AGROFORESTRY AS AN ALTERNATIVE FOR THE LAND APPLICATION OF POULTRY LITTER

by

VINETA MAIRA TERAUDS-STIRRUP

(Under the Direction of Lawrence A. Morris)

ABSTRACT

Agroforestry, particularly silvipasture systems that combine grass and trees, has been proposed an alternative for the common practice of poultry litter application to pastures. Poultry litter was applied at three rates (0, 11.2 and 33.6 Mg ha^{-1}) to three managed vegetation systems (*Festuca arundinacea* Schreb. pasture, *Pinus taeda* L. plantation and a silvipasture system combining the two species). Following poultry litter application, short-term fate of N and P was monitored and three-year pine growth response was measured. Results indicate somewhat improved N and P nutrition and positive growth response of both pine and grass to litter application. Ammonia volatilization was the greatest pathway of N loss and loss through denitrification was minimal. Estimated loss of NH_3-N during a 96-hour period following June litter application ranged from 0.2 to 15.3 kg ha^{-1}. Average soil solution NO_3-N concentrations at 1-m depth exceeded 16 mg L^{-1} on one occasion in the pine plantation during the spring following application. Average concentrations did not exceed 2.21 mg L^{-1} in either the silvipasture or pasture. These results indicate that silvipastures can offer an alternative for poultry litter utilization while retaining many aesthetic and financial benefits associated with trees.

INDEX WORDS: Poultry Litter, Agroforestry, Silvipasture, Ammonia Volatilization, Nitrate Leaching, Denitrification, *Pinus taeda*, *Festuca arundinacea*

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B.S., Geneva College, 1993

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

MASTER OF SCIENCE

ATHENS, GEORGIA

2002

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December 2002

DEDICATION

I would like to dedicate this thesis to my two dear angels, Ariana and Asher, and to Scott, my soul mate and best friend. You have made my life complete and I am grateful for the love and the joy that you bring me each and every day. Thank you for giving me the inspiration that I needed to achieve my dream. Es Jūs mīlu ar visu savu sirdi!

ACKNOWLEDGEMENTS

I would like to thank my major professor, Dr. Larry Morris, for all of his time, help, patience and encouragement. Thanks for not giving up on me Larry! Thank you also to the other members of my committee- Dr. Miguel Cabrera, Dr. Parshall Bush and Dr. Klaus Steinbeck for their valuable advisement.

Thank you to Martha Campbell for all of the time and effort that she spent trying to interpret some of my very complicated lab results. Thank you also to Lee Ogden for helping me with SAS and all of those other complex tasks that were necessary for this project.

I would especially like to thank my husband Scott and my two beautiful children, Ariana and Asher, for being so patient and understanding throughout this challenging journey. A great big thank you to my wonderful parents for encouraging me to finish my degree. I thank them not only for their prayers and support, but also for teaching me about perseverance! Most of all, I thank God for giving me the strength to complete this goal.

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CHAPTER 1

INTRODUCTION

Since the late 1980's, an increase in poultry production has led to rapid growth of the poultry industry in Georgia and surrounding states (Sharpley, 1995). Currently, over 13 billion kg of poultry litter and/or manure are produced annually in the U.S. with over half of this production in the following five states: Georgia, Alabama, Arkansas, North Carolina and California (Moore, 1998). Since many poultry operations are concentrated on small farms having limited acreage, manure disposal is a common problem (Moore, 1995b).

Poultry manure contains high levels of nitrogen (N), phosphorus (P), potassium (K) and many micronutrients. This valuable source of nutrients has the potential to support crop production, as well as to enhance the chemical and physical properties of soil (Hammond, 1994). Except for a small portion used in animal feed, more than 90% of the manure produced in the United States is applied to agricultural land as a low-cost alternative to mineral fertilizers (Moore, 1995b).

