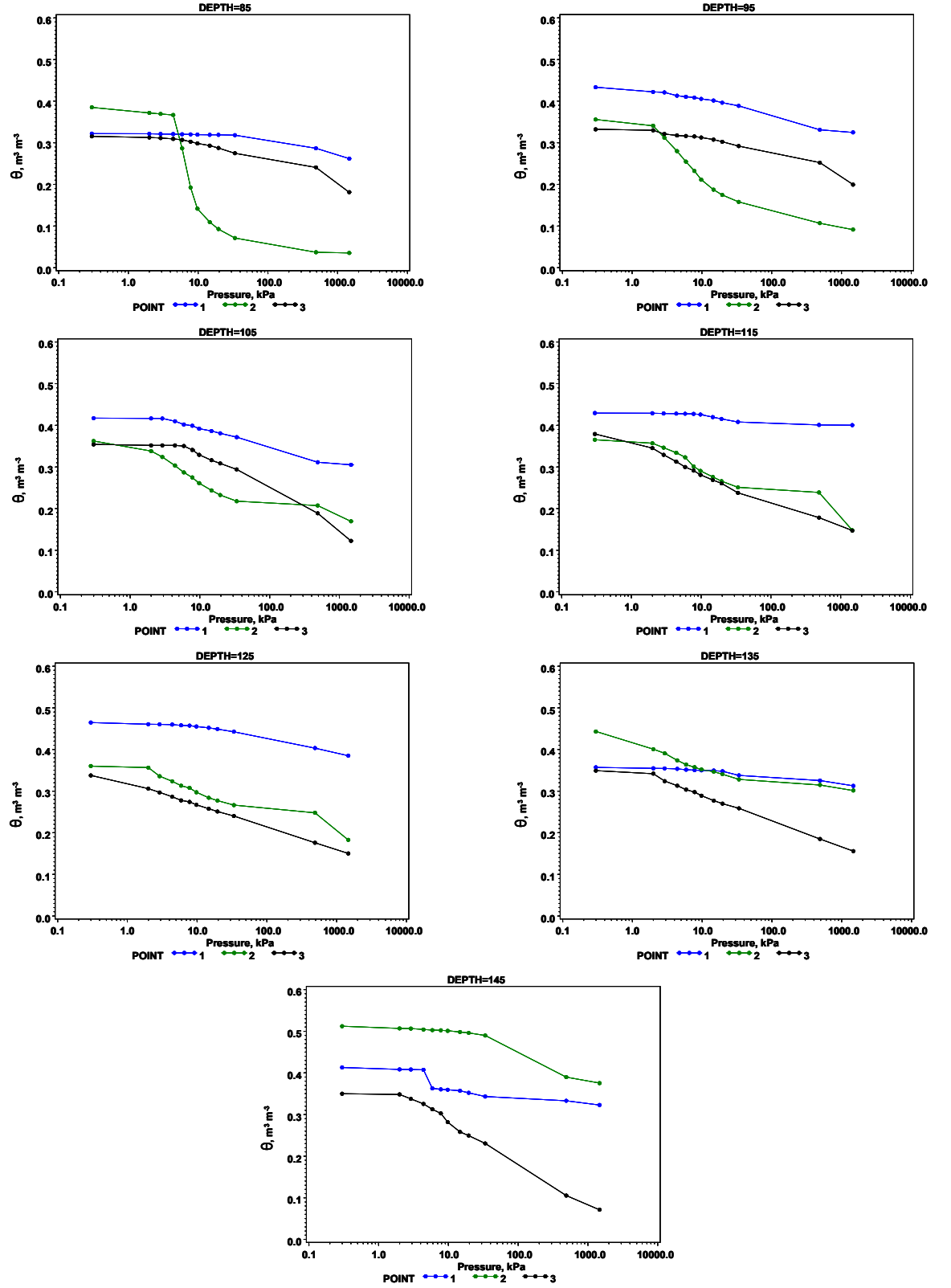


Figure 2.7 Water retention curves of three soil profiles in a North Florida Ultisol under poultry litter application at 8 depths from 85 cm to 145 cm.

Pedotransfer functions for ten suction levels developed for our study site soil are presented in Table 2.1. Clay and organic carbon content was positively correlated at all suction pressure levels. These results agreed with the pedotransfer functions previously developed for similar soil types (Gupta and Larson, 1979; Rawls and Brakensiek, 1985;).

Coarse sand and silt showed a negative relationship with water content at all suction pressures. Previous results were less clear about the relationship between sand and silt with water content. Gupta and Larson (1979) found a positive relationship between soil water content and sand and silt at all suction pressures between 0.04 bars and 10 bars suction pressure. At 15 bars however, the relationship between water content and sand was negative. Rawls and Brakensiek (1985) on the other hand found a negative relationship between water content and sand and a positive relationship for silt.

Bulk density was positively correlated with the water content. In the data set evaluated, along with the bulk density the water retention also increased with depth proving that the relationship between water content and bulk density was positive. Since the clay content increased with depth (Figure 2.3), it was obvious that the water retention also increased at a corresponding rate with depth. Kern (1995) obtained similar results when using the Rawls and Brakensiek (1981) model on a large US soil dataset. However, using other PTFs, Gupta and Larson (1979) and Rawls and Brakensiek (1981) working on a wide range of soils found that the bulk density is related inversely with the water content.

The coefficient of determination was better for pressures over 9.8 kPa ($R^2 > 0.77$). Similar results were obtained in the study by Rawls and Brakensiek (1981). Gupta and Larson (1979) suggested that the low R^2 values observed in the low pressure range could

be related with the presence of soil fragments of >2 mm in size in the undisturbed samples. In our study, the coarse fragments were however found occasionally and overall represented a negligible percentage of the total number of samples.

Table 2.1 Pedotransfer functions for 10 suction pressure levels for a North Florida Ultisol under long term poultry litter application.

Suction Pressure kPa	Pedo Transfer Function, PTF	R²
2.9	$0.37444 - 0.00552*\text{SILT} + 0.09761*\text{VC}^1 - 0.06605*\text{C}^2 + 0.00163*\text{CLAY} + 0.03147*\text{OC}^3$	0.64
9.8	$-0.73744 - 0.02917*\text{C} + 0.00999*\text{M}^4 + 0.00581*\text{CLAY} + 0.03616*\text{OC} + 0.41527*\text{BD}^5$	0.79
33.8	$-1.04125 - 0.03271*\text{C} + 0.01402*\text{M} + 0.00707*\text{CLAY} + 0.03567*\text{OC} + 0.5213*\text{BD}$	0.80
490.4	$-1.31440 - 0.05474*\text{C} + 0.02549*\text{M} + 0.01336*\text{VF}^6 + 0.01143*\text{CLAY} + 0.02626*\text{OC} + 0.41434*\text{BD}$	0.81
1,471.3	$-0.71933 - 0.07436*\text{C} + 0.02.066*\text{M} + 0.00746*\text{CLAY} + 0.26567*\text{BD}$	0.77

¹Very coarse sand; ²Coarse sand; ³Organic carbon; ⁴Medium sand ⁵Bulk density; ⁶Very fine sand

The partial R² of each variable accepted in the multivariate regression analysis is given in the Table 2.2. Clay was found to be the main factor defining soil water retention in these soils. The contribution of organic carbon to soil water retention was greater at low pressures and lesser at higher pressures. This behavior could be due to the predominance of sandy soils in our study. Rawls et al. (2003) found that organic carbon determines the soil water retention at coarser soil textures. At higher pressures organic carbon content was not able to retain water because the coarse texture of the soil. Only at low pressures enhanced effect of clay content would be apparent. Silt and sand fractions had only marginal contributions to the final R².

Table 2.2 Partial R^2 for pedotransfer functions obtained in North Florida soils under long term poultry litter application.

Suction Pressure kPa	Clay	Silt	Very Fine Sand	Medium Sand	Coarse Sand	Very Coarse Sand	Organic Carbon	Bulk Density
	Partial R^2							
2.9	0.37	0.04	0.03	0.10			0.11	
9.8	0.60			0.02	0.01		0.07	0.08
33.8	0.57			0.02	0.03		0.06	0.12
490.4	0.53			0.08	0.05	0.01	0.01	0.12
1,471.3	0.54			0.10	0.04			0.09

Estimated Campbell's parameters are shown in Table 2.3. Johnson et al. (1999) working with Georgia Ultisols found similar values. They also found an increase in both parameters **a** and **b** as the clay increased with depth in the soil profile. Rawls et al. (1991) confirmed this tendency for several soils working several soils in the USDA database.

The goodness of fit of the two models selected is depicted in Figure 2.8. The Campbell model showed higher R^2 for all the suction pressures. An evaluation of residuals showed that the Campbell model was in a better agreement with the observed values than the PTF. The MAE and the RMSE were lower for the Campbell's model at all the pressures.

Cornelis et al. (2001), Tiedje and Tapkenhinrichs (1993) and Kern (1995) obtained higher MAE values for Gupta and Larson (1979) and Rawls and Brakensiek (1981) models when compared to the values obtained with our PTF. One reason could be that the

data sets analyzed in the above referenced reports had more intra-sample variability as more than 5000 samples were studied. Our results also supported the observation that PTFs frequently were valid for narrow or very specific soil conditions (Tietje and Tapkenhinrichs, 1993).

Table 2.3 Parameters a and b of the of the Hutson and Cass modification of the Campbell's water retention equation for a North Florida Ultisol.

Depth cm	Point 1			Point 2			Point 3		
	a	b	R ²	a	B	R ²	A	b	R ²
5	-0.124	2.21	0.98	-0.120	2.625	0.90	-0.164	2.655	0.92
15	-0.217	1.748	0.98	-0.778	3.225	0.90	-0.323	3.38	0.92
25	-0.135	1.965	0.98	-0.817	4.080	0.91	-0.148	1.93	0.92
35	-0.684	2.715	0.97	-0.119	3.328	0.91	-0.01	5.865	0.92
45	-0.301	5.128	0.97	-0.761	2.143	0.91	-0.279	1.398	0.92
55	-0.292	11.836	0.97	-0.486	12.000	0.91	-0.863	12.000	0.92
65	-0.111	11.965	0.97	-0.275	12.000	0.91	-0.585	8.563	0.92
75	-0.489	11.684	0.96	-0.201	1.808	0.92	-0.301	10.468	0.92
85	-0.109	11.632	0.94	-0.223	1.423	0.92	-0.169	11.654	0.92
95	-0.486	11.797	0.94	-0.108	4.578	0.93	-0.354	11.899	0.92
105	-0.478	11.325	0.94	-0.451	10.485	0.93	-0.489	8.132	0.92
115	-0.462	11.898	0.91	-0.132	9.450	0.92	-0.214	7.935	0.92
125	-0.467	11.321	0.91	-0.101	10.356	0.92	-0.986	9.363	0.92
135	-0.457	11.302	0.89	-0.469	11.325	0.91	-0.503	8.753	0.92
145	-.0489	11.023	0.88	-0.389	10.000	0.91	-0.318	4.100	0.92

Both models were found to be able to estimate the water content at higher suction pressures with reasonable accuracy. The PTFs were found to be overestimating the water content at high pressures.

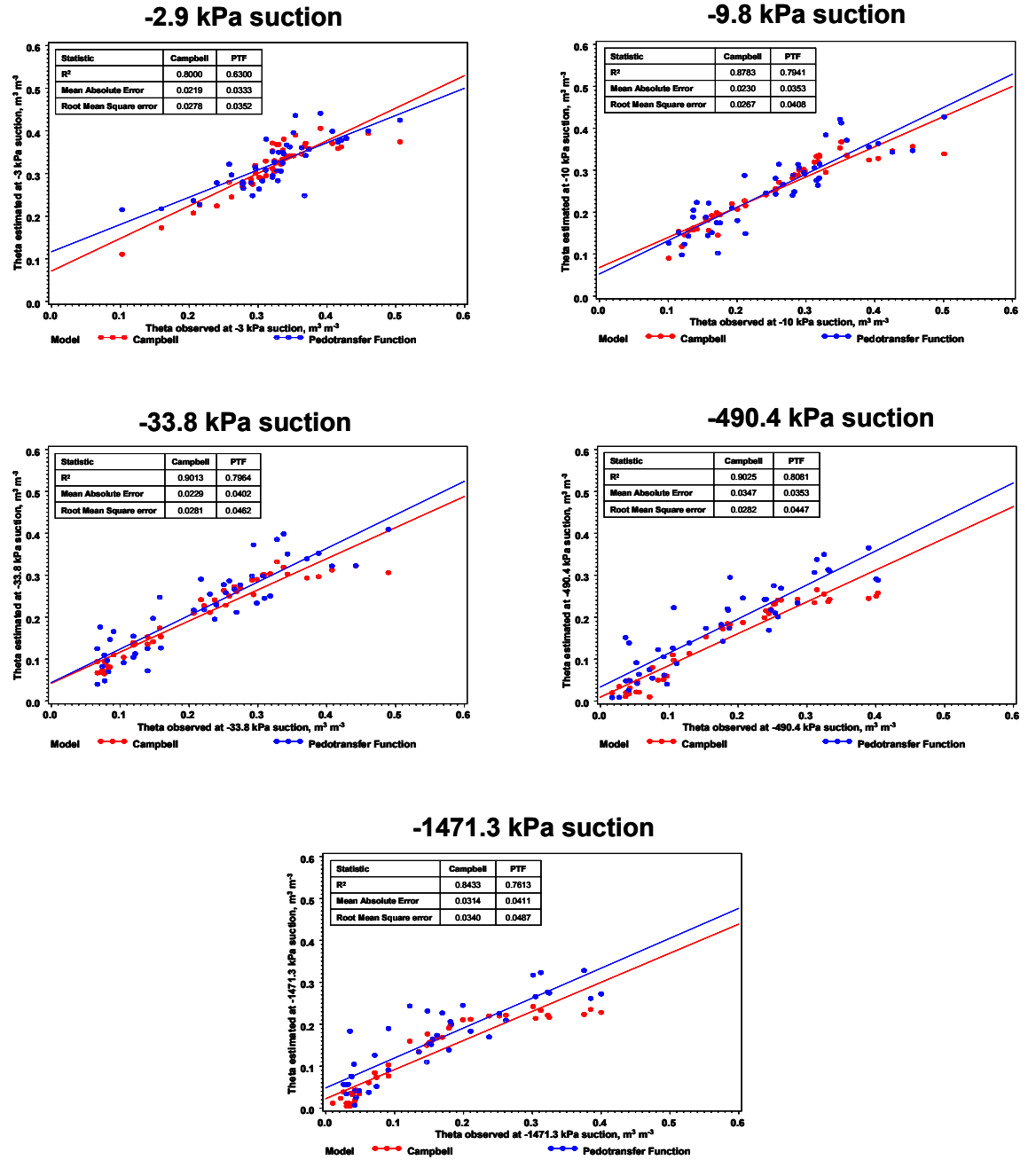


Figure 2.8 Goodness of fit of two water retention models (Campbell vs. PTF) for an Ultisol under long term poultry litter application.

CHAPTER 3

NITRATE MOVEMENT IN SOILS

Poultry litter is a mixture of poultry manure and one or more of the following inert materials: sawdust, wood shavings, wheat straw, peanut hulls or rice hulls (Edwards and Daniel, 1992). A comparative chart providing nutrient composition of poultry litters from different studies is summarized in Table 3.1. The variability observed in the litter composition is probably due to the genetics of the animals, the composition of the feed and the length of storage. It has been recognized that the manure and litter produced by the poultry operations have a great potential as organic nutrient sources for crops and pastures as they supply not only nitrogen (N) but also other plant macro- and micro-nutrients like P, K, Ca, Mg Cu, Zn (Simms and Wolfe, 1994). Poultry manure is highly suitable for land application on agricultural fields producing both pastures and row-crops. (Simms, 1987).

The transformations of the poultry litter N after its disposal on a cropped area are depicted in the N-cycle in Figure 3.1. The first form of inorganic N from the mineralization of organic N is ammonium (NH_4^+). The NH_4^+ is mostly absorbed by root plants but could also be fixed by some soil colloids. When the application is on the soil

Table 3.1 Elemental composition of poultry manures from different studies.

Poultry by-product	Total N	NH ₄ ⁺ -N	P	K	Ca	Mg
	g kg ⁻¹			mg kg ⁻¹		
Poultry litter (Cooperband et al., 2002) ¹	50.9	11.8	25.0	n/a ⁵	n/a	n/a
Broiler litter (Gascho, et al, 2001) ²	25.0	11.0	16.0	16,000	3,000	3,000
Broiler litter (Wood, et al, 1996)	34.7	11.6	24.4	33,800	32,300	7,400
Poultry litter (Robinson & Sharpley, 1995) ⁴	36.0	n/a	15.8	n/a	n/a	n/a
Broiler litter (Malone, 1992)	39.0	11.0	19.0	24,000	24,000	7,000
Poultry litter (Miner, et. al., 2000)	35.0	10.0	6.0	n/a	n/a	n/a
Broiler litter (Stephenson, et al, 1990)	40.0	n/a	16.0	23,000	23,000	5,000
Poultry manure (Simms, 1987) ⁴	48.5	2.1	16.7	19,900	n/a	n/a
Poultry litter (Overcash, et al., 1983)	35.0	9.0	16.0	18,000	31,000	4,000

¹ Average of 2 seasons

² Average of 8 seasons

³ Average of two types of poultry litters

⁴ Average of 3 years

⁵ n/a not available

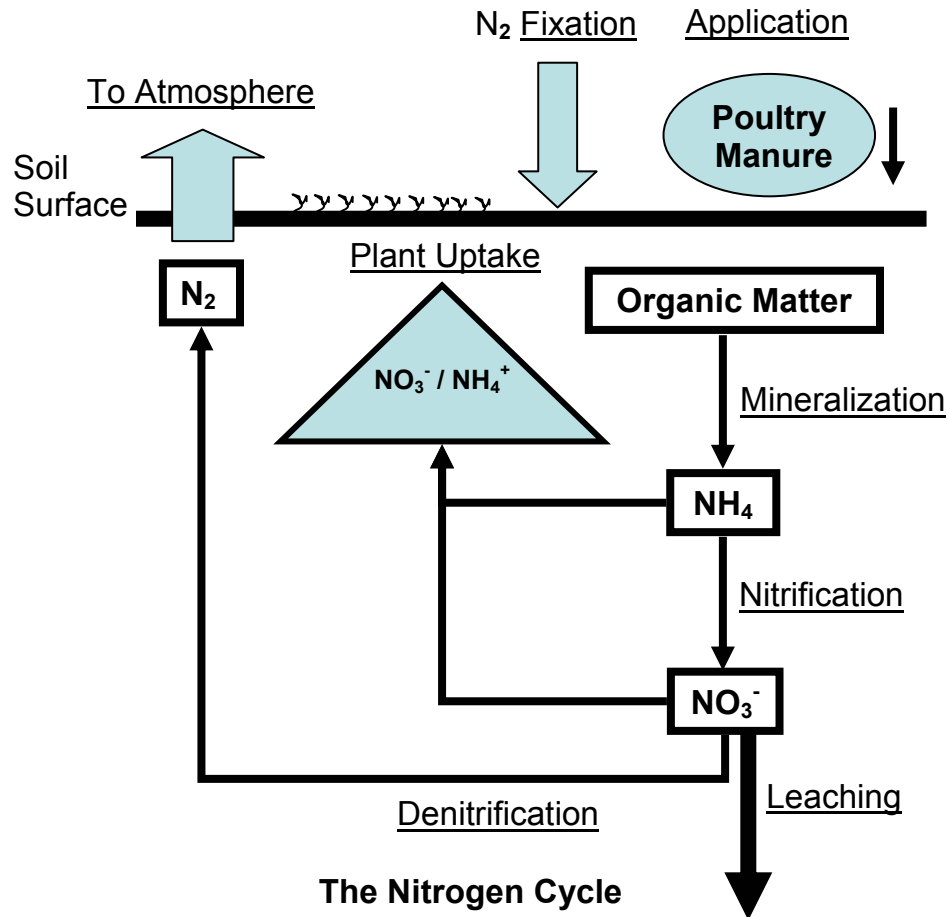


Figure 3.1 The Nitrogen Cycle (Myrold, 1999).

surface and the temperature is high enough, however some of this NH_4^+ could be transformed to $NH_3\uparrow$ that can be lost to the atmosphere through rapid volatilization. If there are nitrifying bacteria in the soil, the NH_4^+ is converted into NO_3^- , an anion that is very soluble in water and is not retained by the negatively charged soil colloids (Havlin, et al., 1999). Nitrate is predominantly absorbed by the plant roots or converted to $N_2\uparrow$ by denitrifying bacteria when ponding conditions are predominant. If there are no plant roots absorbing NO_3^- , and the conditions are not appropriate for denitrification, the nitrate will move vertically and eventually will reach the groundwater.

The manner in which the poultry litter is disposed of in the soil is critical to establishing the risk of groundwater contamination (Edwards and Daniel, 1992). The role of volatilization on poultry litter land application cannot be ignored because it can amount to as much as 40% of the total N litter applied (Cabrera and Vervoort, 1998).

The potential effect of nitrate in groundwater is that children younger than 3 months consuming water with high level of nitrates can develop methemoglobinemia also known as “blue-baby syndrome” (Simms and Wolf, 1994). This is a serious health problem in infants, but other health problems have also been linked with high levels of nitrate in different groups of the population (USEPA, 2002). Due to public health concerns, in 1976 a maximum level of $10 \text{ mg NO}_3\text{-N L}^{-1}$ in drinking water was established (USEPA, 2002).

The potential groundwater impacts due to nitrates as a result of land application of animal manures are considered a non-point source of pollution because of its seasonality, nature, and unidentifiable entry point into the system (USDA-SCS, 1992). Field studies have shown a direct correlation among the application of poultry litter, the accumulation of N in the soil and the movement of NO_3^- through the soil profile into groundwater (Liebhardt, et al., 1979; Bitzer and Simms, 1988; Edwards and Daniel, 1992). Application rates above 13 Mg ha^{-1} of poultry litter consistently resulted in groundwater NO_3^- concentrations higher than the drinking water standard limit of 10 mg L^{-1} (Liebhardt, et al., 1979). Other studies were more conservative suggesting a maximum annual rate application limit of 6.7 Mg ha^{-1} of poultry litter to avoid groundwater contamination (Sims and Wolf, 1994).

Best Management Practices

Best Management Practices (BMPs) according with the Florida legislature are “practices or combinations of practices determined by research or field testing of representative sites to be the most effective and practicable methods of fertilization designed to meet nitrate groundwater quality standards, including economic and technological considerations” (Mylavarapu, 2003). The concept of Best Management Practices (BMPs) was first introduced in response to federal legislation that created the Clean Water Act as a practical and effective means to reduce non-point source pollution.

A broad group of BMPs have been developed to avoid, or reduce the risk of environmental pollution after the application of poultry manures (Mostaghimi, et al., 2001). Particular emphasis has been placed on the selection of appropriate cover crops or pastures in poultry manure spread areas to improve the interception of N compounds by plants, the synchronization between application of the manures and the active phase of plant growth, to increase the efficiency of nutrient uptake. Other more traditional practices include the construction of covered poultry litter storage areas, better poultry litter spreaders (Sims and Wolf, 1994) and on farm waste treatment including composting (Kelleher, et al., 2002).

The poultry farm in this study adopted the conservation plan (BMP) approved by the USDA-NRCS prescribing litter application rates, timing, total area receiving litter applications, crops grown, etc. Adoption of these measures also enabled the producer to participate in federal cost share programs that included construction of storage shed for storing the poultry litter produced on-site.

The objective of this part of the research was to describe nitrate movement in an Ultisol under long term poultry litter application

Materials and Methods

The poultry farm selected for this study is located in the Suwannee County, Florida (Figure 3.2).

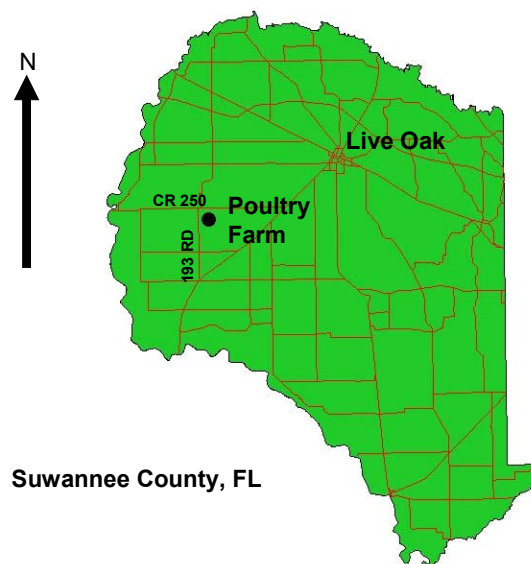


Figure 3.2 Location of the research farm in the Suwannee County, Florida

The selected farm has been involved in the production of broilers for the past 20 years. The farm has three houses producing a total of approximately 375 Mg of poultry litter per year, based upon 6 clean-outs per year. As per the conservation plan, 92% of this poultry litter is applied to the spread areas without incorporation. The spread areas

are planted to Bahia grass, (*Paspalum notatum* Fluegge Bogdan), which is grazed 40% of the time by 55 cattle heads in a daily shift among three areas.

The farm owner signed a PL-566 contract with the USDA-NRCS that required the construction of a waste storage facility and the implementation of different conservation practices (BMPs). Specific measures included seasonal application of fresh poultry litter between March and September to increase the uptake of N by the pastures and minimize the leaching risk during the fall and the winter. Other practices included composting facilities, a pipeline to supply water to the storage and composting facilities, fencing around wetlands and sinkholes, pest management in areas of litter application, exclusion of livestock in wetlands and sinkholes areas and grazing on all pasture fields.