To avoid adverse impacts, the amounts of manure that can be applied to agricultural land must be tied to crop requirements and soil assimilative capacity. Many available areas are approaching full utilization (Robinson et al., 1996). Excessive application of poultry manure can lead to serious environmental degradation. In particular, nitrate (NO_3^-) contamination of surface and groundwater has been a major concern. The negative charge of the nitrate ion (NO_3^-) is repelled by negatively charged clay particles in the soil, making it susceptible to leaching. High concentrations of nitrate can adversely affect the health of humans and animals. Methemoglobinemia or "blue baby" syndrome can be a fatal condition that affects infants under the age of nine months who drink water or are breast-fed by mothers who drink water containing high levels of nitrates (Lee, 1994). Under the Safe Drinking Water Act (Public Law 93-523), the U.S. Environmental Protection Agency established drinking water standards for all potential contaminants and set the maximum contaminant level for nitrate at 10 mg l^{-1} (Fetter, 1994). Tyson et al. (1995) sampled 3,419 domestic wells in Georgia between 1989 and 1993, in areas where livestock or poultry were raised. They found that 3.8% of the shallow wells (less than 100 feet deep) and 0.9% of the deep wells (greater than 100 feet) exceeded the nitrate levels established by the Environmental Protection Agency.

Phosphorus is another potential contaminant associated with poultry waste. When poultry waste is land-applied, it is typically based on N crop requirements, however, crop requirements for P are much less than N and any that is not assimilated by plants is vulnerable to surface runoff. Generally, soils have a high capacity to retain litter-applied P, but long-term application or soil erosion can lead to eutrophication of water which can cause low dissolved oxygen, increased algal blooms, fish kills and other negative impacts associated with diminished water quality.

Because of their efficient nutrient uptake, agricultural and pasturelands are often desired for manure application. However, full utilization of these areas has led to a need for development of alternative systems that can benefit from poultry litter application. Litter application to forests has been a useful alternative, and forest lands are generally available in poultry producing areas of the Piedmont; however, forest application requires a much larger area of land because the level of nutrient uptake is considerably less (Nutter, 1997). The application and even distribution of litter is also a management obstacle in forest plantations.

Agroforestry, which integrates agricultural and timber production on the same unit of land, has been proposed as an alternative land use system which may have more economic and environmental benefits than either agriculture or forestry alone (Campbell, 1989). Silvipasture, an agroforestry system that combines grass and trees, may be a practical alternative for the utilization of poultry litter. The two-tiered root system of the grass and tree combination should increase the efficiency of nutrient uptake. The shallow grass roots intercept nutrients that enter the soil profile while the deeper tree roots assimilate nutrients moving below the grass root zone (Robinson et al., 1996). Fescue grass (*Festuca arundinacea* Shreb.), a dominant perennial pasture grass in the Southern U.S., has been reported to have improved productivity with increased levels of shade, which should also enhance the uptake of nutrients (Strizke et al., 1976). Analyses from the EPIC (Erosion Productivity Impact Calculator) model predict that nitrate leaching decreases in a fescue and pine tree combination (Robinson et al., 1996). Nitrate leaching in a silvipasture system is expected to be 25 to 30 % lower than in a fescue pasture and approximately 10% lower than that of a forest system. A silvipasture system would not only help to solve the problem of limited land areas for poultry litter disposal, but the increased interception of nutrients would reduce the potential risk of nitrate contamination of groundwater.

This study provides initial data on potential for N loss, plant uptake and soil accumulation in three vegetation systems: pasture, silvipasture and pine plantation following a one-time poultry litter application. Additionally, short-term grass growth and three-year tree growth response to poultry litter application is evaluated.

CHAPTER 2

LITERATURE REVIEW

Two wastes commonly associated with poultry production include manure and litter. Laying hen operations produce manure, which is a mixture of poultry feces and urine. The hens are raised in cages constructed over large pits, which receive undiluted manure from the birds (Moore, 1998). Broiler operations typically utilize floor systems, which are single-story houses that have either earth or concrete floors with 5 to 15 cm of bedding material (Sims and Wolf, 1994). These operations produce litter, which is a combination of manure, feathers, feed, and bedding material such as wheat straw, sawdust, wood shavings, peanut hulls or rice hulls (Edwards and Daniel, 1992). The majority of waste (68%) produced in the U.S. is in the form of poultry litter (Moore, 1998).

Poultry litter is a valuable source of nitrogen (N), phosphorus, (P), potassium (K), and other nutrients and trace elements. The composition and nutrient content of litter is influenced by the age and breed of birds, concentration of birds, type and amount of feed, type of bedding, floor type, moisture content of litter and climatic conditions during accumulation (Perkins et al., 1964). Kunkle et al. (1981) studied the effect of flock number on the nutrient content of broiler litter and found that each additional flock of birds increased concentrations of major nutrients from 10 to 15%. Wiese (1991) pointed out that the method of collection, storage method, and method of application also influenced the nutrient content of litter.

This valuable source of nutrients has the potential to support crop production, as well as to enhance the chemical and physical properties of soil (Hammond et al., 1994). Soil structure, tilth, water-holding capacity, water infiltration rate, and microbial activity are properties that can be enhanced by organic matter in poultry manure (Smith and Kemper, 1991). Poultry litter is characterized as the most valuable animal waste for fertilizer use because of a low water content and high concentration of nutrients. (Moore, 1998). Except for a small portion used in animal feed, more than 90% of the manure produced in the United States is applied to agricultural land as a low cost alternative to mineral fertilizers (Moore, 1995b).

Because of the high N requirements of plants and the low N-supplying capacity of many soils, application rates are typically based on the ability of the poultry litter to supply N (Cabrera and Gordillo, 1995). In order to efficiently manage poultry litter as a source of N, it is important to understand the transformations that take place in the soil and the contributions of the litter to the soil N budget (Sims, 1986). Nitrogen added to a site from land-applied litter can accumulate as either organic or mineral N in the soil, or lost through NH_3 volatilization, denitrification, or leaching beyond the root zone or removed by crop uptake (Sharpley et al., 1998).

Mineralization

Poultry litter contains organic and inorganic forms of N, with a greater percentage existing in the organic form (Bitzer and Sims, 1988). Available forms of N for plant uptake are in the inorganic forms of nitrate (NO_3^-) and ammoniacal-N (NH_4^+). Mineralization, a process mediated by microorganisms, converts organic N to available forms of inorganic N. This two-step process consists of ammonification, which converts organic N to an ammoniacal form, and nitrification, which converts ammoniacal nitrogen to nitrate. Mineralization rates are influenced by the characteristics of the poultry litter, the soil and climatic conditions.

A number of investigators have found that N mineralization from poultry litter can be described using a two-pool model. For example, in an incubation study Hadas et al. (1983) found that poultry manure mineralization in soil resulted in an initial rapid phase followed by a slow release of mineral N. During the first week after application, the initial rapid phase mineralized between 34 and 44% of the total N. After 2 to 3 months, 34 to 50% was mineralized during the slow release phase.

The results from another incubation study that examined the effect of selected litter characteristics on mineralization also supported the two-pool model (Gordillo and Cabrera, 1997a). This study showed that 70-96% of the fast pool (50% of the total N) mineralized within 24 hours and >98% of the slow pool mineralized after the 112 day incubation period. From these results, it was determined that the fast pool of mineralizable N could be estimated by the uric acid concentration in the litter. Potentially mineralizable N (fast + slow pools) could be estimated from uric acid and total N concentrations, or from uric acid concentration and C/N of the litter.

Differences in soil properties must also be considered when estimating mineralizable N. Gordillo and Cabrera (1997b) conducted a study to determine the effect of selected soil characteristics on the rate and amount of decomposition of potentially mineralizable N in litter. This study identified that pH and the ratio of sand content/water content at field capacity were soil characteristics that had a significant influence on the fast and slow pools of mineralizable N.

In an incubation study, Sims (1986) evaluated the effect of different temperature and moisture levels on nitrogen mineralization in soil amended with poultry manure. The author found that most of the net N mineralized within 90 days at temperatures of 25° and 40°C and temperatures of 0°C reduced mineralization. Moisture stress inhibited N mineralization, but adequate moisture resulted in 30 to 60% mineralization of organic N. From this investigation, the author concluded that cold, dry conditions could lead to an accumulation of NH_4-N, which increases soil pH. Warm, moist conditions can result in rapid nitrification of NH_4-N, which acidifies the soil.