A spread area, marked in Figure 3.3, of approximately 11 ha. was selected for this study. Three inspection wells were installed during 1999 to monitor nitrate levels in the ground water. The wells were respectively, 22.8 meters, 20.7 and 21.3 meters in depth. Water samples were collected at 6-weekly intervals and immediately refrigerated in the field. Water samples from the wells were analyzed for NO_3^- by the FDACS Laboratory in Trenton, Florida.

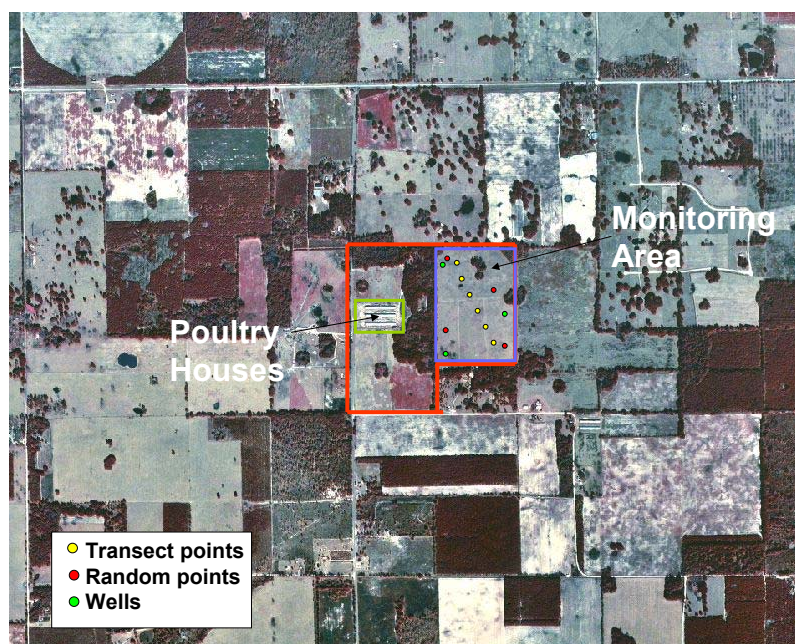


Figure 3.3 Monitoring area in the selected farm.

A weather station was established in May 5, 2001 to record the rain data. On June 26, 2002, additional instruments were added to record radiation and temperature data. Prior to this, a weather station located on a nearby farm was used for collection of weather data.

Information about the activities and management practices on the farm was obtained from the farm records. Systematic record keeping of the agricultural practices was necessary after the establishment of the PL-566 contract with the landowner.

Four points were randomly selected in the 11 ha. study area for soil sampling. Each point was geo-referenced with a GPS unit and a radial-clockwise sampling at two-meters distance from the actual point was adopted for subsequent monthly sampling, to avoid re-

sampling at the previously disturbed point. The sample collection started on January 2001 and finished on October 2002, completing a cycle of 22 months.

At each sampling, soil samples were obtained at 50 cm intervals for the first 1.0 m depth and at 1.0 m depth intervals below the first meter until a textural change with a significant increase of clay content was detected. The clay content was estimated in the field by feel method by hand. Depths were recorded and samples were packed in iceboxes to preserve the samples for further laboratory analysis.

For all the soil samples obtained, NO_3^- and NH_4^+ concentrations were determined using KCl extraction (0.01 N KCl in a 10:1 soil:solution). Both NO_3^- and NH_4^+ were determined with an AlpKem FlowSolution IV Autoanalyzer according to methods EPA 350.1 and 350.1UF (Mylavarapu and Kennelley, 2002). Values were adjusted for soil moisture content.

The graphs (Fig.3.4 – 3.7) contain information about the soil nitrate content in the upper (red line, circles) and the lower soil layers (red line, squares), rain (blue columns) and daily values of ET (red points), nitrate in groundwater obtained from the wells (green lines) - well 13 (triangle); well 14 (diamond); well (15 point) and the applications of poultry litter (black arrows with date and amount of litter applied).

Evapo-transpiration was estimated according to Hargreaves and Samani (1985) method that was adequately calibrated for various locations around the world. Also the model was specially developed for pasture lands. Evapo-transpiration (ET_o) is calculated as:

$$\text{ET}_o = 0.0135 \times \text{RS} (\text{T}^\circ \text{C} + 17.8) \quad 3.1$$

Where RS is solar radiation, T° C is mean temperature in degrees Centigrade; RS and ET_o are in the same units, mm per unit of time. When solar energy is expressed in megajoules per square meter (Wu, 1997), then the RS should be transformed accordingly to:

$$RS_{\text{mm day}^{-1}} = RS_{\text{megajoule day}^{-1}} \times (238.8 / (595.5 - 0.55 T)) \quad 3.2$$

where T is average temperature in degrees Centigrade.

To estimate the N removed by the pasture, two randomly selected squares of Bahia grass samples measuring 0.25m² were taken monthly between October 2002 and March 2003. The samples were obtained by recovering all the grass material above and underground in the selected area and by removing the soil thoroughly. The grass samples were then divided into leaves and rhizomes and roots. The tissue samples were oven-dried at 60°C for 48 hours before grinding. Aliquots of 25 g. were sent to the UF/IFAS Analytical Research Laboratory to analyze for total nitrogen using the TKN procedure (Mylavarapu and Kennelly, 2002) and the TKN values obtained were expressed in kg ha⁻¹.

Results and Discussion

During the period from January 2001 to October 2002, poultry litter was applied six times to the study area. The composition of the poultry litter applied is detailed in Table 3.2. Total nitrogen (TKN) content in the poultry litter samples for both years were relatively similar compared with the information in Table 3.1. Both the P and K contents in the manure were similar to the values reported in the literature. The composition remained steady during the two years observed possibly because the poultry feed program remained unchanged.

The poultry litter application rates varied between years as shown in Table 3.3. During the year 2001, the field received two applications for a total of 4,417 kg ha⁻¹ however during 2002 the total amount was 7,443 kg ha⁻¹, applied in three installments. As the NRCS conservation plan was adopted in 2001, litter applications done prior to and during 2001, did not necessarily follow the BMP guidelines which recommend that the poultry litter be applied only after March of each year.

Table 3.2 Fresh poultry litter composition per year.

Characteristic	Dates	
	2001	2002
Total solids %	77.9	81.7
Total ash %	13.9	17.1
Total N mg kg ⁻¹	31,238	30,625
NH ₃ -N mg kg ⁻¹	5,206	4,988
Total P mg kg ⁻¹	13,875	16,500
Total K mg kg ⁻¹	19,707	25,590
Moisture %	22.1	18.3
pH	8.7	8.6

Table 3.3 Rate of fresh poultry litter applied and the corresponding total N and P.

Date	Poultry Litter Applied	TKN	Total P
	kg ha ⁻¹		
02/04/2001	1,906	46.4	20.6
04/17/2001	2,511	61.1	27.1
02/22/2002	4,551	113.9	61.3
07/11/2002	830	20.8	11.2
08/31/2002	2,062	51.6	27.8

During 2001, the amounts of total N and total P added through fresh poultry litter applications to the field sites were 107.5 kg ha⁻¹ and 47.7 kg ha⁻¹ respectively. During 2002, the total N supplied from the poultry litter was 186 kg ha⁻¹ while the total P

amounted to 100.3 kg ha^{-1} . The N: P ratio in the poultry litter application is approximately 2:1

Point 1

At Point 1 (Figure 3.4), the first application of poultry litter on February 4th, 2001 (2.7 Mg ha^{-1}) produced a peak higher than 10 mg kg^{-1} of $\text{NO}_3\text{-N}$ for both the surface and the clay soil layers (red lines). The litter application was immediately followed by a series of light and heavy rainfall events, which could have contributed to a peak during the subsequent 3 weeks. Also, due to cooler temperatures in February, the Bahia grass growth was probably slow and was not able to capture the nitrate available in the system. Our observation was in conformity with previous research data where the relationship between the application of manures to the soil surface, the initial accumulation of nitrate in the surface and the subsequent depletion of the accumulated N by infiltrating water from the rainfall was demonstrated (Kingery, et al., 1994; Ritter and Bergstrom, 2001). The following four applications of poultry litter (April 17th, 2001; February 22nd, 2002; July 11th, 2002 and August 31, 2002) did not produced peaks higher than 10 mg kg^{-1} of $\text{NO}_3\text{-N}$ in the soil layers evaluated.

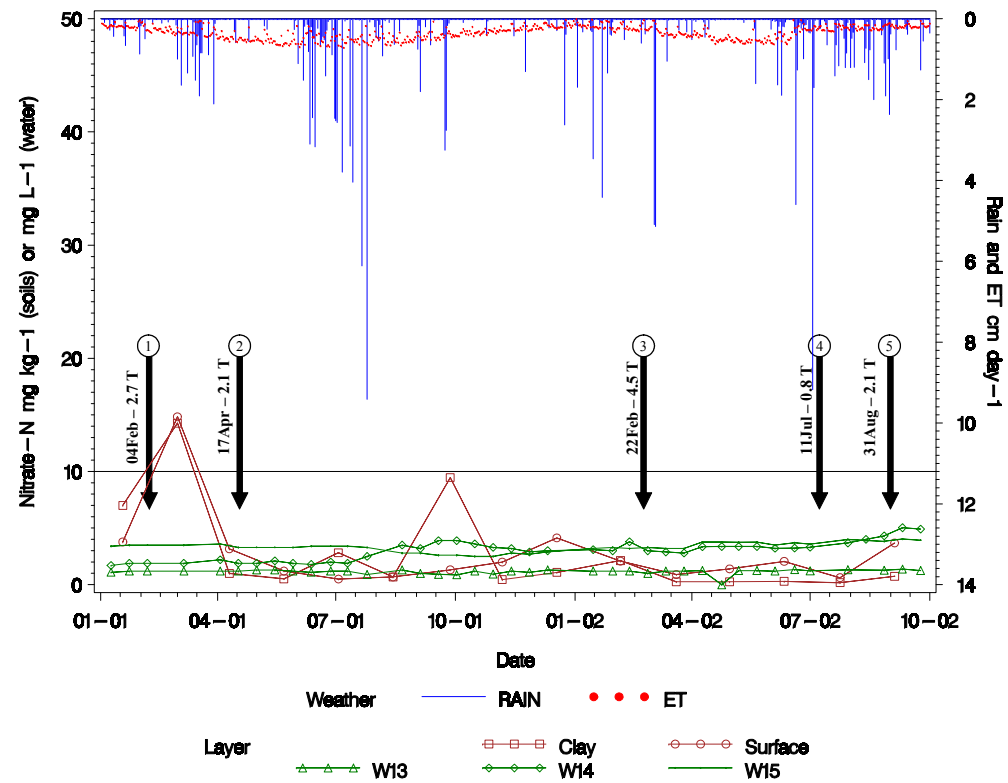


Figure 3.4 Soil nitrate level, groundwater nitrate content, daily rain and evapo-transpiration and poultry litter applications for Point 1.

A nitrate level close to 10 mg kg^{-1} was observed at the surface of the clay layer at the beginning of October, 2001. However, no poultry application was made to the field during the prior few weeks. Two hypotheses could be put forth to explain the occurrence of that peak: i) nitrate was released through the mineralization of residual organic N from poultry litter or dairy manure (from grazing cattle) and/or ii) a portion of the nitrate remaining in the profile from the previous litter application(s) had reached the clay layer since not all of the litter applied mineralized at the same time. Different laboratory and field studies have demonstrated that the mineralization of organic N from poultry manure and poultry manure composts was not completed even after 150 days of the application (Castellanos and Pratt, 1981; Bitzer and Sims, 1988; Tyson and Cabrera, 1993).

The poultry application in February 2002 was immediately followed by a very high rainfall event (52 mm) that could explain why there was no increase in soil nitrate concentration as opposed to 10-22 mm rainfall over a 3 week period in year 2001. The next two poultry applications (July 11th and August 31st, 2002) correspond to a period of strong growth of the bahia grass due to higher temperatures during the summer and sufficient rain.

Bahia grass, as with many other pastures, is able to respond positively to the application of N in terms of higher dry matter yields and forage quality when it is amended from both mineral sources (Stanley and Rhoads, 2000) and organic manure (Adjei and Rechcigl, 2002). Results reported by Adjei and Rechcigl (2002) from an experiment carried out in Florida showed that the N concentration of Bahia grass blades was between 1.02% and 1.12 % when fertilized with ammonium nitrate and 1.06% to

1.22 %, when amended with organic biosolids. With average yields at $3.8 \text{ Mg ha}^{-1} \text{ year}^{-1}$, the total N removed by the pasture was estimated to be about $42 \text{ kg ha}^{-1} \text{ year}^{-1}$.

Volatilization can play an important role immediately after the poultry litter application to the soil surface in decreasing the N available for leaching (Edwards and Daniel, 1992). Up to 48% of N can be lost to the atmosphere due to volatilization, decreasing the N available for leaching (Giddens and Rao, 1975). Several factors can favor volatilization of ammonia mineralized from litter, but the most relevant are soil pH higher than 7.5, the presence of crop residues, air temperatures higher than 45°C , soils near to field capacity moisture and broadcast applications on the soil surface (Havlin, et. al., 1999). Such environmental conditions are a common occurrence in our study area as in many parts of Florida and should explain why the surface soil nitrate levels were low. For example, the pH of the poultry litter applied during the three years of observation was always higher than 8.5 (Table 3.2). An additional factor promoting volatilization was that the poultry litter was broadcast on the soil surface and not incorporated which also partly resulted in the uneven spread of litter.

The inclusion of pastures and other perennial crops as a component of BMP package aimed at minimizing NO_3^- leaching has been well documented (Simms, 1987). Analyses of tissue from Bahia grass obtained from the application area from October 2002 to June 2003, showed that at least 69 kg ha^{-1} of N has been retained by the pasture (Table 3.4). Bahia grass showed reasonable tolerance to low temperatures during the winter and a quick response to the applied poultry litter during the spring, a key component of the BMP adopted at the farm. Both of the above conditions confirm why Bahia grass is preferred among commercial growers of north Florida (Mislevy, et al.,

1991). Other positive characteristics of the pasture observed by Bogdan (1977) are dense fibrous roots and resistance to grazing close to the ground. The optimal grazing rate for Bahia grass is 5 head ha⁻¹ when fertilized with 100-200 kg ha⁻¹ of N (Baki, et al., 1992). The N application rate in our study area therefore suggests that it is possible to increase the number of heads for grazing during the current 45% of the time allowed or even grazing the spread area year-round.

Considering 40% of the grazing time in the manure-spread area, the total N accumulation based on recycling by cattle was estimated to be around 54 kg ha⁻¹ year⁻¹. The estimate was derived based on an average head weight of 272 kg and 0.3 kg of N per hectare per 1000 kg of live weight (USDA-SCS, 1975). However, its contribution to increase the nitrate is less important than the poultry litter application itself since the manure deposition by grazing herds is sparse both in time and in space.

Nitrate levels from samples collected from groundwater wells (green lines in Figure 3.4) did not show strong responses to any of the applications of poultry litter. However, well 14 (W14) showed a gradual increase of NO₃⁻-N levels from 2 to 5 mg L⁻¹.

Point 2

At Point 2 (Figure 3.5), the first two applications in February and April 2001 resulted in two peaks of <10 mg kg⁻¹ of NO₃-N in both the surface and the clay soil layers.

A peak of NO₃-N was observed around mid December 2001 in the surface soil layer. However, we could not directly establish the reason(s) for its occurrence based on the data we had collected. Cooperband, et al. (2002) observed similar unexplained random nitrate peaks in surface soils two months after fresh poultry litter application.

Table 3.4 Dry weigh, N content and N retained by leaves and rhizomes of Bahia grass in the poultry litter spread area from October 2002 to June 2003.

Month	Dry Weight, kg ha ⁻¹			N Content, mg kg ⁻¹		N, Retained kg ha ⁻¹		
	Leaves	Roots and Rhizomes	Total	Leaves	Roots and Rhizomes	Leaves	Roots and Rhizomes	Total
Oct-02	2,033.0	3,835.0	5,868.0	12,425.0	12,350.0	24.5	47.4	71.9
Nov-02	1,810.0	3,411.6	5,221.6	16,125.0	14,150.0	29.2	48.3	77.4
Dec-02	1,344.0	2,798.6	4,142.6	16,375.0	14,050.0	22.0	39.1	61.0
Jan-03	1,514.8	3,131.8	4,646.6	15,275.0	16,275.0	22.8	50.8	73.6
Feb-03	1,288.2	3,190.6	4,478.8	16,450.0	15,650.0	21.2	50.0	71.2
Mar-03	1,761.8	4,786.8	6,548.6	10,375.0	8,950.0	17.8	42.6	60.4

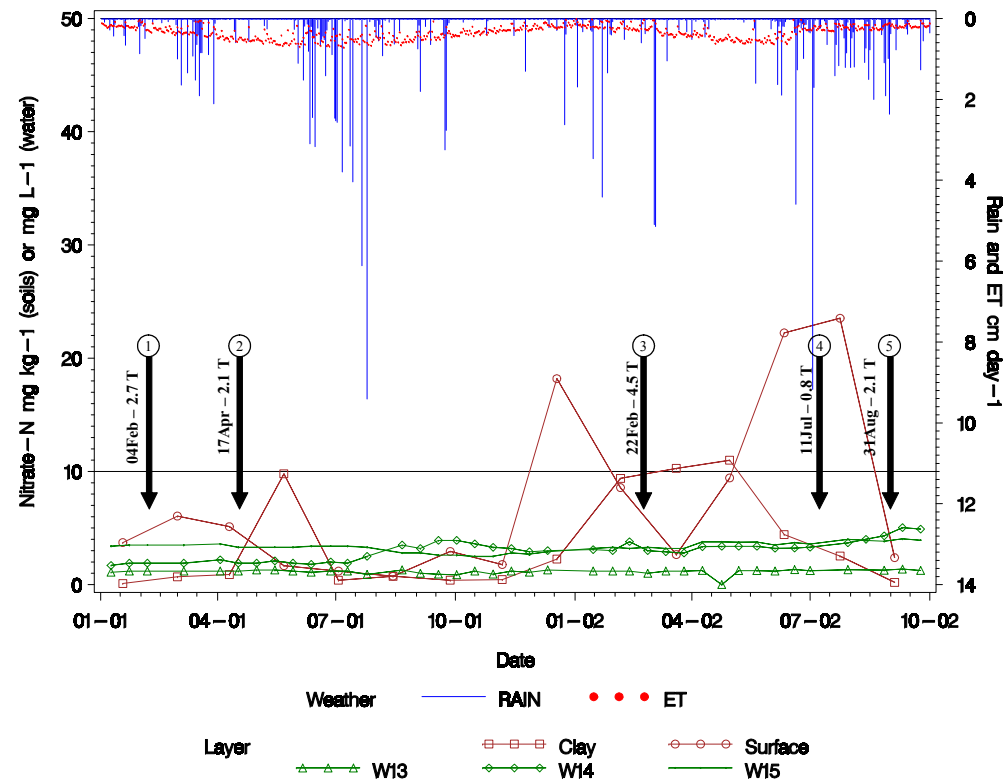


Figure 3.5 Soil nitrate level, groundwater nitrate content, daily rain and evapo-transpiration and poultry litter applications for Point 2.

After poultry application on February 22nd 2002, an increase in NO₃-N concentrations on both surface and clay layers was observed. Growth of Bahia grass is slowed down considerably during the late-Fall and winter seasons due to cool temperatures and as a result any nitrate not taken up by the crop could move through the soil profile after any rainfall event.

Point 3

At Point 3, the first application of poultry litter on February 4th, 2001 produced a peak higher than 10 mg kg⁻¹ of NO₃-N in the surface soil layer (Figure 3.6). The soil nitrate levels higher than 10 mg kg⁻¹ in the clay layer before the application of April 17th, 2001, as shown in Fig. 3.6 were probably a consequence of previous management and litter application rates. Although the poultry litter application on April 17th 2001 did not produce a nitrate peak in the surface soil layer, it did result in a delay in the otherwise decreasing trend in nitrate levels during that period in the clay layer.

Point 4

In 2001, poultry litter applications resulted in increased soil surface nitrate levels of 36 mg kg⁻¹ at Point 4 (Figure 3.7). The next three applications during 2002 at this point did not result in any peaks in the nitrate concentrations either in the soil or in the groundwater.

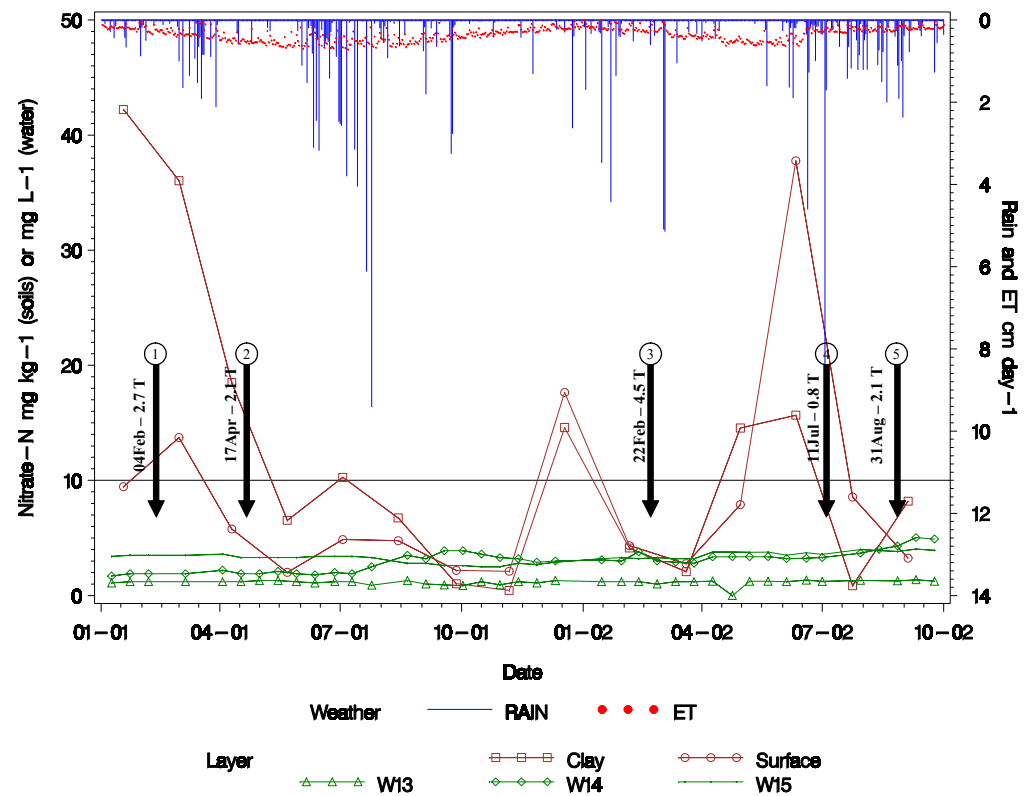


Figure 3.6 Soil nitrate level, groundwater nitrate content, daily rain and evapo-transpiration and poultry litter applications for Point 3.

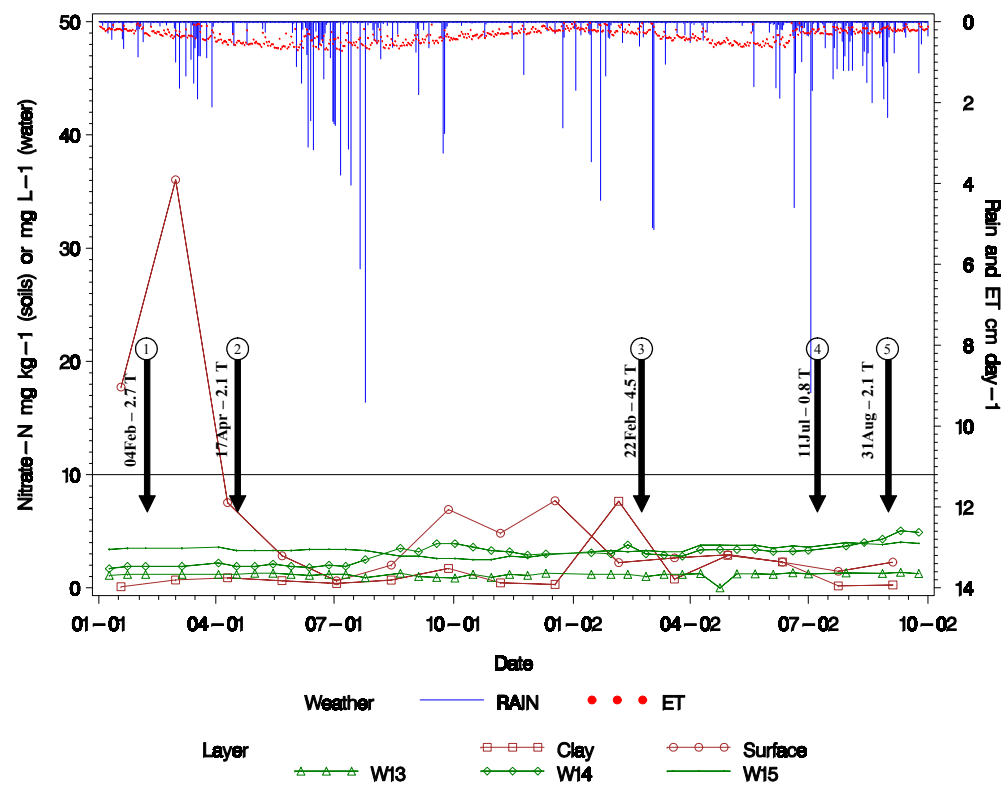


Figure 3.7 Soil nitrate level, groundwater nitrate content, daily rain and evapo-transpiration and poultry litter applications for Point 4.

When poultry litter is not incorporated into the soil, it is possible to promote volatilization of a manure mixture that normally has a high level of uric acid (Havlin, et al., 1999). The vigorous growth of the pasture at the beginning of the spring obviously was playing a key role both in the ammonia volatilization and the nitrate uptake by the plant biomass.

Microbial transformations of nitrate probably played only a marginal role in the depletion of nitrate in the soil layers in our study area because of the predominant sandy texture at the soil surface and negligible or lack of organic carbon contents in the deeper layers. Denitrification was found to occur even under anaerobic conditions where denitrifying bacteria could use an alternate electron acceptor different than oxygen (Myrold, 1999).

The arenic Paleudults of North Florida have a variable sandy surface layer between 20 and 75 cm. deep but can be occasionally even deeper. (Carlisle, et al., 1989). The sandy layer has typically a saturated hydraulic conductivity of 6 cm hr^{-1} . With such a high-saturated hydraulic conductivity, the free water will be moving deeper rapidly through the sandy profile carrying any NO_3^- available in the solution and thereby depleting the nitrate levels in the surficial layers. In the deeper layers, the restrictions for microbial transformation of nitrates are not the anaerobic conditions but the restricted sources of carbon (Myrold, 1999). Organic carbon soil contents decrease rapidly with depth from 0.64% at the A horizon to 0.17% at the Bt1 horizon (71 cm. depth) (Fig. 2.6)

The Bt horizon in Ultisols is a horizon of accumulation of silicate clay (USDA-SCS, 1998). In arenic Paleudults, the clay layer presents a barrier to water movement because of which the hydraulic conductivity is below 1.0 cm hour^{-1} . Eventually the NO_3^-

solution will reach the groundwater passing through the clay layer but the lag between its arrival time at the upper clay layer and its reaching the groundwater can be several months and even years depending on the hydraulic conductivity of the clay layer. The effectiveness of the clay layer as a barrier to water flow was probably the prime reason for low nitrate values in the groundwater extracted from the wells.

During the entire duration of our study, the nitrate content in the groundwater was below 7 mg L^{-1} . The fluctuation in groundwater levels in the three wells located on the study site for the entire duration is depicted in Figure 3.8. Well #15 (W15) had the lowest water table depth and the corresponding nitrate levels recorded in the groundwater were also the lowest (Figure 3.8). The water table never reached the upper two meters of the soil depth during the entire observation period.

The water table measured in the wells followed the rainfall patterns (Fig. 3.8) confirming that the recharge of the Floridan aquifer is mainly due to the movement of surface water through the permeable soils and rocks (SWRD, 2000). The groundwater is connected by an intricate network of cavities and caverns resulting in the dissolution of limestone due to the carbonic acid generated by the transformation of the carbon dioxide diluted in the rain (Hornsby and Ceryack, 2000). The authors concluded that the karst geology of the aquifer that permits changes at points located away from the observational points and can affect the condition of the groundwater proving it difficult to explain local groundwater behavior with the facts obtained at only the local point.

The karst geology also helps explain fluctuations in water levels of the Suwannee River. The natural drainage for the research area is controlling the movement of water even at the surface layers (Crane, 1986). If there is nitrate available in any part of the

soils with *karst* geology through which the water is moving, nitrate can reach points located anywhere in the network.

The source of nitrate in the system is at the soil surface where poultry litter applications are made. Some of the N can be lost to the atmosphere as the poultry litter decomposes while a certain amount of nitrate will eventually be transported to deeper layers of soil if enough water is available. If the nitrate is in a zone below the grass roots, then the anion is usually non-recoverable with high potential to move even deeper.

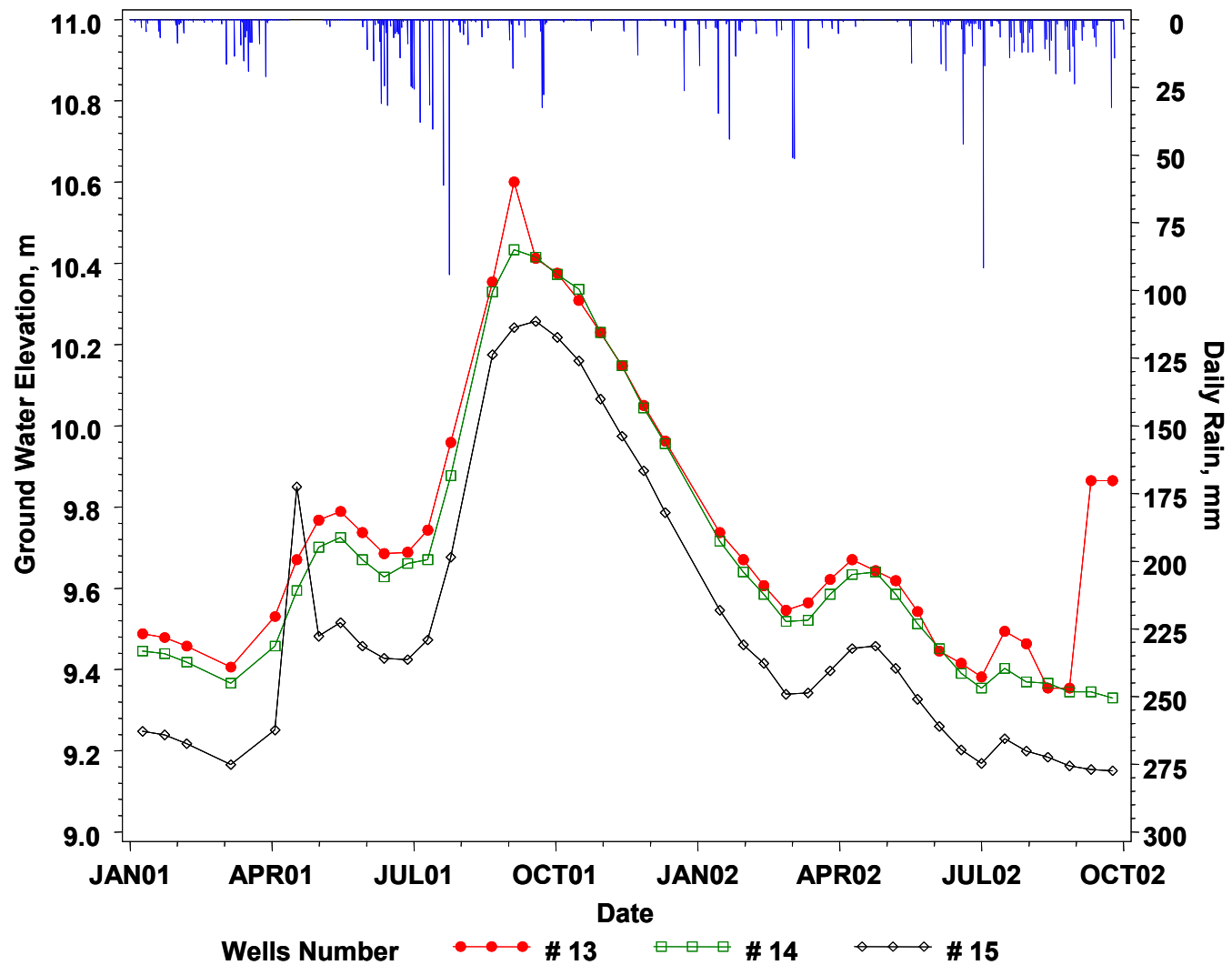


Figure 3.8 Groundwater elevation and daily rain for the period Jan, 2001 to October, 2002

CHAPTER 4

POULTRY MANURE MINERALIZATION

The application of poultry manure to crops and pastures is a common practice in several regions of the USA. Poultry litter is typically a mixture of poultry manure with inert materials typically sawdust, wood shavings, wheat straw, peanut or rice hulls (Edwards and Daniel, 1992). Poultry litter has the advantage of high N content along with significant amounts of other important plant nutrients like P and Ca (Sims and Wolfe, 1994). Often fresh litter removed from the poultry houses is directly land applied using manure spreaders moved by tractors.

Depending of the content of unstable N forms such as uric acid and urea, a portion of the N can be transformed to $\text{NH}_3\uparrow$ in the soil surface and be volatilized, while the rest will be mineralized (Havlin, et al., 1999). If the environmental conditions favor mineralization, NH_4^+ and NO_3^- will be produced as a function of the number of poultry litter applications (Simms and Wolfe, 1994).

The principal concern of both the producers and the regulators is the balance between sustainable crop production and environmental protection. Nitrate is highly soluble in water. If plants are actively growing and have sufficient root biomass, they can catch the nitrate flush from mineralization and take up the nitrate. However, when the poultry application results in nitrate production in excess of plant needs, there is a risk of ground water pollution because of the nitrate's high solubility and its lack of retention by soil colloids (Sharpley, et al., 1998).

Consequently, a wide variety of Best Management Practices (BMPs) have been developed to avoid or mitigate the environmental risks associated with the land application of poultry litter (Mostaghimi, 2001). Incorporation of poultry litter is frequently suggested as a BMP as opposed to surface spreading, because the amount of NO_3^- leached was recorded to be lower than in systems where the poultry litter was spread on the surface (Giddens and Rao, 1975; Moore, et al, 1995).

However, it is important to note that where animals are present all around the year in the field, incorporation is not a management option. Therefore, pastures under grazing represent a special concern and the spreading methods become more important than in crop production because manure application and grazing introduce more heterogeneity in the distribution of N which in turn favors nitrate leaching (Phillips, 1998).

The quantification of N mineralization in soils has received renewed interest because of the increasing public concern about the environmental pollution risks associated with the use of organic wastes for agricultural production (Gagnon and Simard, 1999). The methods for quantifying N mineralization present a set of advantages and drawbacks depending on the type of waste material being evaluated and the type of soil where it will be applied (Bundy and Meisinger, 1994). Field estimates, while more realistic, suffer from more variability because it is not possible to control many of the environmental variables. On the other hand, laboratory experiments have been designed to establish chemical indices that can help estimate the amount of N that may be available for crop uptake after the application of organic wastes (Gordillo and Cabrera, 1997).

Soil nitrification is a complex process affected by several factors and their interactions. The main factors are NH_4^+ supply, population of nitrifying organisms, soil

pH, aeration and moisture and temperature (Havlin, et al., 1999). In the laboratory, homogenization of the sample will minimize the variability, assure similar micro-organism populations, similar NH_4^+ base line and soil pH at the beginning of the trials. In addition, environmental conditions are controlled by using growth chambers with fixed temperature and generally maintaining basic soil moisture content by adding water when necessary (Haddas, et al., 1996; Gordillo and Cabrera, 1997).

In the laboratory, aeration of the soil sample depends on the type of container used. Under controlled conditions, different types of containers have been used such plastic bags with holes (Gordillo and Cabrera, 1997; Qafoku, et.al., 2001; Tyson and Cabrera, 1993) polyethylene cups (Bitzer and Sims, 1988), glass bottles (Chae and Tabatabai, 1986), glass mason jars (Gagnon and Simard, 1999) and pots to determine the effects of aeration. (Qian and Schoenau, 2002).

In addition, the ratio of poultry manure or poultry litter to soil can be varied in laboratory incubation trials to estimate variations in N mineralization. Common N rates used were between 150 and 200 kg ha⁻¹ (Ganon and Simard, 1999; Bitzer and Sims, 1988; Gordillo and Cabrera, 1997). Rarely the poultry litter applications were at levels upwards of 50 Mg ha⁻¹ (Chae and Tabatabai, 1986). The amount of a soil sample varied from 20 (Chae and Tabatabai, 1986) to 30 g (Castellanos and Pratt, 1981) to 800 g (Gordillo and Cabrera, 1997).

Although some research reports have addressed the mineralization process of poultry manure and poultry litter (Bitzer and Sims, 1988; Castellanos and Pratt, 1981; Chae and Tabatabai, 1986; Gagnon and Simard, 1999; Hadas, et al., 1996; Qian and Schoenau, 2002), little consideration has been given to the mineralization process where

higher rates of poultry litter have been applied to soils. To describe the movement of nitrate through the soil profile, simple simulation models have become the tool of choice for decision-makers (Pennell, et al., 1990). Therefore, improved estimates of rate variables controlling mineralization could significantly enhance the reliability of simulation models.

The objective of this research is therefore to determine the mineralization rates as influenced by different poultry litter application rates in sandy soils in laboratory columns and to generate mineralization indices that can be used with N-transformation simulation models.

Materials and Methods

Surface soil sample (0-10 cm) was collected during the spring of 2003 from a field planted to Bahia grass pasture where poultry litter was land applied for over 20 years. The soil sample was obtained from three areas of 1 m² selected randomly. Three samples were obtained by digging with a shovel after the removal of Bahia grass from the surface and were consolidated into one uniform sample. The field is located in the Suwannee County, Florida where the soil is a loamy, silicious, thermic, Arenic Paleudult (Carlisle et al., 1989). The soil samples were transported in iceboxes to the laboratory, air dried, mixed and sieved to pass a 2 mm screen and stored at 4°C. A sample of the homogenized soil was sent to the IFAS ARL for determination of pH, organic carbon, TKN, NO₃-N and NH₄-N as per the standard procedures (Mylavarapu and Kennelly, 2002). Physical characterization methods are depicted in Chapter 2 and the soil characteristics are shown in Table 4.1.

Table 4.1 Selected chemical and physical characteristics of the soil

Characteristic	Status
pH	5.92
Organic Carbon g kg⁻¹	18.6
Total N g kg⁻¹	1.05
NO₃-N mg kg⁻¹	1.74
NH₄-N mg kg⁻¹	3.62
Sand g kg⁻¹	840
Clay g kg⁻¹	44
Bulk Density Mg m⁻³	1.51
C:N Ratio	17.7

Multiple poultry litter samples were collected in polyethylene bags directly from the houses two days after bird removal and were stored in iced filled coolers during transportation to the laboratory where the samples were stored at 4°C until further use.

The main inert component of the poultry litter was wooden shavings. To guarantee the homogeneity of the poultry litter samples, particles >15 -mm were removed before the grinding process. The poultry litter was then homogenized ground and sieved (< 0.2 mm). The characteristics of the poultry litter are in the Table 4.2.

Table 4.2 Selected chemical and physical characteristics of the poultry litter

Characteristic	Status
pH	8.6
Ash, mg kg⁻¹	97,069
Total N, mg kg⁻¹	26,688
Ammonia N, mg kg⁻¹	4,068
Total P, mg kg⁻¹	11,375
Total K, mg kg⁻¹	17,518

An incubation experiment was established to evaluate 8 treatments of poultry litter application including a control (without any litter application) and 7 treatments of 1, 2, 3, 4, 5, 6 and 7 g of poultry litter on 450 g of soil corresponding to land applications of 3, 6,

9, 12, 15, 18 and 21 Mg ha⁻¹ respectively, which amount to an equivalent of total applications of 84, 168, 252, 337, 421, 505 and 589 kg of N ha⁻¹ respectively. These poultry litter rates are common values used in the poultry litter spread areas of north Florida.

Glass jars containing the mixture of soil and homogenized manure were incubated at 30°C during the 60 days of our study. The treatments were arranged in an experimental design of 8 treatments and 4 complete randomized blocks. Samples from the incubated soils were taken at 1, 2, 3, 5, 7, 10, 15, 20, 30, 45 and 60 days. The samples were mixed daily to avoid anaerobic conditions. Original moisture content was maintained throughout the study by adding water as necessary.

Concentrations of inorganic soil N forms were determined in the samples prior to treatment application, at each sampling date and at the end of the incubation period. Nitrate-N and NH₄-N were extracted with a 0.01N KCl (1:6 w/v ratio), and were determined by an Alpkem FlowSolution IV Autoanalyzer. Total N was determined for the soil samples before the application of the treatments and at the end of the incubation period by a standard Kjeldahl procedure (Mylavarapu and Kennelly, 2002).

Mineralized N was considered as the sum of NO₃-N and NH₄-N. Net N mineralized from the applied poultry litter was determined as the difference between the mineral N content in each poultry litter rate treatment and the mineral N content in the control treatment (Tyson and Cabrera, 1993; Hart, et al., 1994; Schaffers, 2000).

The ratio of organic to mineralized N was obtained by dividing the net N mineralized by the N initially added through the poultry litter (Bitzer and Sims, 1988).

To establish the N mineralization potential and the rate constant of mineralization, the model of N pool and first order rate constant was used (Smith, et al., 1980):

$$N_m = N_o [1 - e^{(-kt)}] \quad 4.1$$

-where N_m is the amount of N mineralized at a specific time t , N_o is the maximum percentage of organic N that is mineralizable, and k is the rate constant of mineralization. The NLIN procedure of SAS (1999) was used to estimate the parameters N_o and k . The estimated parameters were evaluated by ANOVA to establish differences between poultry litter treatments. The N pool model has been used in different studies with success and has been demonstrated to describe accurately the process of mineralization (Chae and Tabatabai, 1986; Gordillo and Cabrera, 1997; Tyson and Cabrera, 1993)

Results and Discussion

Organic carbon and TKN levels found in the soil from the poultry litter spread area showed the effects of a long term poultry litter application (Table 4.1). The accumulation of both the Organic carbon and TKN observed at the experimental site was the effect of continuous application of organic amendment and the pasture crop. Similar soils in Suwannee County (Calhoun, et al., 1974) under crop production but without organic amendments have lower organic content (7.0 g kg^{-1}) and lower TKN (0.4 g kg^{-1}).

A soil bulk density value of 1.51 Mg kg^{-1} obtained at the site (Table 4.1) was slightly below the previously published value for these soils (Carlisle, et al., 1989). Long-term addition of poultry litter to this site probably lowered the bulk density, in spite of high sand content of these soils.

Generally a C:N ratio greater than 30 will result in a net immobilization and a ratio lower than 18 will result in a net mineralization (Havlin, et. al., 1999). A C:N ratio of the soil at our study site was found to be 17 which was comparable with the values reported

in other studies (Hadas, et al., 1996; Qian and Schoenau, 2002) and should favor mineralization of N after poultry litter application.

The pH of the poultry litter was alkaline in reaction at 8.6 (Table 4.2) and the TKN values were found to be 26,688 mg kg⁻¹ (Table 4.2). Both values were comparable with the values reported in literature at other similar sites (Bitzer and Sims, 1988; Chae and Tabatabai, 1986; Gagnon and Simard, 1999; Qin and Schoenau, 2002). Accumulation of total mineralized N was observed in all the treatments during the 60 days incubation (Fig. 4.1). The process typically started with a small increase of inorganic N during the first three days followed with a big flush of mineral nitrogen between the 3rd and the 5th days. During this first phase of the flush, the treatments started to differentiate from the control treatment. The high C soil content could explain the fast initial production of mineralized N favoring net mineralization due to lower C:N ratio. Similar results were obtained by Tyson and Cabrera (1993) during the first week of incubation. The rapid release of mineralized N at that time could be a primary potential source of nitrate pollution if plants are not actively growing able to use these inorganic forms.

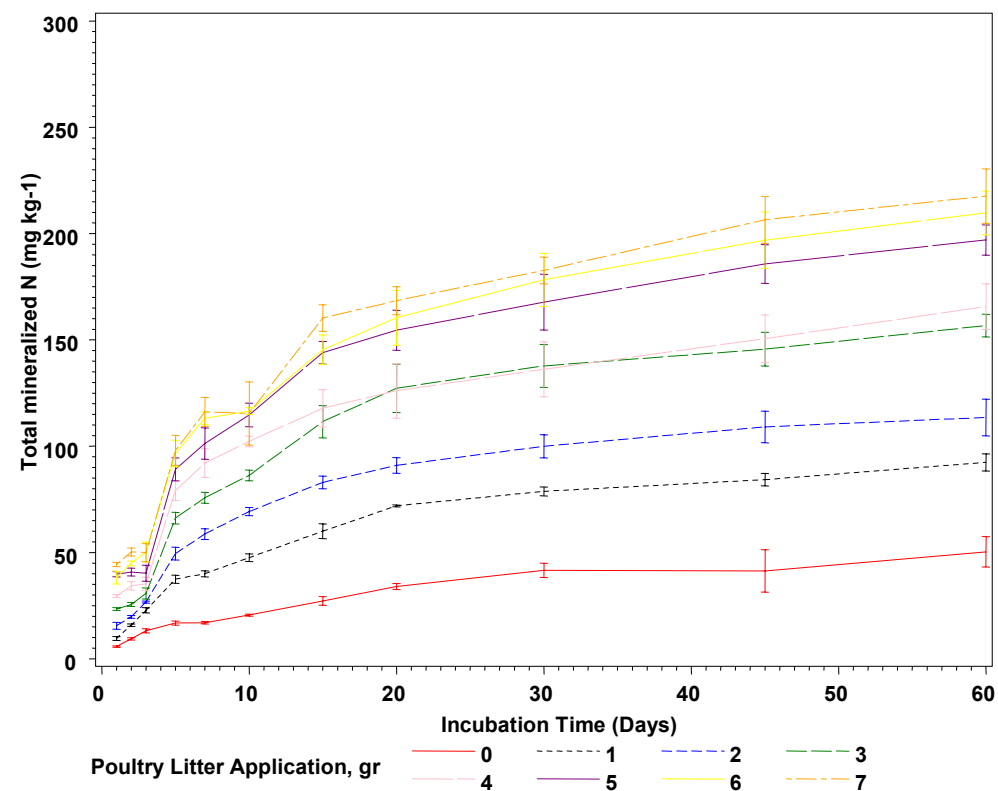


Figure 4.1 Nitrate accumulation under 8 rates of poultry litter in an Ultisol during 60 days of incubation.

The initial flush in mineralized N is followed by a slower production of mineralized N from the 5th up to the 20th day of incubation. Treatments with higher poultry litter rates showed steepest increase compared to treatments that received 1 or 2 g. of poultry litter. Tyson and Cabrera (1993) observed the steepest increase occurring during this second phase that stopped around 30 days of incubation.

The last period of incubation from the 20th day up to the end is distinguished by a slow down in accumulation of mineralized N in the soil. Probably some factors such as water availability and oxygen controlling the mineralization process are not at optimum levels for all the treatments and due to the limited amount of soil.

The accumulation of mineralized N continued during the first 60 days similar to the nitrate flush observed after 60 days of the poultry litter application in a study in soils under corn production (Cooperband, et al., 2002).

The variability in amounts of mineralized soil N increased with the increased length of incubation period. As many factors have been recognized to influence the mineralization process (Castellanos and Pratt, 1981), the relative importance of each of these factors can change during the process resulting in increased variability observed. Previous experimental results measured lower N mineralized variability with other organic amendments such as composts and cattle manure compared to poultry litter (Qian and Schoenau, 2002). The composting process is at the same time decreasing the mineralized N and improving the homogeneity of the product. On the contrary, curing and homogenizing is not possible when the poultry litter is removed from the poultry houses and applied directly to the ground.

The mineralization process in the incubated soil is depicted in the Figure 4.2. A higher mineralization rate was observed at the 5th day of incubation. Treatments with higher poultry litter application mineralized higher amounts of N. Tyson and Cabrera (1993) found a similar tendency, working with Udupts from Georgia, but the absolute values of total inorganic N in samples with around the same manure application were higher than our findings. Gagnon and Simard (1999) observed the similar results of higher net mineralization during the first weeks of incubation on sandy Podzols from Quebec. Bitzer and Simms (1988) during the first 14 days of incubation reported values closer to our absolute values. The previous soil management can be an important factor to determine differential responses to the same application rates of poultry manure. In our case, the field had been receiving poultry litter applications for >20 years.

A slower mineralization process was observed after the 5th day up to 45 days of incubation. The slower process has been reported in other studies and the ratio C:N is cited as the main reason (Tyson and Cabrera, 1993; Qian and Schoenau, 2002).

After the 5th day of incubation, the behavior of mineralization was dependent on the treatments. When 1 and 2 grams of poultry litter were applied to the soil, net mineralization occurred until 45 days of incubation. After 45 days, a net immobilization process was observed. The immobilization process can occur when the C:N ratio is too high as a consequence of two processes: a net increase of carbon in the media resulting from application of plant residues or the exhaustion of the nitrogen source (Havlin, et al., 1999).