Ammonia Volatilization

Loss of NH_3 through volatilization reduces the fertilizer value of poultry litter and increases the potential application rates by decreasing the N content. Poultry litters have a high potential for NH_3 volatilization and high concentrations of atmospheric NH_3 in poultry houses have been shown to adversely affect the health of birds and farm workers (Moore, 1998).

The role of NH_3 emissions as an environmental pollutant is a growing concern. According to ApSimon et al. (1987), livestock wastes and fertilizer applications are the dominant source of NH_3 in the atmosphere. They found that NH_3 emissions over Europe had increased approximately 50% between 1950 and 1987. Van Breemen et al. (1982) pointed out that ammonia, volatilized from manures, and sulfur dioxide, from fossil fuels, combine to form ammonium sulfate. When rainwater deposits ammonium sulfate, it is oxidized in the soil to nitric and sulfuric acid, which results in extremely low pH values (2.8-3.5) and high concentrations of dissolved aluminum in non-calcareous soils.

Hutchinson and Viets (1969) studied the absorption of NH_3 volatilized from cattle feedlots by nearby surface waters (distances between 0.4 and 2 km) and found that absorption rates were up to 20 times greater at sites near feedlots than at control sites. They determined that NH_3 absorbed from the air by water surfaces near feedlots was significantly higher than NH_3 deposited by precipitation. Nitrogen enrichment of streams and lakes could lead to eutrophication, which is defined as an increase in nutrient concentration of surface waters causing an acceleration of algae or water plant growth, depletion of dissolved oxygen and increased turbidity (Sims and Wolf, 1994). These problems can lead to serious degradation of water quality, which could result in fish kills and other undesirable consequences.

Ammonia volatilization is greatest immediately following the land application of animal waste and is a significant pathway of N loss (Reddy et al., 1979). Several studies have shown that NH_3 volatilization is greatest immediately after application and decreases with time. For example, Schilke-Gartley and Sims (1993) found that volatilization from surface applied litter was 4 to 31% of the total N within 12 days. Marshall et al. (1998) applied broiler litter to a tall fescue pasture (*Festuca arundinacea* Schreb.) in the Southeast USA and found that a sharp increase in volatilization occurred 1 to 3 days after litter application and that rates had rapidly decreased to normal levels within 10 days.

Ammonia loss is greatly affected by environmental conditions, soil properties, composition of the litter and the time and method of application. An increase in atmospheric temperature is an important environmental condition that has been related to increases in volatilization rates (Reddy et al., 1979; Beauchamp et al., 1982; Nathan and Malzer, 1994). Studies have shown that a positive correlation between wind speed (or the movement of air) and NH_3 loss also exists. Lauer et al. (1976) found that evaporative conditions that lead to sustained drying, such as continuous air movement and high temperature, increased the process of volatilization. Hutchinson and Viets (1969) also detected maximum volatilization rates when cattle feedlot surfaces were undergoing rapid drying conditions and minimum losses during times of low evaporation.

Nathan and Malzer (1994) reported a significant positive correlation between volatilization rates and atmospheric temperature, wind speed and soil temperature. They reported that NH_3 fluxes followed a diurnal pattern where maximum loss was measured during the middle of the day, when soil temperature and wind speed was highest, and minimum losses early in the morning, when soil temperature was lowest and relative humidity the highest.

Beauchamp et al. (1982) found that rainfall is another environmental factor that influences NH_3 volatilization. During their studies, they observed that rainfall temporarily suppressed volatilization. The authors noted that NH_3 fluxes increased substantially after the rain events ended. Temperature fluxes were also associated with the increases and decreases in volatilization and precipitation, which made it difficult to determine exactly what effect the rain had on the loss of NH_3.

Certain characteristics of poultry litter will determine the amount of NH_3 lost through volatilization following land application. Since volatilization is a pH dependent process, the pH of the litter is an important factor. Poultry litter is an alkaline material with a pH ranging from 7.5 to 8.5 (Sims and Wolf, 1994) and a high pH can increase the ratio of NH_3/NH_4, resulting in greater volatilization rates (Moore, 1998). Studies have shown that decreasing the pH of poultry litter using chemical amendments has been a successful approach to reducing NH_3 volatilization (Moore et al., 1995a). The moisture content of litter will influence also volatilization rates. Cabrera et al. (1994a) found that increasing the water content of whole litter and fine fraction significantly increased volatilization potentials.