Percentage of N mineralized from the N applied as poultry manure after 60 days of

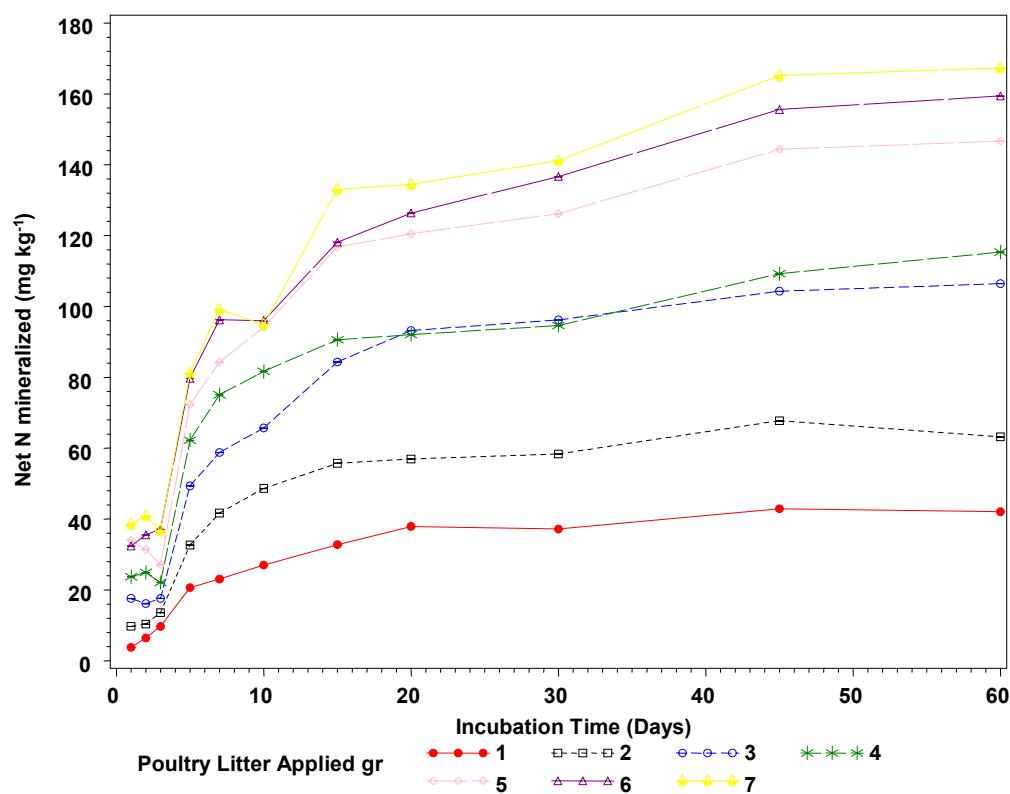


Figure 4.2. Net mineralized N under 8 rates of poultry litter in an Ultisol during 60 days of incubation.

incubation were comparable with previous values reported for similar incubation experiments (Tyson and Cabrera, 1993; Chae and Tabatabai, 1986). Treatments with 3 g or less of poultry litter rates were able to mineralize more than 50% of the nitrogen applied in the poultry litter (Figure 4.3).

The parameters estimated using the N pool model are given in the Table 4.3. The rate constant of mineralization, k is lower in all the treatments than other values reported in the literature for poultry litter (Tyson and Cabrera, 1993). However, similar values of k were reported in Hapludalfs of Iowa (Chae and Tabatabai, 1986). The fact there was a negligible variation in k values observed in our experiment showed the high dependence between k and the soil characteristics.

Table 4.3 Nitrogen mineralization potential (No) and rate constant of mineralization (k) for 7 poultry litter rates incubated in a sandy soil of north Florida.

Treatment poultry litter weigh, gr	No, % Mineralizable N pool	k, d⁻¹ rate constant of mineralization
1	70.7 a ¹	0.12 a
2	52.7 ab	0.14 a
3	57.3 ab	0.12 a
4	44.1 ab	0.17 a
5	46.5 ab	0.13 a
6	41.2 ab	0.13 a
7	37.4 b	0.13 a

¹ Means followed by the same letter are not significantly different according to Tukey at $\alpha=0.05$ probability level.

The N available for mineralization generally increases with a corresponding increase in poultry manure rates but our model showed a decrease in the mineralizable N pool as the poultry manure rate increased. During the process of mineralization the microorganisms generate significant amount of CO₂ (Fuhrmann, 1999). Poultry litter applied to the soil surface had shown significant production of CO₂ as a result of the

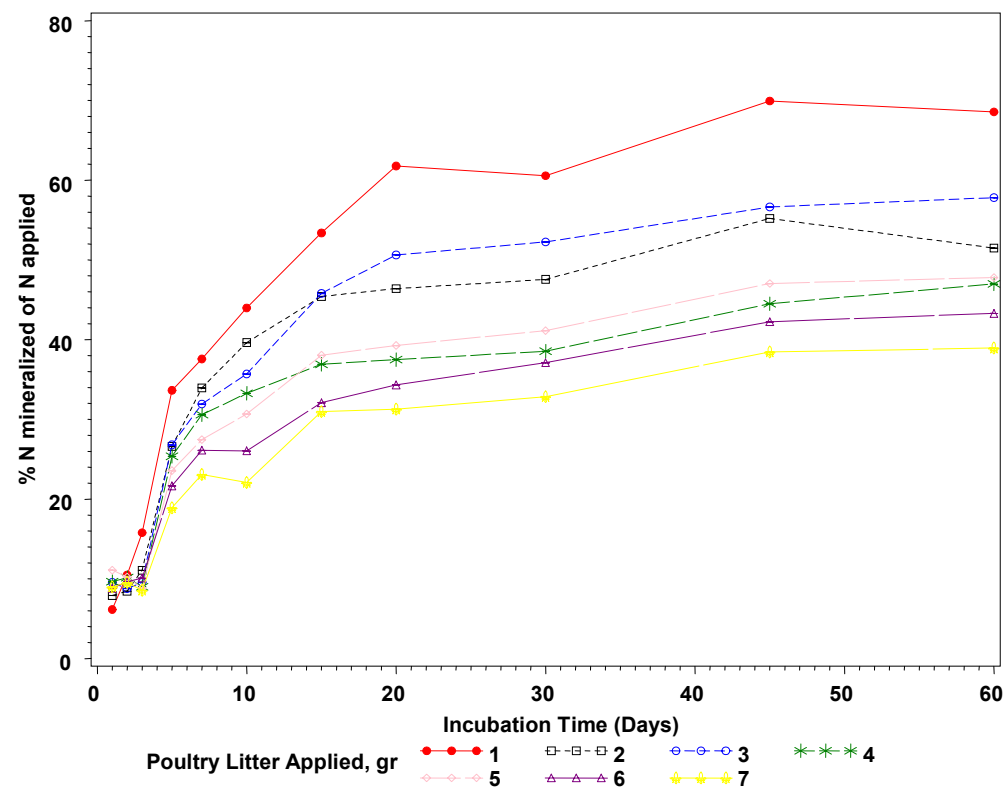


Figure 4.3. Percentage of N mineralized as fraction of N applied from the poultry litter.

respiratory activity of the decomposing microorganisms (Adams, et al., 1997). The respiratory activity not only increases the CO₂ concentration but at the same time consumes O₂ increasing the opportunity for anaerobic conditions. In our study, opportunities for anaerobic conditions to develop were minimal because the jars were opened and stirred well once a day during the entire experimentation period. In the treatments that received higher poultry application rates, anaerobic conditions could explain the lower N mineralization potentials.

For treatments with higher litter rates, the mineralized N was not higher than 40%. Imbalances created by the massive application of poultry manure in different soil indices and the absence of fresh C resources to the system can explain the results obtained.

At the end of the incubation period, the concentration of H⁺ in treatments with more than 4 g of poultry litter were between 63 to 35% of the control treatment, suggesting that at least up to 60 days the application of the poultry litter the pH of the soil increased (Table 4.4).

Treatments receiving 3 g of poultry litter or less decreased or increased slightly the concentration of H⁺. More extensive changes have been observed in other reports (Tyson and Cabrera, 1993). Prior management of the fields from which samples were obtained and incubated has a significant influence on the soil pH. Same soils under natural vegetation with none or small human disturbance, under the same soil taxonomy classification have lower pH levels below 5 (Carlisle, et al., 1989).

Table 4.4 Soil pH after 60 days of incubation for eight rates of poultry litter application

Homogenized Poultry Litter Application		N	pH¹
gr (450 gr soil)⁻¹	Mg ha⁻¹	Kg ha⁻¹	
0	0	0	5.28 a
1	3	84	5.29 a
2	6	168	5.35 a
3	9	252	5.52 a
4	12	337	5.66 a
5	15	421	5.71 a
6	18	505	5.78 a
7	21	589	5.28 a

¹ Means followed by the same letter are not significantly different according to Tukey at $\alpha=0.05$ probability level.

CHAPTER 5 SCENARIOS

Introduction

Using observed events under reasonable, simulated conditions to design interventions to help avoid potential future problems can be a very valuable technique (Godet, 1987). In natural sciences, the scenarios technique has been used to analyze the progression of green house effect and gas emissions (Alcamo and Nakicenovic, 1998), to prioritize research in water resources (Arnell, 1999) and to evaluate the effects of world deforestation process (Leemans, et al., 1996). In farm management, the scenarios technique has been used as a tool to forecast the potential impacts of certain cultivation practices on future production and the consequences for the environment (Olson, 2004).

Scenarios technique is defined as a coherent sequence of assumptions developed from observed, actual conditions to attempt to predict probable future results or events. (Godet, 1987). According to Alcamo (2001), typical features of a scenario include: i) description of progressive changes or steps which a given variable is likely to undergo over a specific period of time and the representation of those changes by graphs or diagrams, ii) driving forces behind the changes (the most important factors that control the changes), iii) the initial time and conditions (Base year), iv) the final year of the proposed scenario or the time horizon, and the time steps or schedules for the frequency of observations established to monitor the process, and v) the Storyline. The description of the changes observed during the simulation of the scenarios.

The application of poultry litter as a source of nutrients for pastures is a common practice in different areas of the USA (Sims and Wolf, 1994). However, there is evidence that such a practice can increase the risk of groundwater contamination (Edwards and Daniel, 1992). The scenarios technique can be profitably utilized to estimate the level of environmental risk and to recommend practices to reduce it.

The objective of this study was to evaluate the scenarios technique as a tool for the assessment of nitrate pollution risk resulting from the application of poultry litter in a north Florida Ultisol. Under such a scenario, the rate of litter application, the weather conditions and the soil physical and chemical characteristics constitute the primary driving forces. The rate of application is a predictable variable because it is part of the BMP directly based on the local Landgrant University soil testing program guidelines. The soil properties are constant and are directly related with the position of the landscape. The weather is however both uncertain and not predictable.

Materials and Methods

To develop the scenarios for poultry litter application on pastures, an area where poultry litter has been land applied for over 20 years in the Suwannee County was selected. Physical characteristics, nitrate, ammonium and organic carbon content were determined by boring three different profiles at the site to establish the background levels (baseline) for the scenario for the selected area. Results from the soil characterization study were summarized in Chapter 3.

Water retention curves (WRC) were determined in the laboratory with undisturbed soil samples, using Tempe Cells. The information obtained was used to determine the parameters a and b of the Hutson and Cass (1987) modification of the Campbell's water retentivity model (Chapter 3) to describe water retention and movement in the soils.

Also, particle size analysis, bulk density and saturated hydraulic conductivity were obtained in the laboratory using the same samples used to determine the WRC.

Soil samples collected were every month for 12 months starting October 2002, at the same points selected previously to evaluate the changes in NO_3^- and NH_4^+ . The samples were transported in a cooler with ice to avoid changes in soil N and refrigerated until further analyses. Nitrate and NH_4^+ were extracted using a solution of KCl of 0.01 N (soil: solution 10:1) and the concentrations were determined with an AlpKem FlowSolution IV Autoanalyzer (Mylavarapu and Kennelly, 2002). Gravimetric soil-water content was determined for each soil layer during the sampling period. Nitrate and ammonium values were adjusted for soil moisture.

LEACHM

We identified that a period of 50 years was appropriate time duration for applying our technique that would yield realistic results on solute movement under standard agricultural management practices. To describe step-wise changes over the period of 50 years, we selected LEACHM simulation model that describes the movement of nutrients through the soil profile (Hutson, 2001).

LEACHM has been recognized as a model with widely accepted algorithms (Johnson, et al., 1999) and has been used in different parts of the world to: evaluate soil salinity over shallow water tables in California (Ali, et al., 2000); predict fertilizer nitrogen requirements (Campbell, et al., 1995); nitrate-N leaching under different tillage systems in Quebec (Dodds, et al., 2000); describe the fate of nitrate and bromide under citrus production in Florida (Paramasivam, et al., 2002), evaluate pesticide fate in orange groves in Florida (Pennell, et al., 1990) and to evaluate the effect of irrigation on nitrate

leaching from crop production in Turkey (Ünlü, et al., 1999). It is a deterministic process-based model that describes the water regime, the chemistry and transport of solute in unsaturated or partially saturated soils to a depth of about two meters (Hutson and Wagenet, 1992).

LEACHM is the acronym for “Leaching Estimation and Chemistry Model” (Hutson, 2001). The model is divided into four modules: 1) LEACHN- describes N and P transport and transformation; 2) LEACHP- simulates pesticide displacement and degradation; 3) LEACHC- describes transient movement of inorganic ions, and 4) LEACHB- describes microbial population dynamics in the presence of a single-support substrate.

In our study, only the LEACHN module was used for simulations of nitrate movement in soil type at the study site.

The results obtained from LEACHN simulation were analyzed using the Chi square test to determine the frequency distribution of soil nitrate content at the end of each year. The cumulative nitrate concentrations in the drainage at the end of 2nd, 10th, 20th, 30th, 40th and 50th years of simulation were analyzed using ANOVA procedures. Response surfaces were generated to graphically evaluate the patterns of nitrate accumulation in the soil (SAS, 1999).

For ANOVA, while specific scenarios formed the treatments, the three observation profiles in the experimental area formed the three replications.

Hydrology

LEACHN solves the transient water flow problems using a finite-difference form of the Richards' equation:

$$\partial\theta / \partial t = \partial[K(\theta) \partial H / \partial z] / \partial z - U(z,t) \quad 5.1$$

-where θ is the water volumetric content ($\text{m}^3 \text{ m}^{-3}$), H is the hydraulic head (mm), K is the hydraulic conductivity (mm d^{-1}), t is the time (d), z is depth positive downwards (mm) and U is a sink term representing water lost per unit time by transpiration (d^{-1}).

Evapotranspiration is an important factor in defining the ‘ U ’ term. LEACHN calculates the daily potential evapotranspiration following the methods of Childs and Hanks (1975):

$$ET_{\text{day}} = (f_{\text{crop}} * ET_{\text{week}}) / 7 \quad 5.2$$

-where ET_{day} is daily potential evapotranspiration, f_{crop} is a crop factor and ET_{week} is total weekly potential evaporation. LEACHN requires total weekly evapotranspiration for the period of simulation, starting the first day of the simulation.

LEACHN uses the functions for water content, pressure potential and hydraulic conductivity based on Campbell (1974) where the pressure potential ‘ h ’ is:

$$h = a(\theta / \theta_s)^{-b} \quad 5.3$$

-where θ is the actual water content, θ_s is the volumetric water content at saturation and a and b are constants. The equation is exponential and is discontinuous at $h = a$ and $\theta / \theta_s = 1$.

The Campbell’s original equation was modified by Hutson and Cass (1987), converting the exponential function to a parabolic function for the discontinuity area for potentials between zero and h_c .

$$h = [a(1-\theta/\theta_s)^{1/2}(\theta/\theta_s)^{-b}] / [(1-\theta/\theta_s)^{1/2}] \quad 5.4$$

-where h_c is the point of intersection of the exponential and parabolic curves, and,

$$h_c = a[2b/(1+2b)]^{-b} \quad 5.5$$

and

$$\theta_c = 2b \theta_s / (1+2b) \quad 5.6$$

The hydraulic conductivity is related with water content based on the Campbell's capillarity model:

$$K(\theta) = K_s(\theta_s \theta_s)^{2b+2+p} \quad 5.7$$

-where $K(\theta)$ is the hydraulic conductivity at volumetric water content θ , K_s is the hydraulic conductivity at saturation and p is a pore interaction parameter.

Solute Movement

Chemical fluxes are estimated in LEACHM using a numerical solution to the convection diffusion equation. The diffusion flux density in aqueous and gas phases is represented by Fick's law:

$$J_D = -D_o \, dc/dz \quad 5.8$$

-where J_D is diffusion flux density, D_o is the appropriate molecular or ionic diffusion coefficient ($\text{mm}^2 \text{d}^{-1}$) in aqueous solution or in air and c is the chemical concentration (mg dm^{-3}).

The total amount of substance (c_T) contained in the solution, sorbed and gas phases in a soil volume of 1 dm^3 are:

$$c_T = \rho c_s + \theta c_L + \varepsilon c_G \quad 5.9$$

-where ρ is the soil bulk density (kg dm^{-3}), ε is the gas filled soil porosity and c_G is the gas phase pesticide concentration; for non-volatile substances c_G is zero.

Almost all the movement of chemicals in soil occurs under non-steady water flow conditions. Under those conditions, the water content θ and water flux q both vary with depth and time. Using continuity relationships of mass over space and time gives:

$$\partial c_T / \partial t = -\partial J_s / \partial z \pm \Phi \quad 5.10$$

-where J_s is total solute flux ($\text{mg m}^{-2} \text{ day}^{-1}$) and Φ represents the unspecified sources or sinks of solute. Then the general transport equation can be expressed as:

$$\partial c_L / \partial t (\theta + \rho K_d + \varepsilon K_H) = \partial [\theta D(\theta, q) \partial c_L / \partial z - q c_L] / \partial z \pm \Phi \quad 5.11$$

-where c_L is the concentration of chemical in the solution (mg dm^{-3}), t is time, θ is volumetric water content ($\text{m}^3 \text{ m}^{-3}$), K_d is the distribution coefficient ($\text{dm}^3 \text{ kg}^{-1}$), K_H is the modified Henry's law constant, q is the macroscopic water flux and ρ is soil bulk density (kg dm^{-3}).

Nitrogen Transformation

LEACHN uses the Johnson et al, (1987) approach to represent transformations and fluxes of N, between three organic pools (visualized easily degradable feces, residue and relatively more stable humus fraction), and mineral NH_4^+ and NO_3^- .

The decomposition of organic products liberating N or mineralization is following a first order kinetic function:

$$\partial C / \partial t = -\mu_{mi} C_i \quad 5.12$$

where C_i represents the concentration of humus residues or feces, and μ_{mi} are the first order rate constants.

The conversion from NH_4^+ to NO_3^- is:

$$\partial \text{NH}_4^+ / \partial t = -\mu_{nit} \max(0, (\text{N}_{\text{NH}_4} - \text{N}_{\text{NO}_3} / r_{\max})) \quad 5.13$$

where $-\mu_{nit} \text{N}_{\text{NH}_4}$ is a potential rate, decreasing as a maximum $\text{NO}_3^- / \text{NH}_4^+$ concentration ratio $r_{\max}$.

Nitrification, reduction of NO_3^- to gaseous N, follows the Michaelis-Menten kinetics:

$$\partial N_{NO_3} / \partial t = -\mu_{denit} N_{NO_3} (z) / (N_{NO_3} (z) + c_{sat}) \quad 5.14$$

-where $-\mu_{denit}$ is a potential rate of denitrification and c_{sat} is the half-saturation constant.

Crops

LEACHM is not a crop model but includes some features related with the ability of plants to uptake nutrients. The user has the option to input the N plant uptake, the phenological development of the crop and the rooting depth. The crop cover is calculated by the sigmoidal curve:

$$\text{Crop cover} = (\text{Crop cover at maturity}) / 1 + \exp[6-(12t_i/t_2)] \quad 5.15$$

-where t_i is time elapsed since germination and t_2 is total time between germination and plant maturity.

Validation

The validation of the model was performed by comparing the water content observed in the field against the predicted values from LEACHM (Lidon, et al., 1999). Two statistics were used to test the goodness of fit of the model:

1) The mean absolute error MAE:

$$MAE = [1/N] \sum_{i=1}^N |P_i - O_i| \quad 5.16$$

Where N is the number of samples, P_i is the predicted value for the i^{th} member of the group and O_i is the observed value for the i^{th} member of the group.

2) The root mean square error:

$$RMSE = [1/N \sum_{i=1}^N (P_i - O_i)^2]^{1/2} \quad 5.17$$

Scenarios

The scenarios were organized by practices of fertilization or changing physical or meteorological characteristics. Weather data for the 50 years duration at the

meteorological station of Mayo, Florida, located near our experimental area was obtained from the National Climatic Data Center (NOAA, 2004).

Each scenario was performed using a total of 50 years at 10 year time intervals. Each consecutive period of 10 years used the results from the previous 10-year period as initial conditions.

The last day of each year simulated was used to evaluate the changes in soil nitrate and the accumulative nitrate in the drainage observed during that year.

Amendments

Scenarios were designed to evaluate recommended N application rates for Bahia grass and to estimate the effect of high rates of poultry litter applications (spread in one, two or four applications per year). An additional scenario was designed to compare the effect of application of an additional 50 kg ha⁻¹ year⁻¹ of ammonium nitrate along with the prescribed litter application of the poultry litter, which is a common practice to give an early boost to crop growth in late spring. The scenarios are depicted in the Table 5.1.

Table 5.1 Scenarios for amendments application.

Scenario	#	Treatments
N rates	1	1) 50 kg N from poultry litter 2) 100 kg N from poultry litter 3) 160 kg N from poultry litter
N rates + 50 kg N from ammonium nitrate	2	1) 50 kg N from poultry litter + 50 kg N from ammonium nitrate 2) 100 kg N from poultry litter + 50 kg N from ammonium nitrate 3) 160 kg N from poultry litter + 50 kg N from ammonium nitrate
1000 kg N from poultry litter	3	1) One application on April 2) Split into two applications: April and May 3) Split in four applications: April, May, July and August

Sequence Dry -Wet Years

The purpose of this scenario is to show the effect of rainfall on the nitrate leaching and its interaction with the litter application rate.

The weather data obtained from the Mayo station for the 50-year duration was divided into two alternate sequences of 5 rainy years and 5 dry years. Similar to other treatments, these results were also compared with the low BMP, 50 kg ha⁻¹ poultry litter application. The average precipitation for dry years was 1,138 mm year⁻¹ and for wet years was 1,553 mm year⁻¹.

A factorial design was selected to analyze the data. Two main factors were evaluated: 1) weather conditions- sequence of dry-wet years and the real weather pattern during these years, and 2) rates of poultry litter in terms of N applied per year- 50, 100 and 160 kg ha⁻¹.

Sandy profile

An entirely sandy profile was constructed by replacing the clay layers in each profile with the same sand layer immediately before the clay layer in each profile. For the first profile, the new profile retained the first three layers from the original profile and the fourth layer was then repeated 12 times; for profiles 2 and 3, the new profile retained the first four layers from the original profile and the fifth layer of sand was repeated 11 times.

A factorial design was used to analyze the information generated. Two main factors, the type of soil and the poultry litter application were used. The levels in the soil type were the original sand-clay profiles and the new sandy profiles obtained. The levels in the poultry litter application were 50, 100 and 160 N kg ha⁻¹ year⁻¹.

Results and Discussion

Validation

The results for the validation are shown in the Table 5.2 and in the appendices A.1 to A.6. LEACHN predicted the water content with reasonable accuracy observed in the field. The prediction was better for the surface layers than for the deeper layers. Also the predictions were better for Points 1 and 2 than for Point 3. The water content in the deeper layers was possibly over-estimated by the model. Previous studies also documented a few difficulties in validating LEACHN for soil water regime. Ramos and Carbonell (1991) were not able to control the water flow on European soils. On Georgia soils, Johnson et al. (1999) also needed to adjust the initialization values to improve the LEACHM prediction.

Table 5.2 Mean absolute error (MAE¹) and root mean square (RSME¹) for the LEACHM water regime prediction for an Ultisol of North Florida.

Depth cm	Point 1		Point 2		Point 3	
	MAE	RSME	MAE	RSME	MAE	RSME
5	.06	.08	.06	.07	.06	.08
15	.04	.05	.05	.08	.09	.12
25	.03	.04	.09	.11	.02	.03
35	.03	.04	.04	.04	.05	.07
45	.10	.12	.02	.03	.01	.01
55	.16	.19	.16	.20	.08	.10
65	.11	.14	.17	.19	.07	.10
75	.10	.11	.01	.01	.10	.13
85	.11	.13	.01	.03	.14	.17
95	.12	.15	.07	.08	.15	.17
105	.14	.16	.15	.17	.11	.13
115	.14	.17	.09	.11	.10	.13
125	.14	.17	.17	.20	.08	.10
135	.11	.13	.20	.23	.14	.16
145	.15	.18	.11	.16	.08	.10

¹ Lower values for both MAE and RSME indicated higher proximity between the calculated value and the observed values.

Scenarios

Although LEACHM was used to simulate processes with 100 year time horizons, (Acuttis, et al., 2000), the typical duration of simulation was 15 years or 1000 rain events (Hutson, 2001). However, to arrange long term sequences of events for long durations, a computer program or sub-routine might be used. However, in our case, the computer program we developed to arrange the data in desired sequential patterns was not completely successful in that the transitions between sequences were identifiable on the trend line. In simulations of 100 years it was also possible to identify from the results the sequences of years that were used to produce the results (Acutis et al., 2000) showing that the transition was not complete.

Amendments

Table 5.3 depicts the analysis of frequencies of soil nitrate content for the fertilizer treatments that received poultry litter and poultry litter+50 kg ha⁻¹ year⁻¹ of ammonium nitrate. The IFAS recommended rates of 50, 100 and 160 kg ha⁻¹ year⁻¹ showed significantly higher frequency in the soil nitrate levels below 10 mg kg⁻¹, confirming the N efficiencies resulting from the rates suggested. The high rate of poultry litter application, 1000 kg⁻¹ year⁻¹ of N (Table 5.3), showed significantly higher counts than the expected values according to Chi-square analysis for classes 2 and 3.

The application of additional 50 kg ha⁻¹ of N through ammonium nitrate showed significantly higher values for expected frequency of nitrate contents >10 mg kg⁻¹, even in the lower poultry litter rate of 50 kg ha year⁻¹. The application of mineral fertilizer with poultry litter rates higher than 50 kg N ha⁻¹ year⁻¹, resulted not only in a significant increase in the soil nitrate levels >10 mg kg⁻¹ but also significantly decreased the frequency of soil nitrate values <10 mg kg⁻¹. When the additional soluble N fertilizer was

used to supplement the litter application rates for a faster recovery of the bahia grass during the early spring, the potential for leaching was significantly increased..

Table 5.3 Frequency distribution of soil nitrate concentrations when N rates from poultry litter were applied alone or in combination with 50 kg ha⁻¹ year⁻¹ of N from ammonium nitrate during a 50 year simulation in an Ultisol of North Florida.

Statistic	Nitrate in the soil, mg kg ⁻¹			Total
	<=10	>10 , <=20	>20	
50 kg ha ⁻¹ year ⁻¹ from poultry litter				
Frequency	2235	15	0	2250
Expected	1674.4	441.29		
Cell chi square	187.7	411.8		
Percent	99	1		100
100 kg ha ⁻¹ year ⁻¹ from poultry litter				
Frequency	2188	62	0	2250
Expected	1674.4	441.29		
Cell chi square	157.5	326		
Percent	97	3		100
160 kg ha ⁻¹ year ⁻¹ from poultry litter				
Frequency	2098	151	1	2250
Expected	1674.4	441.3	134.3	
Cell chi square	107.2	191.0	132.3	
Percent	93	7	0	100
1000 kg ha ⁻¹ year ⁻¹ from poultry litter				
Frequency	817	609	824	2250
Expected	1674.4	441.3	134.3	
Cell chi square	439.1	63.7	3542.5	
Percent	36	27	37	100
50 kg ha ⁻¹ year ⁻¹ from poultry litter + 50 kg ha ⁻¹ year ⁻¹ N from fertilizer				
Frequency	1748	489	13	2250
Expected	1674.4	441.3	134.3	
Cell chi square	3.2	5.2	109.5	
Percent	77	22	1	100
100 kg ha ⁻¹ year ⁻¹ from poultry litter + 50 kg ha ⁻¹ year ⁻¹ N from fertilizer				
Frequency	1431	785	34	2250
Expected	1674.4	441.3	134.3	
Cell chi square	35.4	267.7	74.9	
Percent	63	35	2	100
160 kg ha ⁻¹ year ⁻¹ from poultry litter + 50 kg ha ⁻¹ year ⁻¹ N from fertilizer				
Frequency	1204	978	68	2250
Expected	1674.4	441.3	134.3	
Cell chi square	132.2	652.8	32.7	
Percent	54	43	3	100

The tendency of accumulation of nitrate in the soil with time and depth for the scenarios with the application of three IFAS rates of N through poultry litter alone and with 50 kg ha⁻¹ of N from ammonium nitrate are depicted as a Surface Response graph (Figs. 5.1 and 5.2; Figures for Points 2 and 3 are contained in Appendix B). Although for all the treatments during the period of simulation a tendency for nitrate accumulation was observed, the range of accumulation was higher for higher N applications. The addition of ammonium nitrate increased the nitrate contents both at the surface and at the bottom of the profile. Such behavior was evidently due to higher solubility and mobility of mineral fertilizer.

The estimated total concentration of nitrate in the drainage at the bottom of our 150 cm observation depth is depicted in the Figure 5.3. Higher accumulation was observed in the higher rates of poultry litter application, particularly where ammonium nitrate was added. The lower accumulation was obtained, as expected in the scenario using the lower poultry litter amendment. Point 2 had the tendency to show a higher accumulation than the other points.

The ANOVA showed that the differences between treatments were not observed during the first two years of application (Table 5.4). After 10 years of simulation the main effects were significantly different. The interaction was not significant through the period of evaluation. The addition of mineral fertilizer had a

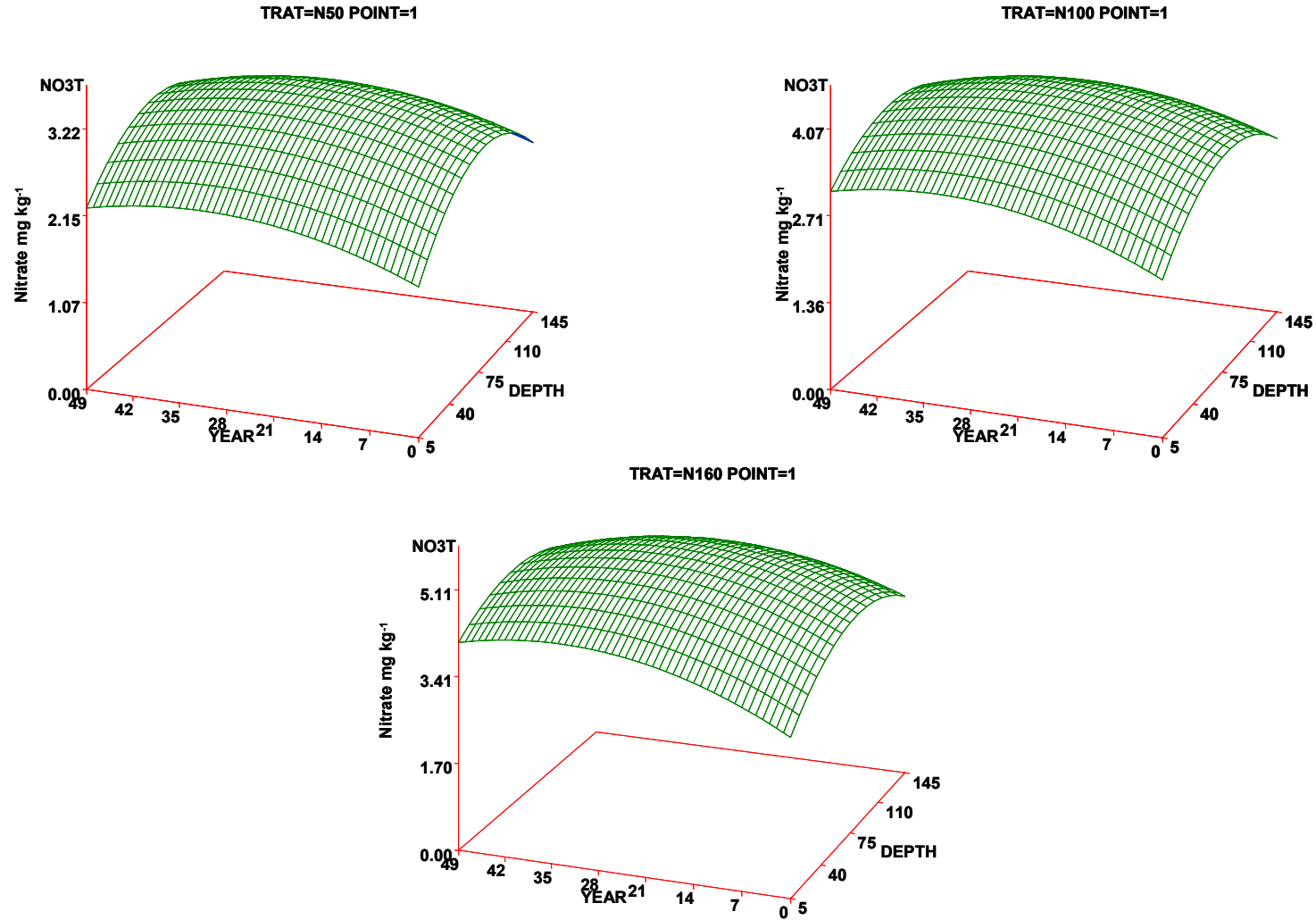


Figure 5.1 Soil nitrate (mg kg⁻¹) surface responses for 50 years of simulated scenarios receiving 50 (N50), 100 (N100) and 160 (N160) kg ha⁻¹ of nitrogen from poultry litter a Ultisol of North Florida. Point 1.

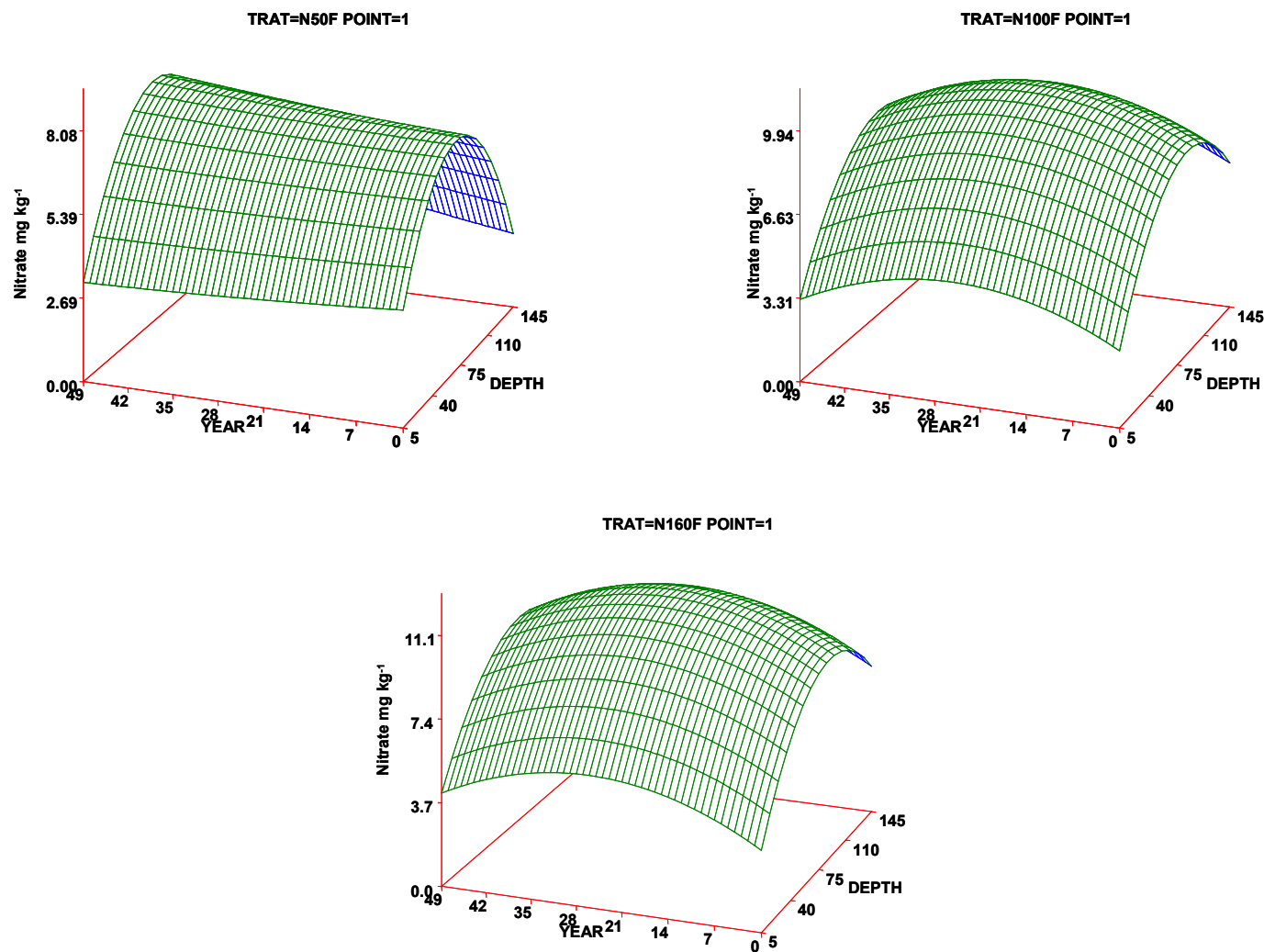


Figure 5.2 Surface responses for 50 years of simulated scenarios receiving 50 (N50F), 100 (N100F) and 160 (N160F) kg ha^{-1} of nitrogen from poultry litter and 50 kg ha^{-1} of nitrogen from ammonium nitrate in a Ultisol of North Florida. Point 1.

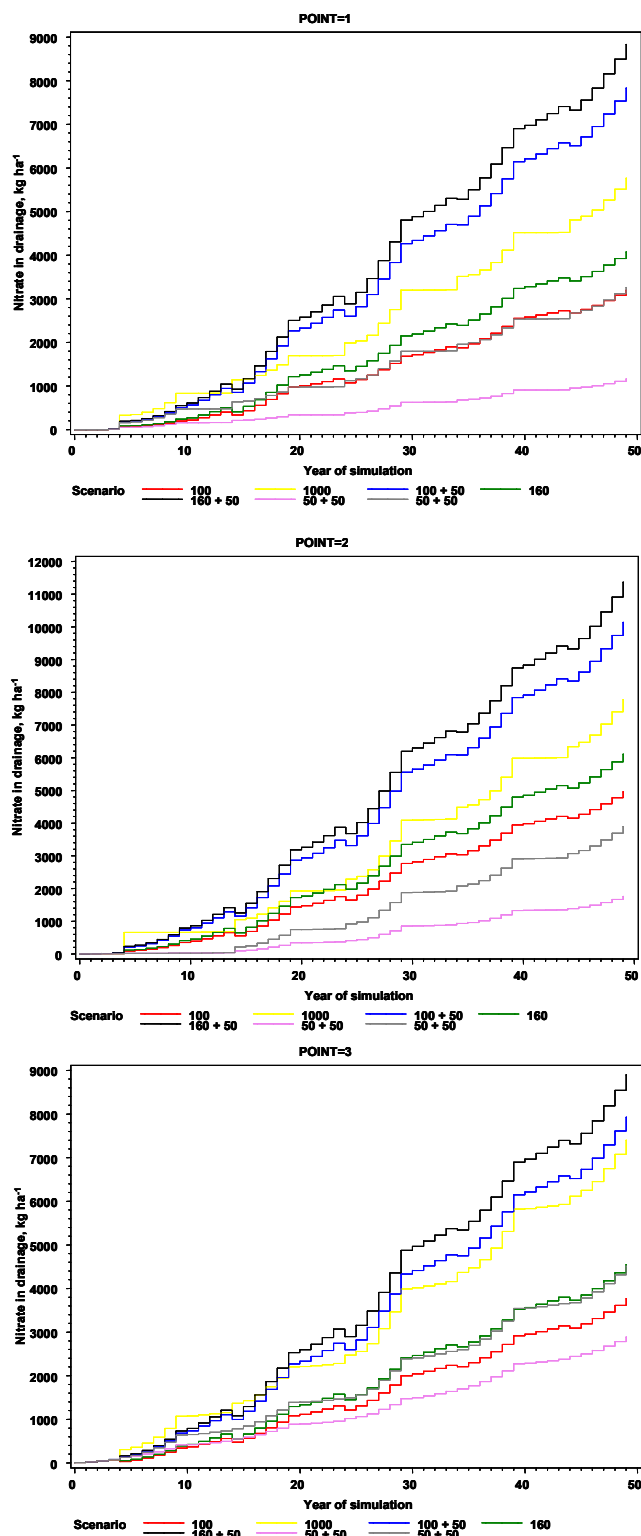


Figure 5.3 Estimated total nitrate concentrations in the drainage (kg ha⁻¹ year⁻¹) for scenarios with N doses (50, 100, 160 and 1000 kg ha⁻¹ year⁻¹) from poultry litter and N doses combined with 50 kg ha⁻¹ year⁻¹ ammonium nitrate simulated during 50 years in a Ultisol of North Florida.

strong effect on the nitrate lost in the drainage irrespective of the amount of poultry litter application. The treatment of 50 kg ha⁻¹ year⁻¹ of N from poultry litter + 50 kg ha⁻¹ year⁻¹ of ammonium nitrate was equivalent to the treatment of 100 kg ha⁻¹ N year⁻¹ coming from the poultry litter. When the same rate of ammonium nitrate was added to the treatment receiving 160 kg ha⁻¹ year⁻¹ of N from the poultry litter, the accumulated nitrate in drainage was significantly different than the same treatment without ammonium nitrate. LEACHM showed a slow response in the first few years of application for all the treatments.

Table 5.4 Significance of sources of variation for nitrogen treatments simulated in a North Florida soil.

Sources of variation	Years of simulation					
	2	10	20	30	40	50
Source of Nitrogen	NS	*	**	**	**	**
Doses of nitrogen	NS	*	**	**	**	**
Interaction	NS	NS	NS	NS	NS	NS

* values significantly different at P=0.05 according to F test; ** values significantly different at P=0.01 according to F test; NS- values not significantly different at P>0.05 according to F test

The frequency analysis for the application of 1000 kg ha⁻¹ year⁻¹ of nitrate in one, two and four applications is presented in the Table 5.5. The split of 1000 kg ha⁻¹ N year⁻¹ of from poultry litter did not improve the counts for nitrate soil values >10 mg kg⁻¹. Even one split application of the four equal doses of 250 kg ha⁻¹ year⁻¹ was considerably higher than the maximum application suggested by IFAS (Kidder, et al., 2002). The results also agreed with previous reports that estimated a maximum application rate of 9 Mg_{ha}-1 year-1 of poultry litter to avoid nitrate leaching (Simms and Wolf, 1994).

Table 5.5 Distribution analysis of the frequencies of soil nitrate when 1000 kg ha year of N from poultry litter is applied in one, two or four annual applications during a simulation of 50 years to an Ultisol of North Florida.

Statistic	Nitrate in the soil, mg kg ⁻¹			Total
	<=10	>10 , <=20	>20	
1000 kg ha-1 year-1 N, one application				
Frequency	817	609	824	2250
Expected	1674.4	441.3	134.3	
Cell chi square	439.1	63.7	3542.5	
Percent	36	27	37	100
1000 kg ha year N, splitted in two applications				
Frequency	761	560	929	2250
Expected	1144.5	436	669.5	
Cell chi square	128.5	32.3	100.6	
Percent	34	25	41	100
1000 kg ha year N, splitted in four applications				
Frequency	765	560	925	2250
Expected	1144.5	436	669.5	
Cell chi square	125.8	35.3	97.5	
Percent	34	25	41	100

The estimated total amount of nitrate in the soil when 1000 kg ha⁻¹ N year⁻¹ was applied is depicted in Figure 5.4. Poultry litter application at such a high rate increased the level of nitrate in all the soil profiles, particularly in the middle layers. The nitrate levels declined with time in all the soil layers. One reason could be the poor adjustment of the response surface model to the data from deeper layers. LEACHN was probably not able to recognize the nitrate produced when litter was applied at the 1000 kg N ha⁻¹ yr⁻¹ rate and therefore failed to adjust the corresponding nitrate leaching levels. But when the same doses were partitioned into two or four smaller applications, then nitrates started to move faster through the soil profile. Probably LEACHN was not sensitive to the amount of litter applied, particularly at the higher end. Previous reports showed work with a wide range of N doses (Khakural and Robert, 1993; Paramasivam, et al, 2002) none of the studies had N rates > 250 kg ha⁻¹.

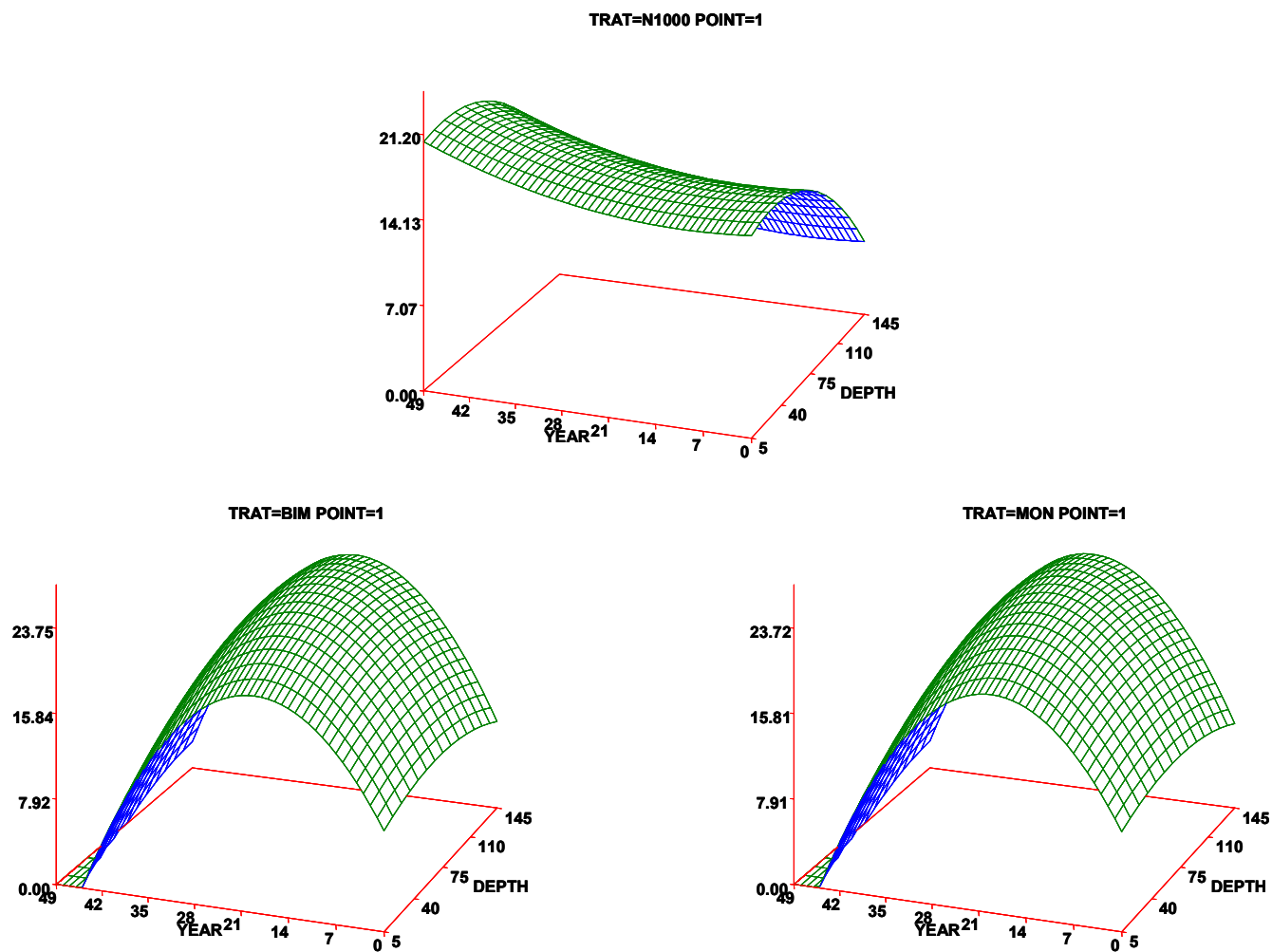


Figure 5.4 Surface responses for 50 years of simulated scenarios receiving $1000 \text{ kg ha}^{-1} \text{ year}^{-1}$ of nitrogen from poultry litter in one application (N1000) in two applications (BIM) and in four applications (MON) in a North Florida soils. Point 1.

Also work using animal manures was scarce (Jemison, et al., 1994). The doses reported were not higher than $100 \text{ kg ha}^{-1} \text{ year}^{-1}$ of N. There is a possibility that when using LEACHN for higher doses of N, a correction factor need to be developed.

Analysis of variance showed that litter application through split doses increased nitrate levels at the bottom of the 150 cm deep profile for simulation at all the times except at 2 years after the application (Table 5.6). The interaction between the main sources was not significant at any of the times evaluated.

Table 5.6 Significance of sources of variation for nitrogen treatments simulated in a North Florida soil.

Source of variation	Years of simulation					
	2	10	20	30	40	50
Source of Nitrogen	NS	**	**	**	**	**
Application split	NS	**	**	**	**	**
Interaction	NS	NS	NS	NS	NS	NS

* values significantly different at $P=0.05$ according to F test; ** values significantly different at $P=0.01$ according to F test; NS- values not significantly different at $P>0.05$ according to F test

Sequence Wet – Dry years

The results from analysis of frequencies for soil nitrate when an alternating sequence of 5 rainy and 5 dry years were simulated are detailed in Table 5.7.

The two lower rates of N, 50 and $100 \text{ kg ha}^{-1} \text{ year}^{-1}$ of N suggested by IFAS resulted even under the weather adverse conditions in either none or negligible instances of $>10 \text{ mg kg}^{-1}$ soil nitrate levels. The higher rates of N application however significantly increased the frequency of soil nitrate levels higher than 10 mg kg^{-1} as expected.

Table 5.7 Distribution analysis of the frequencies of soil nitrate when three recommended rates of nitrogen from poultry litter are applied under an alternating sequence of 5 wet and 5 dry years for 50 years of simulation in an Ultisol of North Florida.

Statistic	Nitrate in the soil, mg kg ⁻¹			Total
	<=10	>10 , <=20	>20	
50 kg ha ⁻¹ year ⁻¹ from poultry litter				
Frequency	2224	26	0	2250
Expected	2153.3	96.0		
Cell chi square	2.3	51.0		
Percent	99	1		100
100 kg ha ⁻¹ year ⁻¹ from poultry litter				
Frequency	2162	88	0	2250
Expected	2153.3	96		
Cell chi square	.03	0.7		
Percent	96	4		100
160 kg ha ⁻¹ year ⁻¹ from poultry litter				
Frequency	2013	234	3	2250
Expected	2153.3	96	0.7	
Cell chi square	9.1	198.4	8.2	
Percent	90	10	0	100

The alternate wet-dry cycles of 5 years each showed increased levels of nitrate in the layers located around 1 meter depth in the soil (Figure 5.5) obviously due to the decreased movement of solute with increased accumulation of clay. The accumulation is higher for higher applied N rates.

The ANOVA showed that the treatments were significantly different at all times observed except in the second year (Table 5.8). The interaction between the alternate weather regimes and the N rates was significantly different at all times.