Soil properties have been documented as factors that influence volatilization rates as well. Higher losses of NH_3 have been associated with increases in soil temperature and soil moisture (Adriano et al., 1974; Nathan and Malzer, 1994). Texture has also been recognized as an important soil property that can influence NH_3 volatilization. Chao and Kroontje (1964) reported larger NH_3 losses from coarse textured soils, while losses from fine textured soils were proportional to their soil pH. Avnimelech and Laher (1977) found that soil pH and buffering capacity are factors that can influence volatilization rates.

The method of application will have a great effect on the amount of NH_3 lost through volatilization. Surface application has been associated with higher ammonia volatilization rates than incorporation, because soil incorporation reduces the direct exposure of the litter to environmental conditions that promote NH_3 volatilization. Nathan and Malzer (1994) reported 23 times lower volatilization rates from incorporated poultry manure than surface applied manure. Schilke-Gartley and Sims (1993) found that surface applied poultry litter resulted in a 20% average loss of total N through volatilization, whereas immediate incorporation reduced losses to only 3% of the total N applied.

Denitrification

Denitrification is a microbially mediated process. It is a second pathway through which atmospheric loss of N can occur following poultry litter application. It is generally thought to be a less important pathway since microbially available C, the presence of NO_3^- and anaerobic conditions, from an intense rainfall or a high water table, are all necessary for denitrification to occur (Edwards and Daniel, 1992). As with ammonia volatilization, soil characteristics can be important in determining rates. For example, sandy soils that are well aerated will result in greater NO_3^- losses through leaching, whereas clay soils can create anaerobic conditions, which favor the loss of NO_3^- through denitrification (Pratt, 1979). Johnson and Wolf (1995) found that soils must be aerobic for a period of time long enough for nitrification to supply NO_3^-, but not long enough for microbes to deplete the available C necessary for denitrification to occur. Broadbent and Clark (1965) explained that “aerobic denitrification” could occur in soils with adequate oxygen such as fine-textured soils. Although the larger pores are filled with air, the smaller pores can be filled with water developing anaerobic microsites where denitrification can occur.

Rolston et al. (1978) applied manure to a Yolo loam soil and monitored denitrification rates under different soil temperature and moisture levels. Under anoxic conditions and temperatures of 23°C the amount of N_2 produced was between 6 and 20 times greater than N_2O production. Very little denitrification occurred at a soil temperature of 8°C or below, indicating that microbial activity was impacted. The presence of crops also increased denitrification rates due to the addition of available C necessary for denitrification.

Cabrera and Chiang (1994b) incubated poultry litter at four water contents for 13 days to evaluate denitrification losses. They found that denitrification was significant at the highest water content and increased with the addition of NO_3^- (15 mg N g^{-1}). The authors found that between 41 and 79% of the initial NO_3^- was lost through denitrification.

Marshall et al. (1999) quantified N loss through denitrification from tall fescue (*Festuca arundinacea* Schreb.) for 2 years following broiler litter application in the Southeast USA. They found that total loss of N gas represented less than 5% of the total N applied. From this study, the authors concluded that denitrification rates were highly variable and that the land application of broiler litter to pastures in the Southeast minimally impacts trace gas emission into the environment.

Nitrate Leaching

During the process of nitrification, ammoniacal N is oxidized to form nitrate. The negative charge of the NO_3^- ion is repelled by negatively charged clay particles in the soil, making it susceptible to leaching (Tyson et al., 1995). Any NO_3^- that is not used by plants or converted to gas through denitrification will ultimately be available to leach through the soil profile and possibly into the groundwater. Nitrate contaminated groundwater is another growing environmental concern that has been linked to confined animal operations and the agricultural industry.