The simulated weather conditions significantly increased the levels of nitrate at the bottom of the profile, with potential for movement into deeper soil layers through drainage.(Figure 5.6).

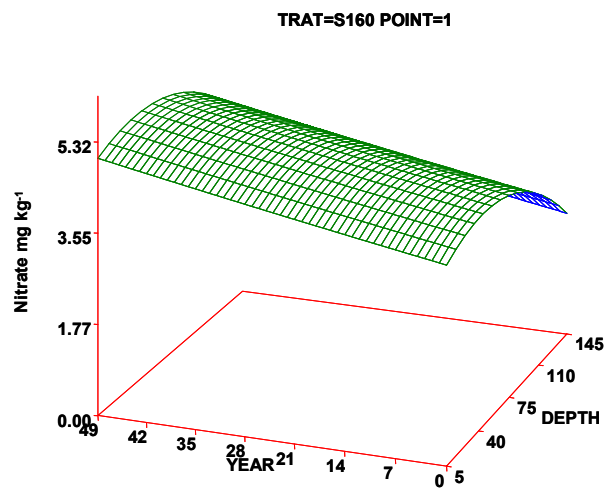
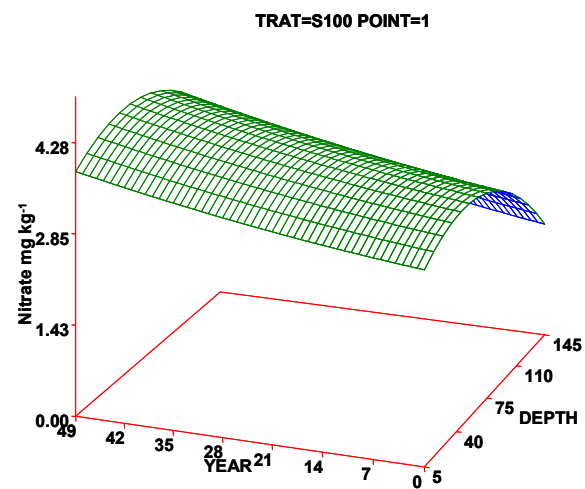
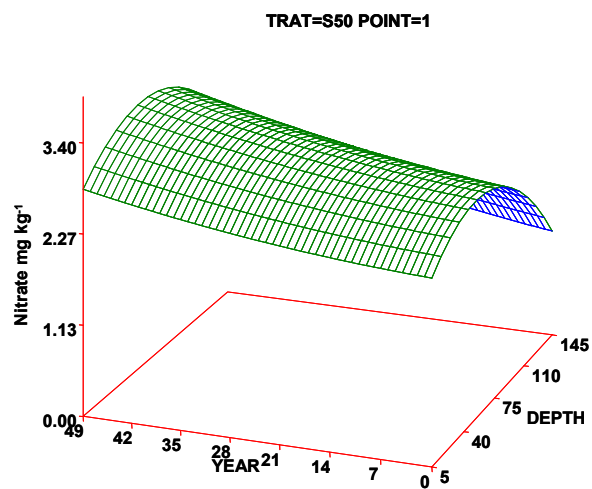


Figure 5.5 Surface responses for 50 years of simulated scenarios of alternate 5-year sequence of wet-dry years receiving N from poultry litter (R50, 50 kg ha⁻¹ year⁻¹, R100, 100 kg ha⁻¹ year⁻¹ and R160 160 kg ha⁻¹ year⁻¹) in a North Florida soil. Point 1

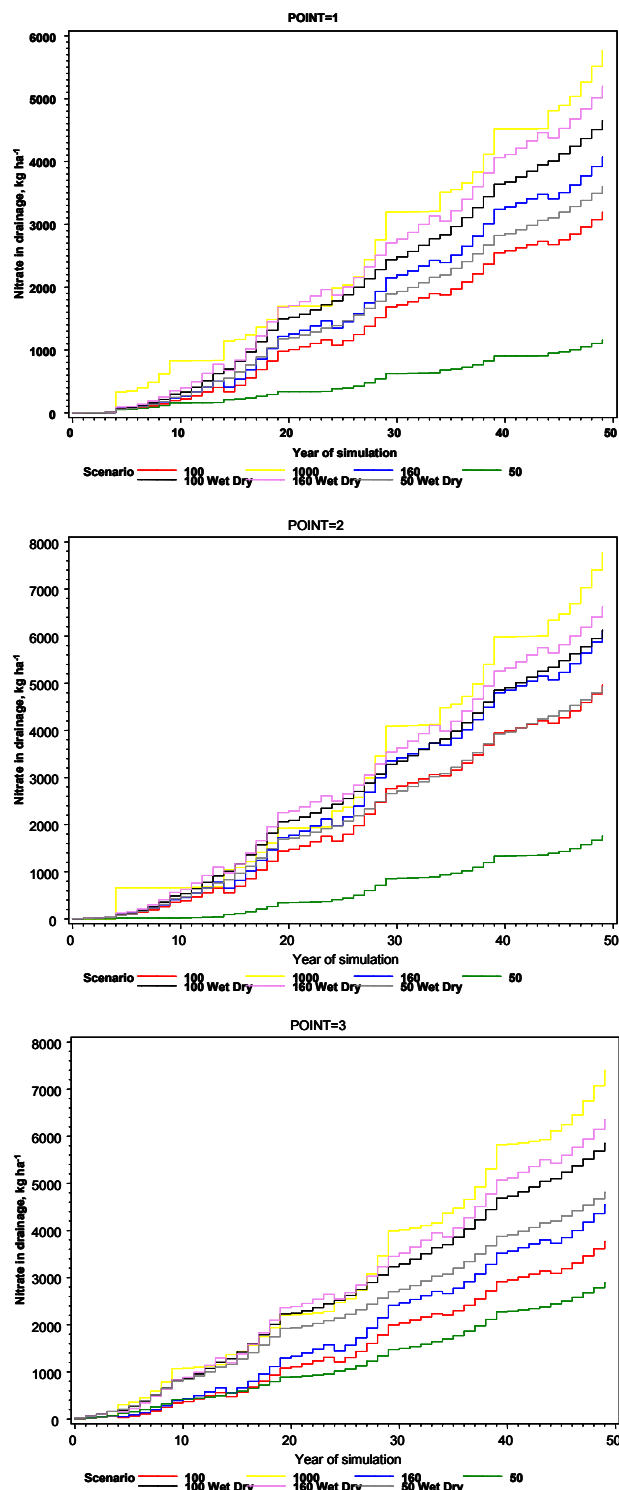


Figure 5.6 Simulated accumulation of nitrate for treatments of poultry litter applied (50, 100, 160 and 1000 kg ha year of N) with an real weather regime and with a simulated weather sequence of alternating 5 wet and 5 dry years in an Ultisol of North Florida.

stronger than the effect of apply an extra doses of mineral fertilizer to the poultry litter application.

Table 5.8 Significance of sources of variation for nitrogen treatments simulated in a North Florida soil.

Source of variation	Years of simulation					
	2	10	20	30	40	50
Source of Nitrogen	NS	**	**	**	**	**
Weather regime	NS	**	**	**	**	**
Interaction	NS	NS	NS	NS	NS	NS

* values significantly different at $P=0.05$ according to F test; ** values significantly different at $P=0.01$ according to F test; NS, values not significantly different at $P>0.05$ according to F test

Sandy profile

Table 5.9 contains the results for the distribution analysis of soil nitrate contents for a completely sandy profile that received three rates of N through poultry litter. The results obtained from the simulation indicated that the lowest dose of $50 \text{ kg ha}^{-1} \text{ year}^{-1}$ of N resulted in >89% of instances with $<10 \text{ mg kg}^{-1}$ nitrate concentrations in the profile even in the entirely sandy profile. The other two higher doses significantly increased the frequency of soil nitrate levels $>10 \text{ mg kg}^{-1}$. Nevertheless more than 95% of the nitrate levels in the soil are located below the critical range of 10 mg kg^{-1} . A quick comparison with alternate dry-wet year simulation revealed that the weather pattern had a higher influence on the soil nitrate concentrations and distributions compared to the soil texture in this simulation. Annual precipitation is considered as the primary factor driving the nitrate leaching process in many soils due to the high water solubility of the anion (Mostaghimi, et al., 2001).

Table 5.9 Frequency Distribution of soil nitrate levels at three recommended rates of N through poultry litter applied to a simulated sandy profile over a 50 year period.

Statistic	Nitrate in the soil, mg kg ⁻¹			Total
	<=10	>10 , <=20	>20	
50 kg ha ⁻¹ year ⁻¹ from poultry litter				
Frequency	2239	11	0	2250
Expected	2191	58.7		
Cell chi square	1.1	38.7		
Percent	99	1		100
100 kg ha ⁻¹ year ⁻¹ from poultry litter				
Frequency	2220	30	0	2250
Expected	2191	58.7		
Cell chi square	0.4	14.0		
Percent	99	1		100
160 kg ha ⁻¹ year ⁻¹ from poultry litter				
Frequency	2166	83	1	2250
Expected	2191	58.7	0.3	
Cell chi square	0.3	10.1	1.3	
Percent	96	4	0	100

A slight increase in nitrate levels was observed in the soil profile with time (Fig. 5.7) even in a continuously sandy profile. This feature differed from the pattern observed in the dry-wet scenario in that the accumulation at the bottom of the profile in the sandy profile was much smaller.

The effect of a sandy profile on elevated levels of nitrate in the drainage was less strong than the effect observed with the sequence of wet-dry periods. The effect of the sand profile is stronger at Point 2. At the highest rate of N applied (160 kg ha⁻¹), both the normal profile and the sand profile showed similar trends in nitrate movement.. Albert (2002) found that LEACHN analysis showed that water moved rapidly through a typical sandy soil profile of north Florida.

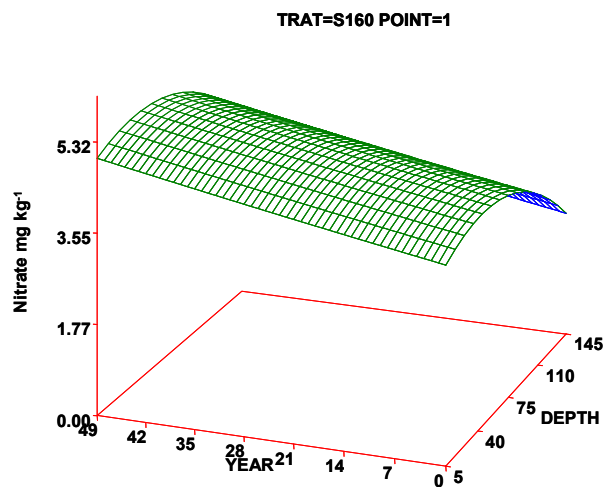
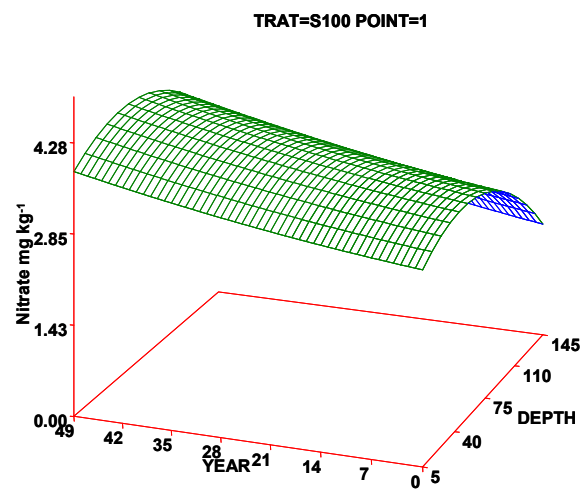
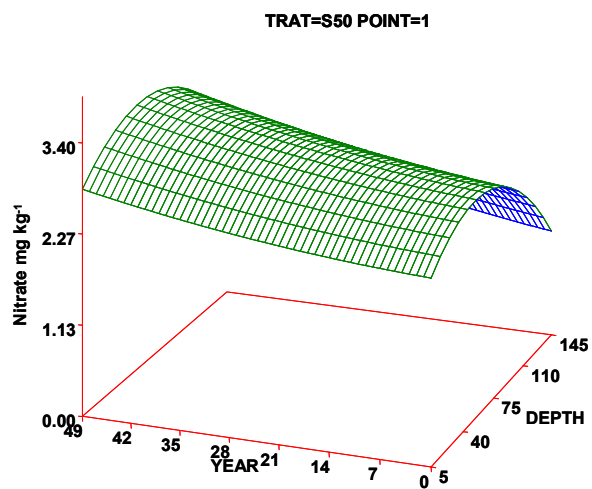


Figure 5.7 Surface responses for 50 years of simulated scenarios of application of nitrogen from poultry litter (S50, 50 kg ha⁻¹ year⁻¹, S100, 100 kg ha⁻¹ year⁻¹ and S160 160 kg ha⁻¹ year⁻¹) in a simulated sand profile. Point 1.

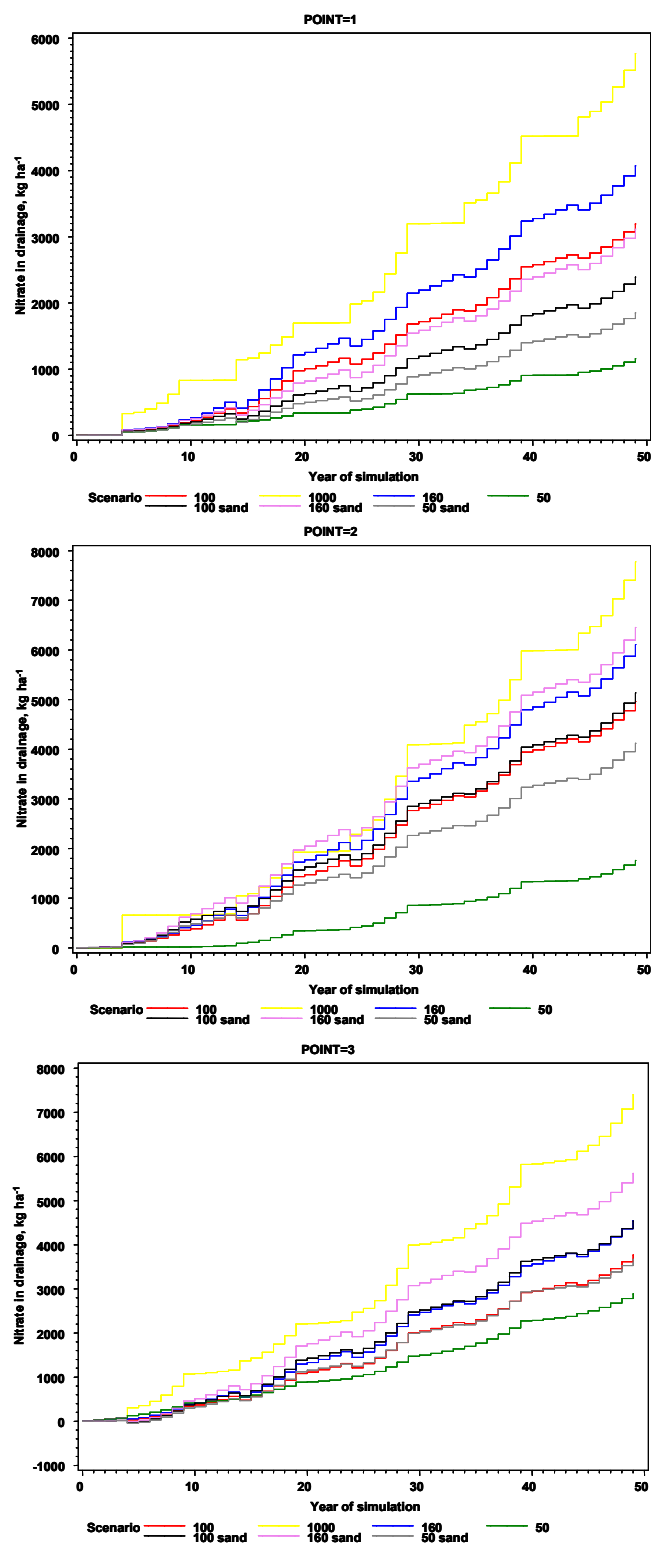


Figure 5.8 Accumulation of nitrate during 50 years of simulation for treatments of poultry litter applied (50, 100, 160 and 1000 kg ha year of N) on an Ultisol of North Florida and in an artificial sand profile.

These results demonstrated that the rate of application and the weather conditions were more sensitive variables for LEACHM than the soil physical characteristics of the profile.

The ANOVA showed significant differences among treatments of N from the poultry litter but no differences due to the texture of the soil layers (Table 5.10) confirming that the amount of nitrate produced is directly dependent on the amount of litter applied and is of primary importance.

Table 5.10 Significance by sources of variation for nitrogen treatments and soil profiles simulated in a North Florida soil.

Source of variation	Years of simulation					
	2	10	20	30	40	50
Source of Nitrogen	NS	**	**	**	**	**
Profile	NS	NS	NS	NS	NS	NS
Interaction	NS	NS	NS	NS	NS	NS

* values significantly different at $P=0.05$ according to F test; ** values significantly different at $P=0.01$ according to F test; NS- values not significantly different at $P>0.05$ according to F test.

CHAPTER 6 CONCLUSIONS

The application of poultry litter was associated with the accumulation of nitrate in the surface soil layers from previous management. If the weather conditions favored a strong growth of bahia grass then no new peaks in nitrate concentrations were identified in the clay layer. Isolated soil nitrate peaks not directly related with applications of litter could not be completely explained although partly could have been due to differential rates mineralization of residual organic N from the poultry litter. Rainfall played a primary role in the movement of nitrate through the soil profile.

The continuous application of poultry litter resulted in lower bulk densities at the top soil layers in spite of the higher sand content at those depths in the three profiles. The saturated hydraulic conductivity was higher in the soil surface layers and decreased with depth as clay content increased with depth. Surface soil layers being sandy lost water rapidly even at the smallest increase in extraction pressure.

Campbell's model is better than PTFs in the estimation of water retention characteristics. At least in the dataset used, where the intrinsic variability was due to the changes in the soil profile, Campbell's was able to predict water content at all depths. PTFs however remain an alternate option to describe soil water movement especially when the resources are limited. PTF's with a wider range of application should be developed to estimate water retention characteristics on areas where the information is not available.

At 60 days, net N mineralized was 42.1, 63.2, 106.4, 115.3, 146.7, 159.4 and 167 mg kg⁻¹ for equivalent land applications of 3, 6, 9, 12, 15, 18 and 21 Mg ha⁻¹ of poultry manure representing 69, 51, 58, 47, 48, 43 and 39 % of the total N applied.

Our results suggested that new Best Management Practices should not only recommend a decrease in the total number of poultry litter applications but also the partitioning of that amount into smaller doses.

The four soil points evaluated demonstrated the magnitude of variability even in a small area (11 ha.) that was subjected to a relatively homogenous management. The inherent spatial variability observed proved that generalization about the potential pollutant risk related with agricultural practices from an area was not possible. Such limitations should be duly considered when formulating best management practices.

LEACHM is a potential tool for the analysis of BMP scenarios in Ultisols of North Florida. The differential sensibility of the model to different variables of the environment should be considered when applying the model. The model responded well to normal doses of nitrogen below 250 kg ha year of N from the poultry litter. However the performance of the model when massive doses of nitrogen are applied to the soil was not satisfactory.

The scenarios technique was able to differentiate between different N options developed by IFAS for Bahia grass fertilization, characterizing the nitrate movement in the profile and calculating the expected nitrate load in the drainage. Higher N application rates obviously resulted in higher cumulative nitrate values in the drainage.

The application of additional nitrogen from ammonium nitrate with the application of poultry litter as the main source of nitrogen was a potential source for leaching in

Ultisols of North Florida. The scenarios established with a sequence of wet dry years suggested that the effect of adverse weather conditions on the nitrate leaching risk could be forecast with the help of the scenarios technique.

APPENDIX A
SOIL PROFILES WATER CONTENT VALIDATION

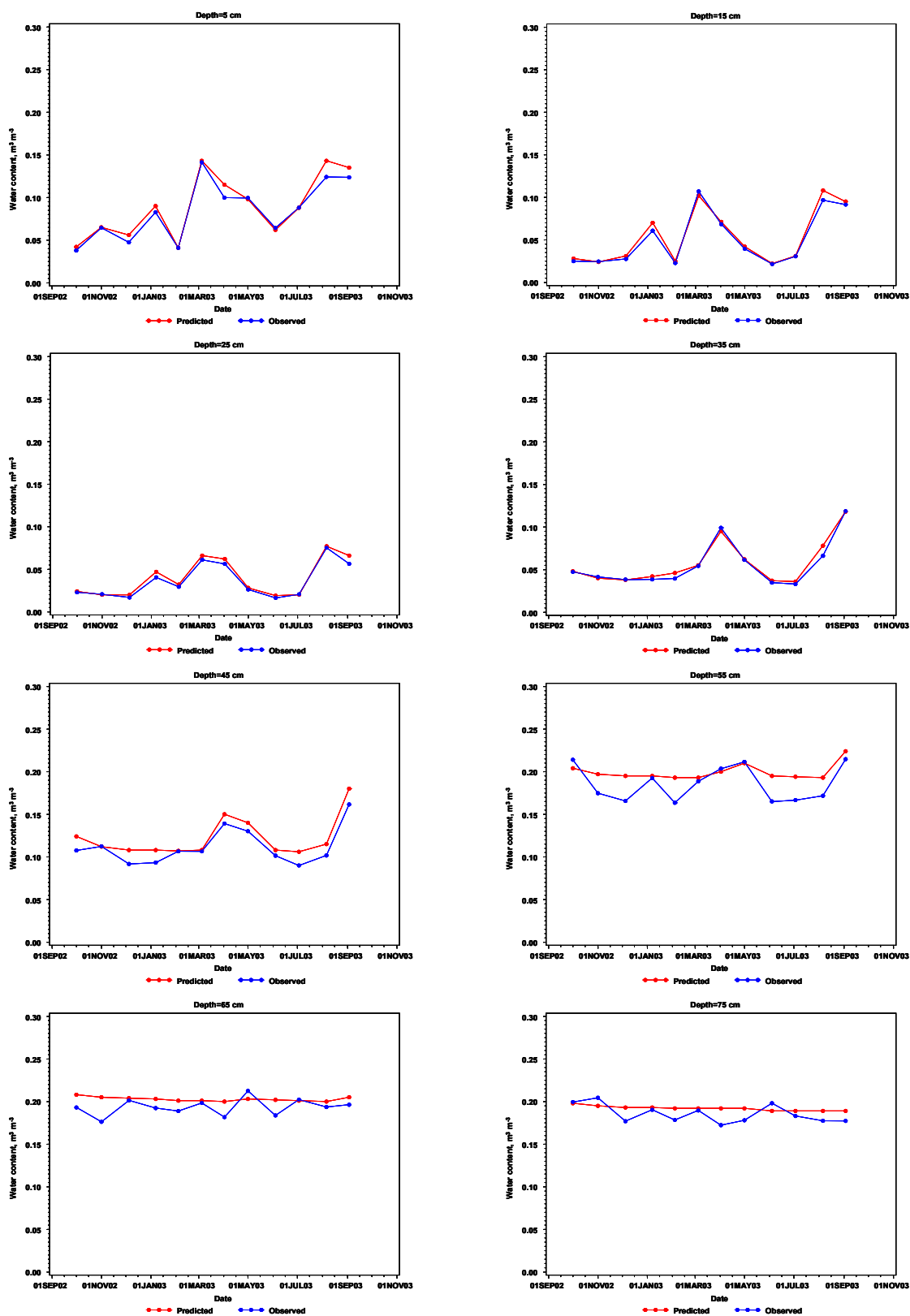


Figure A1. Water content observed versus LEACHM prediction for an Ultisol under long term poultry litter application. Pont 1, depths 5 to 75 cm.

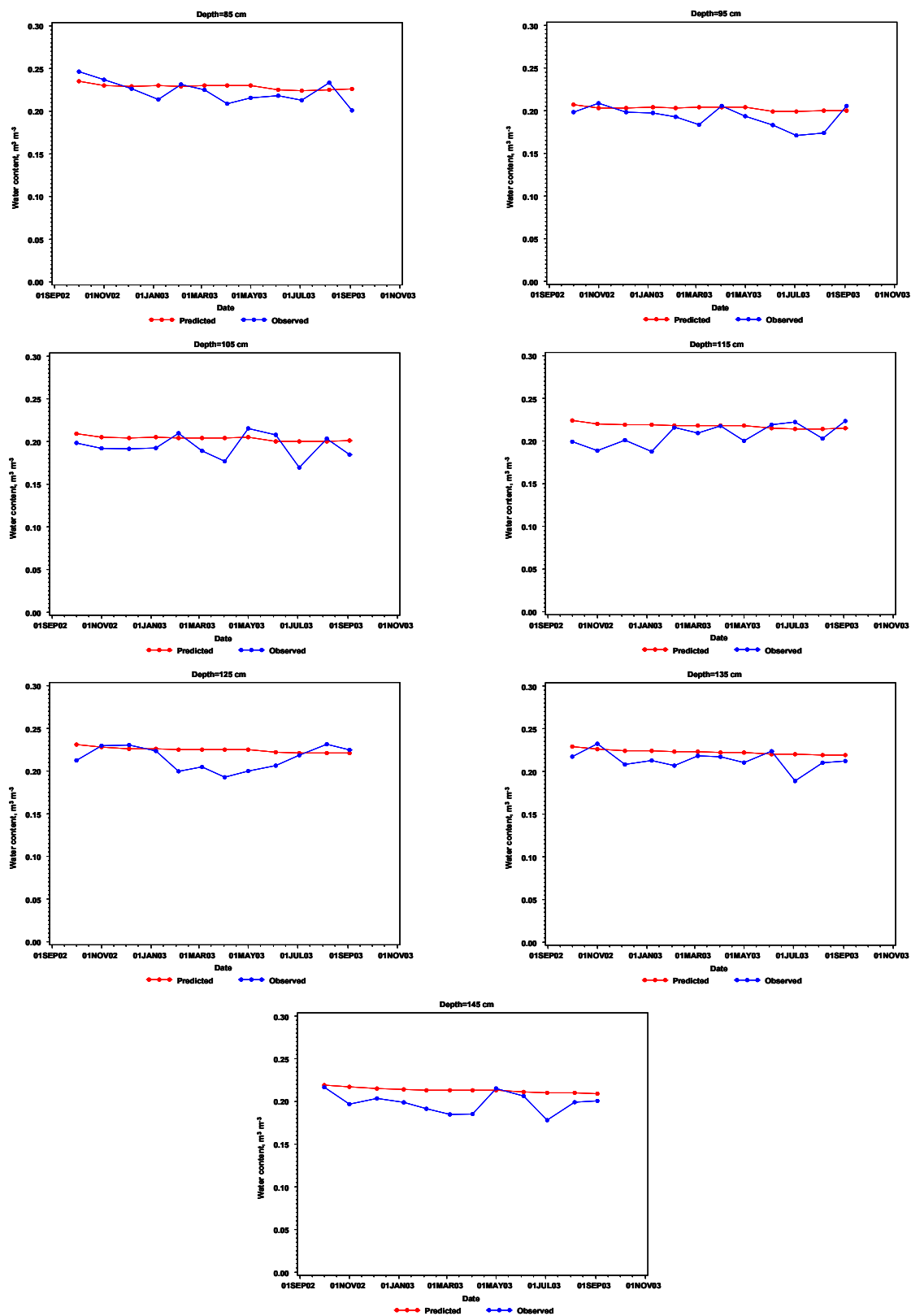


Figure A2. Water content observed versus LEACHM prediction for an Ultisol under long term poultry litter application. Pont 1, depths 85 to 145 cm.

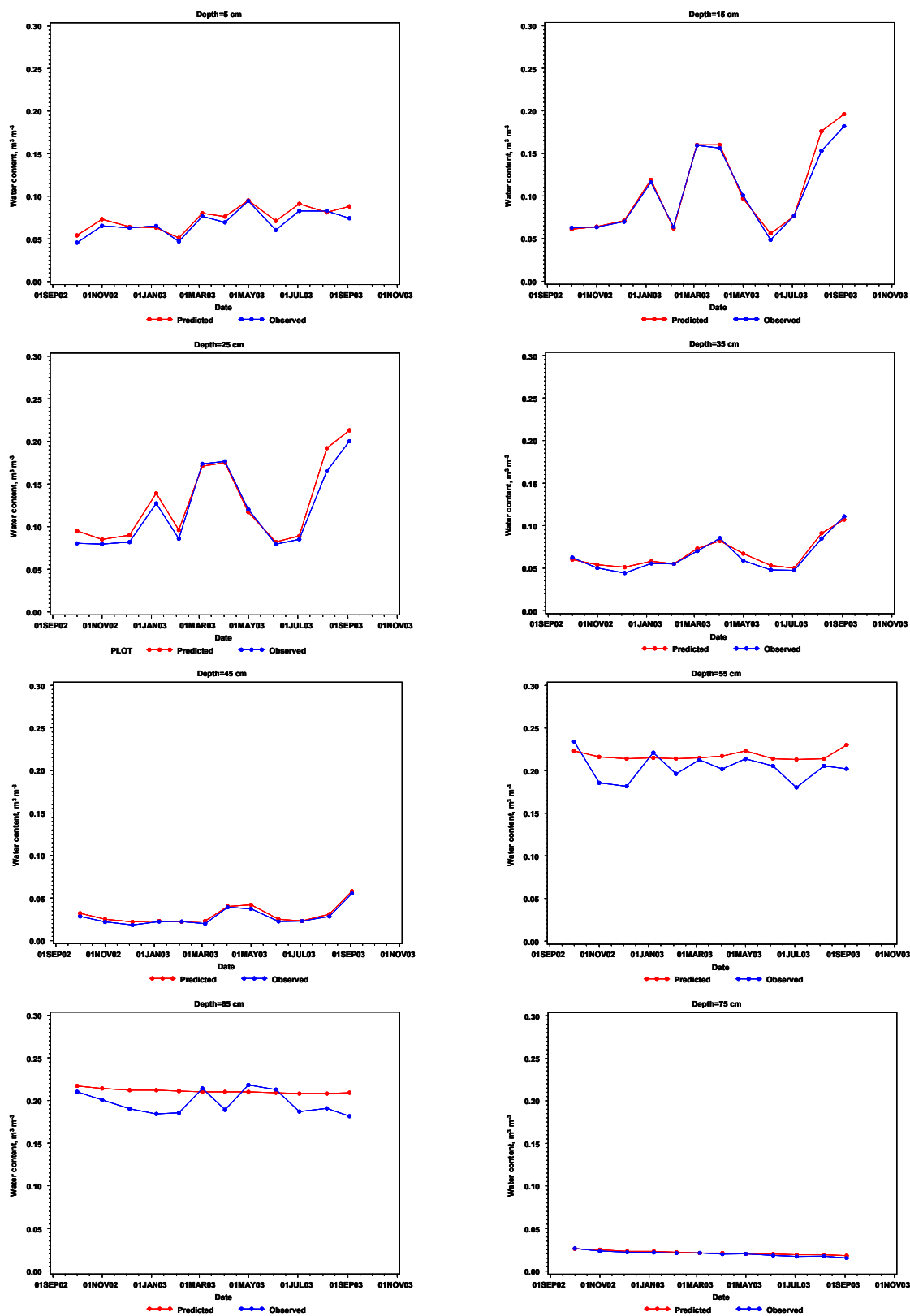


Figure A3. Water content observed versus LEACHM prediction for an Ultisol under long term poultry litter application. Pont 2, depths 5 to 75 cm.

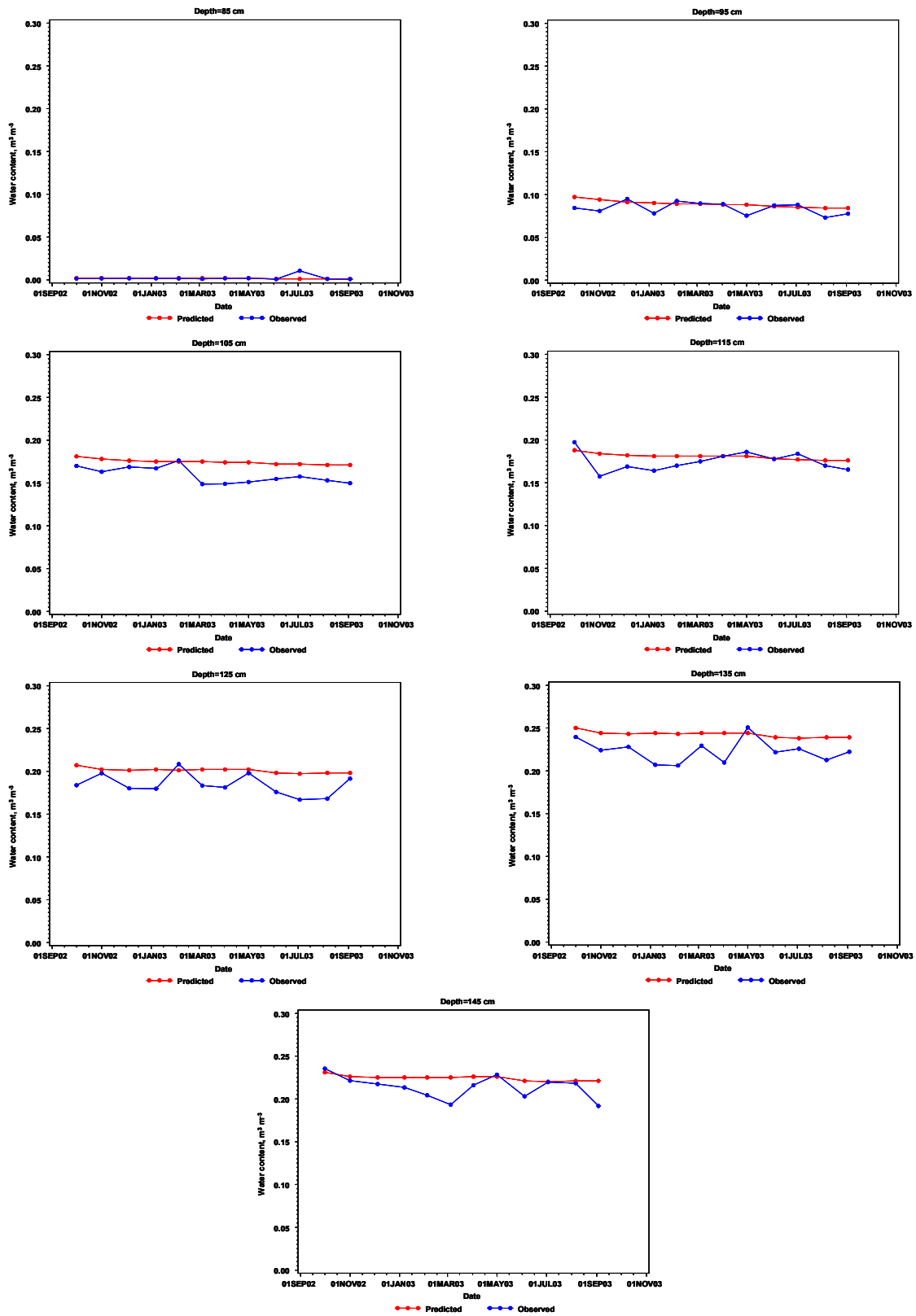


Figure A4. Water content observed versus LEACHM prediction for an Ultisol under long term poultry litter application. Point 2, depths 85 to 145 cm.

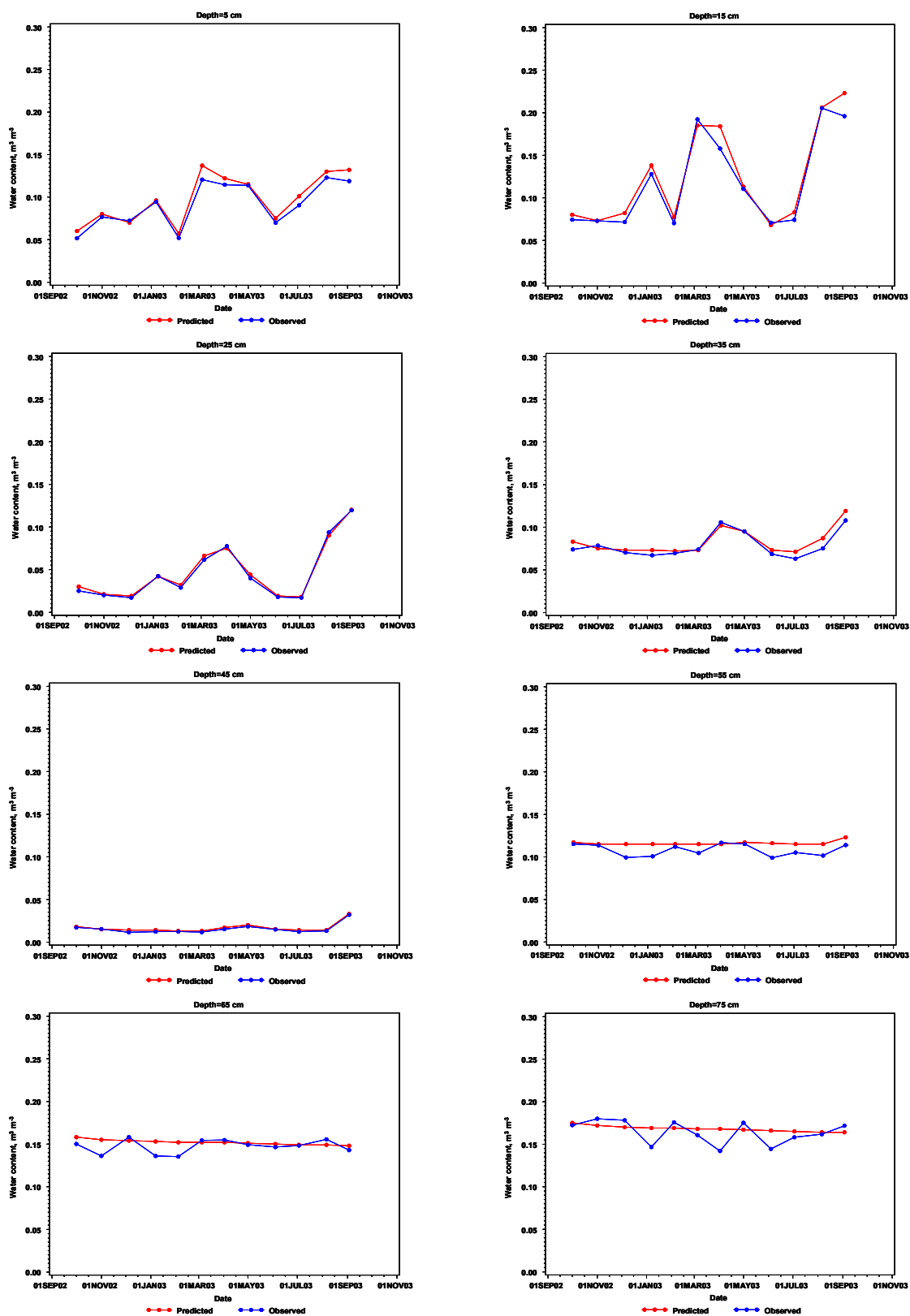


Figure A5. Water content observed versus LEACHM prediction for an Ultisol under long term poultry litter application. Point 3, depths 5 to 75 cm.

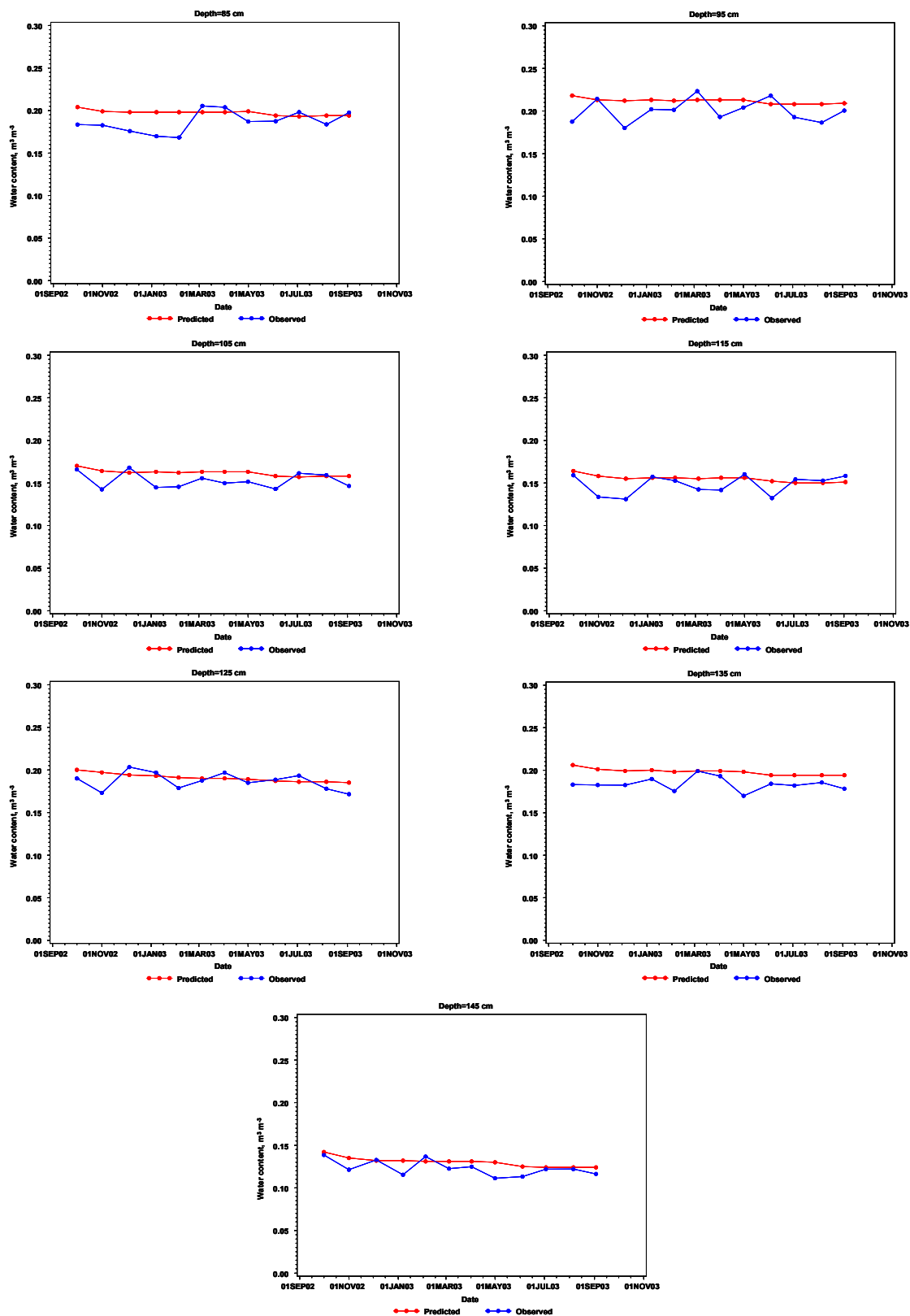


Figure A6. Water content observed versus LEACHM prediction for an Ultisol under long term poultry litter application. Point 3, depths 85 to 145 cm.

APPENDIX B
SURFACE RESPONSES FOR POINTS 2 AND 3

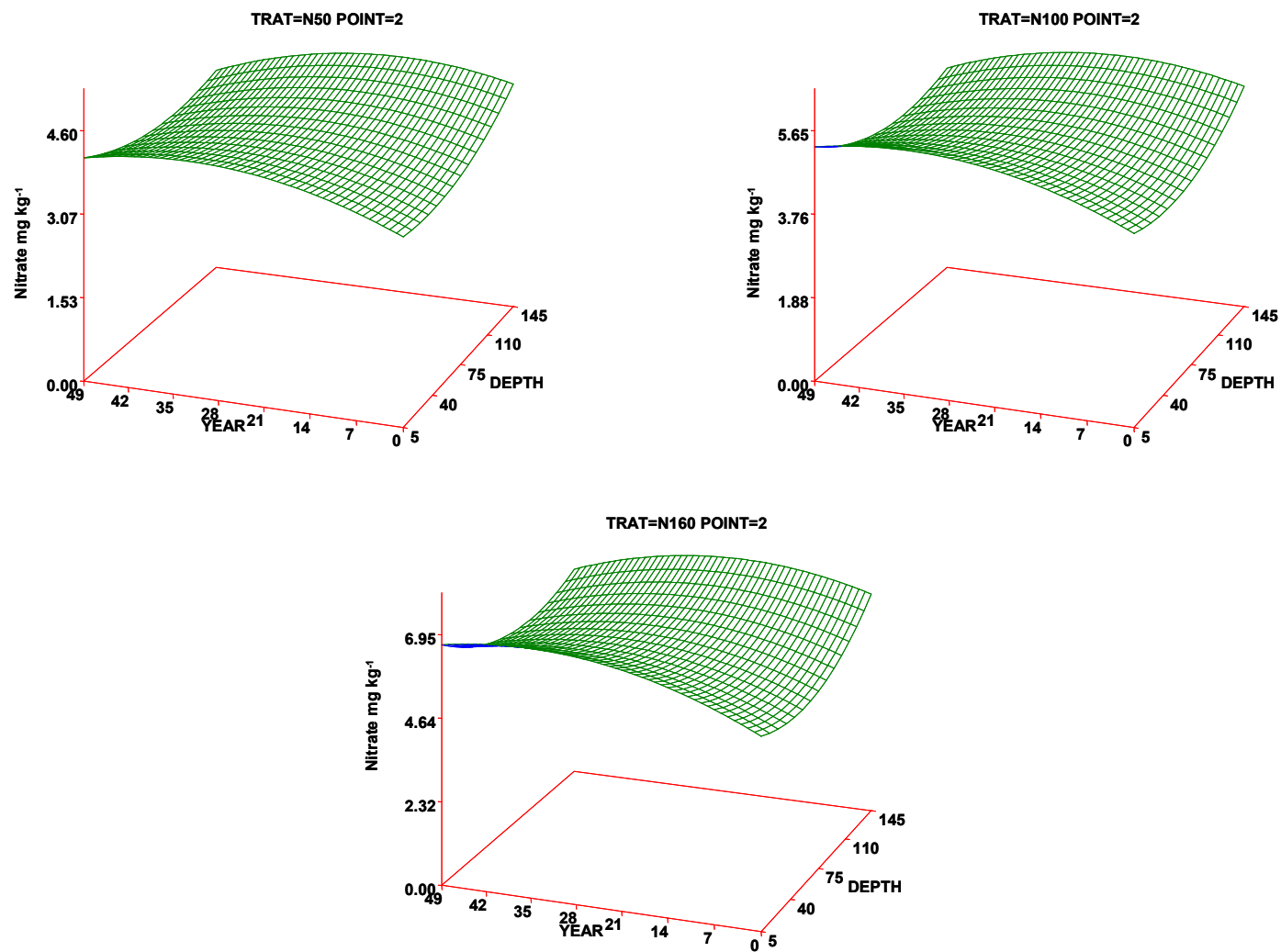


Figure B.1 Soil nitrate (mg kg^{-1}) surface responses for 50 years of simulated scenarios receiving 50 (N50), 100 (N100) and 160 (N160) kg ha^{-1} of nitrogen from poultry litter a Ultisol of North Florida. Point 2.

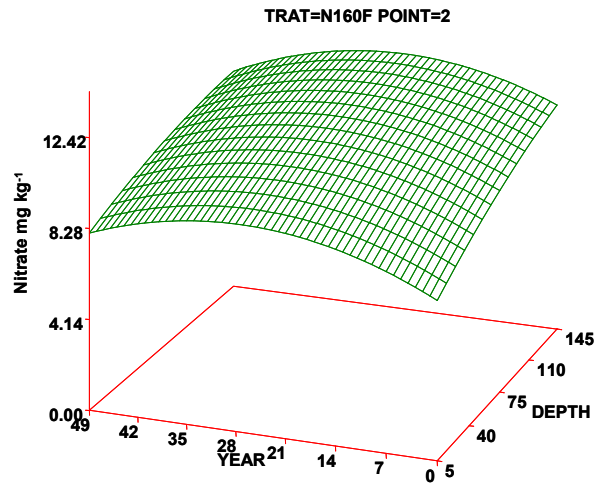
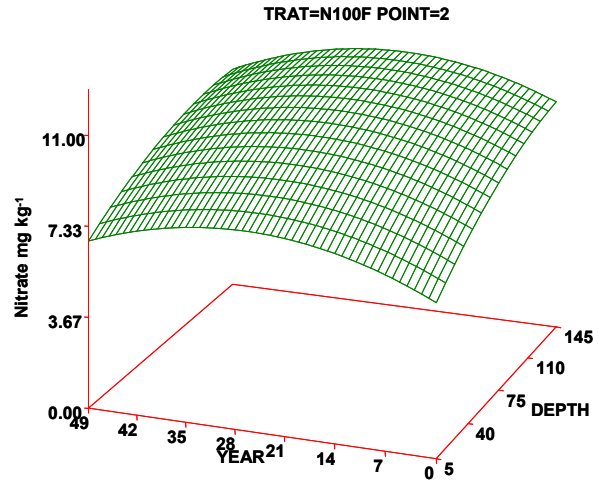
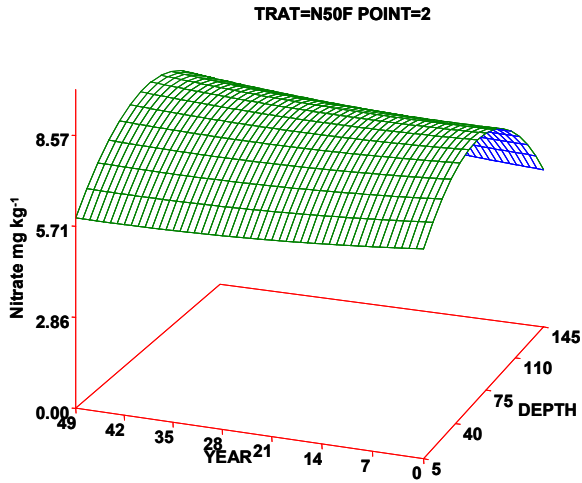


Figure B.2 Surface responses for 50 years of simulated scenarios receiving 50 (N50F), 100 (N100F) and 160 (N160F) kg ha^{-1} of nitrogen from poultry litter and 50 kg ha^{-1} of nitrogen from ammonium nitrate in a Ultisol of North Florida. Point 2.