High concentrations of NO_3^- in drinking water can be detrimental to the health of humans and animals. Methemoglobinemia or “blue baby” syndrome is a toxic condition that can occur when bacteria in the digestive tract reduces NO_3^- to NO_2^- (nitrite), which then oxidizes iron in the hemoglobin molecule, interfering with oxygen transport (Sims and Wolf, 1994). Infants are particularly sensitive to this because their stomachs are not acidic enough to suppress the bacteria responsible for reducing NO_3^- to NO_2^-. Under the Safe Drinking Water Act (Public Law 93-523), the U.S. Environmental Protection Agency established drinking water standards for all potential contaminants, setting the maximum contaminant level for NO_3-N at 10 mg/liter (Fetter, 1994).

Between 1989 and 1993, Tyson et al. (1995) sampled 3,419 domestic wells in Georgia to determine the extent of NO_3^- contamination. They found that 3.8% of the shallow wells (less than 100 feet) and 0.9% of the deep wells (greater than 100 feet) exceeded the nitrate levels established by the EPA. The results from this study showed that shallow groundwater contamination was associated with livestock and poultry operations.

Ritter and Chirnside (1984) conducted a groundwater study in Delaware and found that 32% of coastal and 21% of non-coastal Sussex County had average NO_3-N concentrations exceeding 10 mg/L NO_3-N. They determined that NO_3^- contamination in four out of the five top ground water problem areas were directly related to poultry manure. Kingery et al. (1994) studied the impact of long-term land application of broiler litter and reported significant accumulation of NO_3^- in the soil at or near bedrock, which greatly increases the potential for groundwater contamination.

Nitrate contamination of groundwater has typically been related to areas that have vulnerable water resources such as shallow aquifers or coarse textured soils and excessive N additions from fertilizer inputs or high animal densities (Sharpley et al., 1998). Hydrologic and environmental conditions that promote leaching such as high rainfall, irrigation or limited crop uptake are also factors that could be responsible for these areas having excessive NO_3^- levels in groundwater.

The application of poultry manure or litter in excess of crop requirement will result in the movement of NO_3^- through the soil (Liebhardt et al., 1979). Adams et al. (1994) reported that concentrations of NO_3^- in soil solution increased with higher application rates of poultry litter. These investigators suggested that application when crop uptake and microbial activity is highest, such as late spring or early summer, would decrease NO_3^- loss through the soil profile. Additionally, to avoid NO_3^- contamination of groundwater, the land application of poultry litter should not only be tied to the crop requirement, but it should be applied when environmental conditions, such as high rainfall, do not promote leaching.

Plant Uptake

Agricultural Crops and Pasture Grasses

Many studies have documented the benefits of poultry litter or manure application for agricultural crops and pasture grasses. Perkins et al. (1964) reported significant yield responses of corn, cabbage, cotton, oats, and grass-legume mixtures to poultry manure additions. Increased yields of tall fescue (*Festuca arundinacea* Schreb.) (Vandepopuliere et al., 1975; Hunneycutt et al., 1988) and bermudagrass (*Cyndon* *dactylon* (L.) Pers.) (Hunneycutt et al., 1988; Wood et al., 1993) have also been reported from poultry litter applications.

Application rates in excess of a crops ability to utilize all of the nutrients can, however, have negative effects on the plants being fertilized. Shortall and Liebhardt (1975) found that the germination and yield of corn (*Zea Mays* L.) was significantly reduced by excessive soil salinity as a result of high layer manure applications. Vandepopuliere et al. (1975) determined that poultry manure application rates exceeding 100 Mg ha^{-1} decreased fescue yields. Lucero et al. (1995) found that rates of 22.9 Mg ha^{-1} and above depressed the growth of fescue and bluegrass. Vest et al. (1994) recommended that poultry litter application to fescue and orchargrass should not exceed an annual rate of 13.4 Mg ha^{-1}.

Excessive litter application to pasture grass can also negatively affect the health of grazing cattle. Stuedemann et al. (1975) studied the health and performance of beef cattle grazing fescue that had been fertilized with broiler litter. They observed a higher incidence of grass tetany and fat necrosis in cattle that had grazed the litter-amended pastures and recommended that broiler litter fertilization of fescue should not exceed 9 Mg $ha^{-1}yr^{-1}$.