LIST OF REFERENCES

- Acutis, M., G. Ducco and C. Grignani. 2000. Stochastic use of LEACHN model to forecast nitrate leaching in different maize cropping systems. *European Journal of Agronomy* 13:191-206.
- Adams, T.T., S.A. Thompson, M.L. Cabrera and M.A. Eiteman. 1997. Respiration in broiler litter slurry surface applied to soil. *Bioresource Technology* 60:123-129.
- Adjei, M.B. and J.E. Rechcigl. 2002. Bahiagrass production and nutritive value as affected by domestic wastewater residuals. *Agronomy Journal* 94(6):1400-1410.
- Ahuja, L.R., F. Fiedler, G.H. Dunn, J.G. Benjamin and A. Garrison. 1998. Changes in soil water retention curves due to tillage and natural reconsolidation. *Soil Science Society of America Journal* 62(5):1228-1233.
- Albert, M. 2002. Monitoring and modeling the fate and transport of nitrate in the vadose zone beneath a Suwannee river basin vegetable farm. Thesis of Master of Engineering. University of Florida, Gainesville, 179 p.
- Alcamo, J. 2001. Scenarios as tools for international environmental assessments. Environmental Issue Report No. 24. European Environment Agency. Copenhagen, Denmark. 31 p.
- Alcamo, J and N. Nakicenovic. 1998. Long term greenhouse gas emission scenarios and their driving forces. *Mitigation and Adaptation for Global Change* 3(2-4):95-466.
- Ali, R., R.L. Elliot, J.E. Ayars and E.W. Stevens. 2000. Soil salinity modeling over shallow water tables. I: Validation of LEACHC. *Journal of Irrigation and Drainage Engineering* 126(4):223-233.
- Arnell, N.W. 1999. Climate change and global water resources. *Global Environmental Change* 9(1):31-49.
- Arya, L.M. and Paris, J.F. 1981. A physico-empirical model to predict the soil moisture characteristic from particle size distribution and bulk density data. *Soil Science Society of America Journal* 45:1023-1030.
- Asbury, C.E. and E.T. Oaksford. 1997. A comparison of drainage basin nutrient inputs with instream nutrient loads for seven rivers in Georgia and Florida, 1986-1990. U.S. Geological Survey. Water-Resources Investigations Report 97-4006. US Department of the Interior. US Geological Survey, Tallahassee, Fl.

- Baki, B.B., I.B. Ipon and C.P. Chen. 1992. *Paspalum notatum* Fluegge. In: L. 't Mannetje and R.M. Jones (ed) p. 181-183. Plant resources of South-East Asia No. 4. Forages. Pudoc-DLO, Wageningen, The Netherlands.
- Barzegar, A.R., A. Yousefi and A. Daryashenas. 2002. The effect of addition of different amounts and types of organic materials on soil physical properties and yield of wheat. *Plant and Soil* 247:295-301.
- Bitzer, C.C. and J.T. Sims. 1988. Estimating the availability of nitrogen in poultry manure through laboratory and field studies. *Journal of Environmental Quality* 17(1):47-54.
- Bogdan, A.V. 1977. Tropical pasture and fodder plants. Longman Inc., New York, 475 p.
- Bouma, J. 1989. Using soil survey data for quantitative land evaluation. *Advances in Soil Science* 9:177-213.
- Brooks, R.H. and A.T. Corey. 1966. Properties of porous media affecting fluid flow. *Journal of the Irrigation and Drainage Division. American Society of Civil Engineers* 92:61-68.
- Bundy, L.G. and J.J. Meisinger. 1994. Nitrogen availability indices. In: *Methods of Soil Analysis, Part 2. Microbiological and Biochemical Properties*. R.W. Weaver, ed. Soil Science Society of America, Madison, WI. p. 951-984.
- Bussink D.W. and O. Oenema. 1998. Ammonia volatilization from dairy farming systems in temperate areas: a review. *Nutrient Cycling in Agroecosystems* 51:19-33.
- Cabrera, M.L. and A.A. Vervoort. 1998. Effect of timing of simulated rain on ammonia volatilization from surface-applied broiler litter. *Communications in Soil Science and Plant Analysis* 29(5&6):575-586.
- Calhoun, F.G., V.W. Carlisle, R.E. Caldwell, L.W. Zelazny, L.C. Hammond and H.L. Breland. 1974. Characterization data for selected Florida soils. *Soil Science Research Report Number 74-1*. University of Florida – IFAS. USDA – Soil Conservation Service. Gainesville, Florida 293 p.
- Campbell, C.A., Y.W. Jame, O.O Akinremi and M.L. Cabrera. 1995. Adapting the potentially mineralizable N concept for the prediction of fertilizer N requirements. *Fertilizer Research* 42:61-75.
- Campbell, D.J. and J.K. Henshall. 2000. Bulk density. p. 315-348. In K.A. Smith and C.E. Mullins, ed. *Soil environmental analysis. Physical methods*. Second edition. Marcel Dekker, Inc., New York.
- Campbell, G.S. 1974. A simple method for determining unsaturated conductivity from moisture retention data. *Soil Science* 117(6):311-314.

- Carlisle, V.W., F. Sodek, M.E. Collins, L.C. Hammond and W.G. Harris. 1989. Characterization Data for Selected Florida Soils. Soil Science Research Report Number 89-1. University of Florida – IFAS. USDA – Soil Conservation Service. Gainesville, Florida 306 p.
- Cassel, D.K. 1982. Tillage effects on soil bulk density and mechanical impedance. P. 45-67. in P.W. Unger and D.M. Van Doren, ed. Predicting tillage effects on soil physical properties and processes. ASA Special Publication 44. ASA and SSSA, Madison, Wisconsin.
- Castellanos, J.Z. and P.F. Pratt. 1981. Mineralization of manure nitrogen – Correlation with laboratory indexes. Soil Science Society of America Journal 45(2):354-357.
- Chae, Y.M. and M.A. Tabatabai. 1986. Mineralization of nitrogen in soils amended with organic wastes. Journal of Environmental Quality 15(2):193-198.
- Childs, S.W. and R.J. Hanks. 1975. Model of soil salinity effects on crop growth. Soil Science Society of America Procedures 39:617-622.
- Clapp, R.B. and G.M. Hornberger. 1978. Empirical equations for some soil hydraulic properties. Water Resources Research 14:601-604.
- Cooperband, L, G. Bollero, F. Coale. 2002. Effect of poultry and composts on soil nitrogen and phosphorus availability and corn production. Nutrient Cycling in Agroecosystems. 62:185-194.
- Cornelis, W.M., J. Ronsyn, M Van Meirvenne and R. Hartmann. 2001. Evaluation of pedotransfer functions for predicting the soil moisture retention curve. Soil Science Society of America Journal 65(3):638-648.
- Crane, J.J. 1986. An investigation of the geology, hydrogeology and hydrochemistry of the lower Suwannee river basin. State of Florida. Department of Natural Resources. Bureau of Geology. Report of Investigation No. 96. Florida Geological Survey in cooperation with the Suwannee River Management District, Tallahassee, Florida, 166 p.
- Deaton, J.W. 1995. Environmental factors involved in growth and development. p. 119-138. In: P. Hunton (ed.) Poultry Production. Elsevier, Amsterdam, The Netherlands.
- Dexter, A.R. 1988. Advances in characterization of soil structure. Soil and Tillage Research 11(2):199-238.
- Dodds, G.T., C.A. Madramootoo and V.K. Serem. 2000. Predicting nitrate-N leaching under different tillage systems using Leachm and NTRM. Transactions of the ASAE 41(4):1025-1034.

- Draper, N.R. and H. Smith. 1981. Applied regression analysis. 2nd. Edition. John Willey and Sons, New York, New York. 709 p.
- Edwards, D.R. and T.C. Daniel. 1992. Environmental impacts of on-farm poultry waste disposal – A review. *Bioresource Technology* 41:9-33.
- FDACS. 2002. Florida Agricultural Statistics. Livestock, Dairy and Poultry Summary. Florida Department of Agriculture and Consumer Services. Tallahassee, Florida. p. 43-66.
- Fuhrmann, J.J. 1999. Microbial metabolism. p. 189-217. In: D.M. Sylvia, J.J. Fuhrmann, P.G. Hartel and D.A. Zuberer (ed.) *Principles and Applications of soil microbiology*. Prentice Hall, Upper Saddle River, New Jersey.
- Gagnon, B. and R.R. Simard. 1999. Nitrogen and phosphorous release from on-farm and industrial composts. *Canadian Journal of Soil Science* 79:481-489.
- Gardner, C.M., D. Robinson, K. Blyth and J.D. Cooper. 2000. Soil water content. p. 1-64. In K.A. Smith and C.E. Mullins, ed. *Soil environmental analysis. Physical methods*. Secon edition. Marcel Dekker, Inc., New York.
- Gascho, G.J. R. Hubbard, T.B. Brenneman, A. W. Johnson, D.R Sumner and G.H Harris. 2001. Effects of broiler litter in an irrigated, doubled-cropped, conservation-tilled rotation. *Agronomy Journal* 93(6):1315-1320.
- Gee, G.W. and J.W. Bauder. 1986. Particle size analysis. p. 383-411. In A. Klute, ed. *Methods of soil analysis. Part 1. Physical and mineralogical methods*. 2nd. Edition. American Society of Agronomy, Madison, Wisconsin.
- Giddens, J. and M.A. Rao. 1975. Effect of incubation and contact with soil on microbial and nitrogen changes in poultry manure. *Journal of Environmental Quality* 4:275-278.
- Gijssman, A.J., S.S. Jagtap and J.W. Jones. 2002. Wading through a swamp of complete confusion: how to choose a method for estimating soil water retention parameters for crop models. *European Journal of Agronomy* 18:75-105.
- Godet, M. 1987. *Scenarios and strategic management*. Butterworths, London, England, 210 p.
- Gordillo, R.M. and M.L. Cabrera. 1997. Mineralizable nitrogen in broiler litter: I. Effect of selected litter chemical characteristics. *Journal of Environmental Quality* 26(6):1672-1679.
- Gupta, S.C. and W.E. Larson. 1979. Estimating soil water retention characteristics from particle size distribution, organic matter percent and bulk density. *Water Resources Research* 15(6):1633-1635.

- Hadas, A., L. Kautsky and R. Portnoy. 1996. Mineralization of composted manure and microbial dynamics in soils affected by long-term nitrogen management. *Soil Biology and Biochemistry* 28(6):733-738.
- Hamblin, A.P. 1985. The influence of soil structure on water movement, crop root growth, and water uptake. *Advances in Agronomy* 38:95-158.
- Hargraves, G.H. and Z.A. Samani. 1985. Reference crop evapotranspiration from temperature. *Transactions of ASAE* 1(2):96-99.
- Hart, S.C., J.M. Stark, E.A. Davidson and M.K. Firestone. 1994. Nitrogen mineralization, immobilization, and nitrification. In: *Methods of Soil Analysis, Part 2. Microbiological and Biochemical Properties*. R.W. Weaver, ed. Soil Science Society of America, Madison, WI. p. 985-1018.
- Havlin, J.L., J.D. Beaton, S.L. Tisdale and W.L. Nelson. 1999. *Soil Fertility and Fertilizers. An Introduction to Nutrient Management*. Prentice Hall, Upper Saddle River, New Jersey, 499 p.
- Hillel, 1998. *Environmental Soil Physics*. Academic Press, San Diego, CA, 771 p.
- Hornsby, D. and R. Ceryak. 2000. Springs of the Aucilla, Coastal and Waccasassa Basins in Florida. Department of Water Resources, Suwannee River Water Management District. Live Oak, Florida, 66 p.
- Hornsby, D. and R. Mattson. 1998. Surface water quality and biological monitoring annual report, 1997; Suwannee River Water Management District, WR98-03, Live Oak, FL.
- Hornsby, D., R. Mattson and T. Mirti. 2002. Surfacewater Quality and Biological Annual Report. June 2002. Department of Water resources. Suwannee River Water Management District. WR-01-02-04. Live Oak, FL. 14 p.
- Hutson, J.L. 2001. Leaching estimation and chemistry model. Model description and user's guide. School of Chemistry, Physics and Earth Sciences, The Flinders University of South Australia, Adelaide, South Australia. 142 p.
- Hutson, J.L. and A. Cass. 1987. A retentivity function for use in soil-water simulation models. *Journal of Soil Science* 38:105-113.
- Hutson, J.L. and R.J. Wagenet. 1992. LEACHM 'Leaching Estimation and Chemistry Model' (LEACHM): Version 1.0, Volume 2. Continuum Water Resources Institute. Center for Environmental research, Cornell University, Ithaca, New York.
- Jemison, J.M., J.D. Jabro and R. Fox. 1994. Evaluation of LEACHM: II. Simulation of nitrate leaching from nitrogen-fertilized and manured corn. *Agronomy Journal* 86(5):843-851.

- Johnson, H., L. Bergstrom, P.E. Janson and K. Paustian. 1987. Simulated nitrogen dynamics and losses in a layered agricultural soil. *Agriculture, Ecosystems and Environment* 18:333-356.
- Johnson, A.D., M.L. Cabrera, D.V. McCracken and D. Radcliffe. 1999. LEACHN simulations of nitrogen dynamics and water drainage in an Ultisol. *Agronomy Journal* 91(7):597-606.
- Kelleher, B.P., J.J. Leahy, A.M. Henihan, T.F. O'Dwyer, D. Sutton and M.J. Leahy. 2002. Advances in poultry litter disposal technology – a review. *Bioresource Technology* 83:27-36.
- Kern, J.S. 1995. Evaluation of soil water retention models based on basic soil physical properties. *Soil Science Society of America Journal* 59(7):1134-1141.
- Khakural, B.R. and P.C. Robert. 1993. Soil nitrate leaching potential indices: using a simulation model as a screening system. *Journal of Environmental Quality* 22(6):839-845.
- Kidder, G., C.G. Chambliss and R.S. Mylavarapu. 2002. UF/IFAS standardized fertilization recommendations for agronomics crops. Fact sheet SL-129. Soil and Water Science Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, Florida. p 9
- Kingery, W.L., C.W. Wood, D.P. Delaney, J.C. Williams and G.L. Mullins. 1994. Impact of long-term land application of broiler litter on environmentally related soil properties. *Journal of Environmental Quality* 23(1):139-147.
- Klute, A. 1986. Water retention: Laboratory methods. P. 635-662. In A. Klute, ed. *Methods of soil analysis. Part 1. Physical and mineralogical methods*. 2nd. Edition. American Society of Agronomy, Madison, Wisconsin.
- Leemans, R., A. van Amstel, C. Battjes, G.J.J. Kreileman and A.M.C. TPET. 1996. The land cover consequences of large scale utilization of biomass as an energy source. *Global Environmental Change* 6(4):335-358.
- Lidon, A., C. Ramos and A. Rodrigo. 1999. Comparison of drainage estimation methods in irrigated citrus orchards. *Irrigation Science* 19:25-36.
- Liebhardt, W.C., C. Golt and J. Tupin. 1979. Nitrate and ammonium concentrations of ground water resulting from poultry manure applications. *Journal of Environmental Quality* 8(2):211-215.
- Malone, G.W. 1992. Nutrient enrichment in integrated broiler production system. *Poultry Science* 71:1117-1122.
- Miner, J.R., F.J. Humenik and M.R. Overcash. 2000. Managing livestock wastes to preserve environmental quality. Iowa State University Press, Ames, Iowa. p. 318.

- Mislevy, P., G.W. Burton and P. Busey. 1991. Bahiagrass response to grazing frequency. *Soil and Crop Science Society of Florida Proceedings* 50:58-64.
- Moore, P.A., T.C. Daniel, A.N. Sharpley and C.W. Wood. 1995. Poultry manure management: Environmentally sound options. *Journal of Soil and Water Conservation* 50(3):321-327.
- Mostaghimi, S., K.M. Brannan, T.A. Dillaha and A. C. Bruggeman. 2001. Best management practices for nonpoint source pollution control: selection and assessment. p 257-304. In: W.F Ritter and A. Shirmohammadi (ed). *Agricultural nonpoint source pollution. Watershed management and hydrology*. Lewis Publishers, Boca Raton, FL
- Mylavarapu, R.S. 2003. Role of an Extension Soil Testing Program in the Development of Best Management Practices: A Florida Case Study. *Journal of Extension*, 45(4):[online] available at: <http://www.joe.org/joe/2003august/a7.shtml>. (verified on 3 March, 2004).
- Mylavarapu, R.S. and E.D. Kennelly. 2002. UF/IFAS Extension Soil Testing Laboratory (ESTL) Analytical Procedures and Training Manual. Circular 1248. Soil and Water Science Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida Gainesville, 19 p.
- Myrold, D.D. 1999. Transformations of Nitrogen. p. 260-294. In: D.M. Sylvia, J.J. Fuhrmann, P.G. Hartel and D.A. Zuberer (ed.) *Principles and Applications of soil microbiology*. Prentice Hall, Upper Saddle River, New Jersey.
- Nemes, A., M.G. Schaap and J.H.M. Wosten. 2003. Functional evaluation of pedotransfer functions derived from different scales of data collection. *Soil Science society of America Journal* 67(4):1093-1102.
- NOAA. 2004. National Climatic Data Center. [Online] Available at <http://lwf.ncdc.noaa.gov/oa/ncdc.html>. (verified 16 Jan. 2004).
- Olson, K.D. 2004. *Farm management. Principles and strategies*. Iowa State Press, Ames Iowa. 429 p.
- Overcash, M.R., F.J. Humnik and J.R. Miner. 1983. *Livestock Waste Management Vol I.* CRC Press, Boca Raton, Florida. p 114-180.
- Paramasivam, S., A.K. Alva, A. Fares and K.S. Sajwan. 2002. Fate of nitrate and bromide in an unsaturated zone of a sandy soil under citrus production. *Journal of Environmental Quality* 31:671-681.
- Pennell, K.D., A.G. Hornsby, R.E. Jessup and P.S.C. Rao. 1990. Evaluation of five simulation models for predicting aldicarb and bromide behavior under field conditions. *Water Resources Research* 26(11):2679-2693.

- Philips, W.A. 1998. Use of manure on grazing lands. p 157-171. *In* J.L Hatfield and B.A. Stewart (ed). Animal waste utilization: Effective use of manure as a soil resource. Ann Arbor Press, Chelsea, MI.
- Poulsen, T.G., P. Moldrup, T. Yamaguchi and O.H. Jacobsen. 1999. Predicting saturated and unsaturated hydraulic conductivity in undisturbed soils from soil water characteristics. *Soil Science* 164(12):877-887.
- Qafoku, O.S., M.L. Cabrera, W.R. Windham and N.S. Hill. 2001. Rapid methods to determine potentially mineralizable nitrogen in broiler litter. *Journal of Environmental Quality* 30(1):217-221.
- Qian, P. and J.J. Schoenau. 2002. Availability of nitrogen in solid manure amendments with different C:N ratios. *Canadian Journal of Soil Science* 82:219-225.
- Ramos, C. and E.A. Carbonell. 1991. Nitrate leaching and soil moisture prediction with the LEACHM model. *Fertilizer Research* 27:171-180.
- Rawls, W.J. and D.L. Brakensiek. 1981. Estimating soil water retention from soil properties. *Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers* 108:166-171.
- Rawls, W.J. and D.L. Brakensiek. 1985. Prediction of soil water properties for hydrologic modeling. p. 293-299. *In* E. Jones and T.J. Ward (ed). Watershed management in the eighties. Proceedings of the Symposium of Irrigation and Drainage Division, American Society of Civil Engineers. Denver, Colorado April 30 – May 1, 1985. American Society of Civil Engineers, New York, New York.
- Rawls, W.J., T.J. Gish and D.L. Brakensiek. 1991. Estimating soil water retention from soil physical properties and characteristics. *Advances in Soil Science* 16:213-234.
- Rawls, W.J., Y.A. Pachepsky, J.C. Ritchie, T.M. Sobecki and H. Bloodworth. 2003. Effect of soil organic carbon on soil water retention. *Geoderma* 109:1-16.
- Ritter, W.F. and L. Bergstrom. 2001. Nitrogen and water quality. p 59-89. *In*: W.F Ritter and A. Shirmohammadi (ed). Agricultural nonpoint source pollution. Watershed management and hydrology. Lewis Publishers, Boca Raton, FL
- Robinson, J.S. and A.N. Sharpley. 1995. Release of nitrogen and phosphorus from poultry litter. *Journal of Environmental Quality* 24(1):62-67.
- SAS. 1999. SAS/STAT Users guide. Version 8. SAS Institute Inc., Cary, North Carolina. 1768 p.
- Schaffers, A.P. 2000. In situ annual nitrogen mineralization predicted by simple soil properties and short-period field incubation. *Plant and Soil* 221:205-219.

- Sharpley, A., J.J. Meisinger, A. Breeuwsma, J.T. Sims, T.C. Daniel and J.S. Schepers. 1998. Impacts of animal manure management on ground and surface water quality. P. 173-242. *In* J.L. Hatfield and B.A. Stewart, ed. Animal waste utilization: Effective use of manure as a soil resource. Ann Arbor Press, Chelsea MI.
- Sharpley, A.N., S.J. Smith and W.R. Bain. 1993. Nitrogen and phosphorus fate from long term poultry litter applications to Oklahoma soils. *Soil Science Society of America Journal* 57(4):1131-1137
- Simms, T. 1987. Agronomic evaluation of poultry manure as a nitrogen source for conventional and no-tillage corn. *Agronomy Journal* 79(3):563-570.
- Simms, J.T. and D.C. Wolf. 1994. Poultry waste management: agricultural and environmental issues. *Advances in Agronomy* 52:1-83.
- Smith, J.L., R.R. Schnabel, B.L. McNeal and G.S. Campbell. 1980. Potential errors in the first-order model for estimating soil nitrogen mineralization potentials. *Soil Science Society of America Journal* 44:996-1000.
- Sodek, F., V.W. Carslile, M.E. Collins, L.C. Hammond and W.G. Harris. 1990. Characterization Data for Selected Florida Soils. Soil Science Research Report Number 90-1. University of Florida – IFAS. USDA – Soil Conservation Service. Gainesville, Florida 317 p.
- SRWMD. 2000. Water Management Plan. Suwannee River Water Management District, Live Oak, Florida, 105 p.
- Stanley, R.L. and F.M. Rhoads. 2000. Bahiagrass production, nutrient uptake, and soil-test P and K. *Soil and Crop Science of Florida Procedures* 59:159-163.
- Stephenson, A.H., T.A. McCaskey and B.G. Ruffin. 1990. A survey of broiler litter composition and potential value as a nutrient resource. *Biological Waste* 34:1-9.
- Tietje, O. and V. Hennings. 1996. Accuracy of the saturated hydraulic conductivity prediction by pedo-transfer functions compared to the variability within FAO textural classes. *Geoderma* 69:71-84.
- Tietje, O. and M. Tapkenhinrichs. 1993. Evaluation of pedo-transfer functions. *Soil Science Society of America Journal* 57(4):1088-1095.
- Tomasella, J., Ya. Pachepsky, S. Crestana and W.J. Rawls. 2003. Comparison of two techniques to develop pedotransfer functions for water retention. *Soil Science Society of America Journal* 67(4):1085-1092.
- Tyson, S.C. and M.L. Cabrera. 1993. Nitrogen mineralization in soils amended with composted and uncomposted poultry litter. *Communication in Soil Science and Plant Analysis* 24(17&18):2361-2374.

- Ünlü, K., Özenirler and C. Yuteri. 1999. Nitrogen fertilizer leaching from cropped and irrigated sandy soil in Central Turkey. *European Journal of Soil Science* 50:609-620.
- USDA. 2003. Poultry – Production and value. United States Department of Agriculture. National Agricultural Statistics Service. April 2003.
- USDA-SCS. 1975. Agricultural waste management field manual. United States Department of Agriculture. Soil Conservation Service, Washington, DC.
- USDA-SCS. 1992. Agricultural Waste Management Field Handbook. United States Department of Agriculture. Soil Conservation Service, Washington, DC.
- USDA-SSS. 1998. Keys to Soil Taxonomy. United States Department of Agriculture. Natural Resources Conservation Service. Soil Survey Staff. 8th. Edition. Washington, D.C., 328 p.
- USEPA. 1994. National water quality inventory. 1992 Report to Congress. U.S. EPA 841-R-94-001. Published March 1994. Office of Water. U.S. Government Printing Office, Washington, DC.
- USEPA. 2002. Consumer Fact sheet on: Nitrates/Nitrites. United States Environmental Protection Agency. [Online] Available at <http://www.epa.gov/safewater/dwh/c-ioc/nitrates.html> (verified January 6th 2004).
- USNASS. 1997. Census Ranking of States and Counties. United States National Agricultural Statistics Service. [Online] Available at <http://www.nass.usda.gov/census/census97/rankings/tbl26.pdf> (verified January 6th 2004).
- Vereecken, H., J. Maes, J. Feyen and P. Darius. 1989. Estimating the soil moisture retention characteristic from texture bulk density and carbon content. *Soil Science* 148:389-403.
- Willat, S.T. and D.M. Pullar. 1983. Changes in soil physical properties under grazed pastures. *Australian Journal of Soil Research* 22:343-348.
- Wood, B.H., C.W. Wood, K.H. Yoo, K.S. Yoon and D.P. Delaney. 1996. Nutrient accumulation and nitrate leaching under broiler litter amended corn fields. *Communications in Soil Science and Plant Analysis*: 27(15-17):2875-2894.
- Wu, I-Pai. 1997. A simple evapotranspiration model for Hawaii: The Hargraves model. Cooperative Extension Service. College of Tropical Agriculture and Human Resources. University of Hawaii at Manoa. CTAHR Fact Sheet. Engineer's Notebook no. 160, May 1997.

Youngs, E. G. 2000. Hydraulic conductivity of saturated soils. p 141-182. In K.A. Smith and C.E. Mullins, ed. Soil environmental analysis. Physical methods. Second edition. Marcel Dekker, Inc., New York.

BIOGRAPHICAL SKETCH

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