Agroforestry and Forestry

Because of their efficiency at nutrient uptake, agricultural and pasturelands are often desired for poultry litter and manure application. However, full utilization of these areas has led to a need for the development of alternative systems that can benefit from litter application.

Agroforestry, which integrates agricultural and timber production on the same unit of land, has been proposed as an alternative land use system which may have more economic and environmental benefits than either agriculture or forestry alone (Campbell, 1989). Silvipasture is an agroforestry system that combines trees with pasture grass, typically for livestock forage. Silvipasture systems are the most common form of agroforestry in the southern U.S. (Zinkhan and Mercer, 1997).

In a 20-year silvipasture study, Lewis et al. (1983) compared slash pine (*Pinus elliottii*) planted in fertilized Coastal bermudagrass (*Cynodon dactylon*), dallisgrass (*Paspalum dilatatum*) and Pensacola bahiagrass (*Paspalum notatum*) to slash pine planted in native vegetation. The trees grown in pasture produced considerably more growth in diameter, height, and harvestable wood than trees grown in native vegetation. In a similar study, Clason (1995) found that Coastal bermudagrass (*Cynodon dactylon*) established in a 20-year-old loblolly pine (*Pinus taeda* L.) plantation enhanced timber production and maintained a high quality forage resource after 5 years.

An agroforestry study conducted in Sweden found that the presence of trees increased the utilization of nitrogen and moisture in the soil, reducing the potential for NO_3^- leaching and accumulation of N (Browaldh, 1995). A silvipasture system may offer a practical alternative for the utilization of poultry litter because the two-tiered root system of the grass and tree combination should increase the efficiency of nutrient uptake. The high root densities of grass make it very effective at water and nutrient uptake and competition (Campbell, 1989). The deep and spreading roots of trees in a silvipasture system will utilize water and nutrients from depths of the soil profile that the shallow grass roots cannot contact, reducing the loss of nutrients beyond the nutrient absorbing zone of the soil (Nair, 1984). Trees also provide the beneficial role of soil conservation by protection against erosion and improvement of soil physical properties such as permeability, water-holding capacity and aggregate stability (Nair, 1984).

Although no research has yet tested the effectiveness of a silvipasture system for the utilization of poultry litter, one particular study in Spain compared the response of a silvipasture fertilized inorganically to a silvipasture amended with milk sewage (Rodriguez et al., 2000). Due to the slow release of nutrients in the milk sewage, the trees increased significantly in diameter and height and the pasture production was improved. The inorganic fertilizer increased grass productivity, but because of competition, tree growth rates were relatively slow.

Fescue grass (*Festuca arundinacea* Shreb.), a dominant perennial pasture grass in the southern U.S., has been reported to have improved productivity with increased levels of shade (Strizke et al., 1976). They found that the best production of fescue occurred under 63% shade and that the concentration of NO_3-N in the forage also increased significantly with shading levels. Analyses from the EPIC (Erosion Productivity Impact Calculator) model have shown that NO_3^- leaching decreases in a fescue and pine tree combination (Robinson et al., 1996). Nitrate leaching in a silvipasture system is expected to be 25 to 30 % lower than in a fescue pasture and approximately 10% lower than that of a forest system. Loblolly pine production is limited by the lack of available soil nitrogen in many areas of the southeast U.S. (Zinkhan and Mercer, 1997), therefore, poultry litter applied to a silvipasture with loblolly pine and fescue could provide the nitrogen and other nutrients necessary for pine production as well as pasture improvement. A silvipasture system would not only help to solve the problem of limited land areas for poultry litter disposal, but the increased interception of nutrients would reduce the potential risk of nitrate contamination of groundwater.

Although poultry litter application to forests can offer a useful alternative, and forest lands are generally available in poultry producing areas of the Piedmont, forest application requires a much larger area of land as the level of nutrient uptake is considerably less (Nutter, 1997). The application and even distribution of litter is also a management obstacle on forest plantations.

Samuelson et al. (1998) studied the influence of poultry litter on an 18-year-old loblolly pine (*Pinus taeda* L.) stand. They found that the average stem diameter had increased 38% and that foliar N and P concentrations had also increased as a result of a one-time application of poultry litter at 10 Mg ha^{-1}.

Bush and coworkers (Bush et al. 1998; 1999) studied the use of poultry litter and pelletized poultry litter as a P source on P-deficient sites at pine stand establishment. These investigations showed that pelletized poultry litter could serve as a source of P on deficient sites that would normally be fertilized with diammonium phosphate or triple super phosphate. However, the potential for such uses to significantly impact poultry litter management are limited because of low application rates appropriate for young plantations.

Most soils beneath pine plantations have low P concentrations and provide a large sink for P applied in poultry litter. Moreover, it is clear that poultry litter has the potential to improve tree growth in pine plantation systems. However, pine plantations have a relative low demand for N, and application rates necessary to control leaching from pine plantations may be so low as to provide relatively little opportunity for litter utilization. Silvipastures provide the benefits of plantations and may improve N uptake. It is unclear how these systems compare when all aspects of N uptake, loss and accumulation are evaluated.

The objectives of this study were to evaluate the potential for loss of N through selected pathways in pasture, silvipasture and pine plantation systems and to determine growth response to poultry litter application. Specifically, to 1) determine if NO_3^- leaching potential is less in a silvipasture system than in a pure grass or pine plantation system, 2) evaluate the initial fate of poultry litter-applied N and P and 3) determine plant growth response to poultry litter application.

CHAPTER 3

MATERIALS AND METHODS

Response to a one-time application of broiler litter at three rates (0, 11.2 and 33.6 Mg ha^{-1}) was studied in existing pasture, silvipasture and pine plantation in the Piedmont of Georgia. Following application, ammonia volatilization, denitrification and soil solution concentrations were monitored. Additionally, grass uptake and pine growth and uptake were evaluated.

Site Description

The research for this study was conducted at the Dempsey Research Farm located at the University of Georgia Agricultural and Environmental Sciences Experiment Station in Griffin, Georgia. This area is characterized by a 30-year average annual precipitation of 127-137.16 cm a year. The precipitation between November 1998 and November 1999 was below average (Fig. 1) and results from this study reflect these extremely dry conditions. The soils of the study area are representative of the major poultry-producing Piedmont region of Georgia and adjacent states, and are typified by soils of the Cecil series (Typic Kandiudult). The research site consisted of a large fescue grass (*Festuca arundinacea* Shreb.) pasture, a loblolly pine (*Pinus taeda* L.) plantation and a silvipasture system combining the two species. The silvipasture plantation consisted of two adjacent rows of loblolly pines planted 0.91 m apart in an east-west orientation,

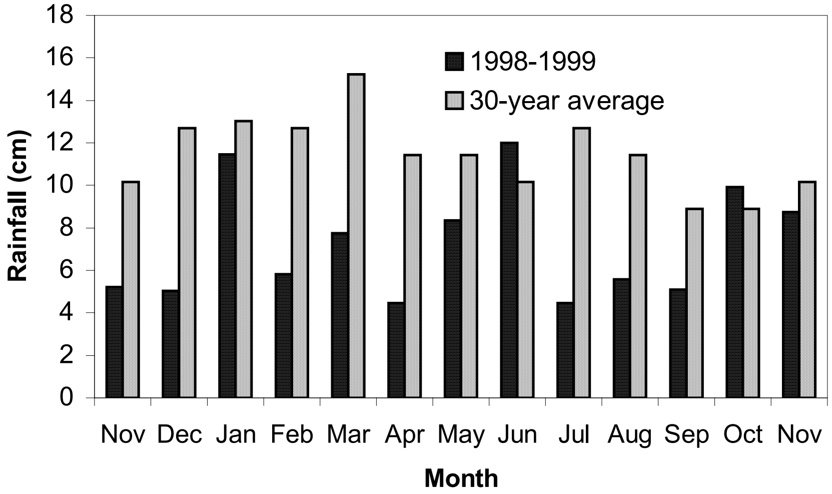

Fig. 1. Long-term average precipitation and precipitation during the study period for Griffin, GA.

alternating with approximately 9.15 m feet of fescue grass. The trees in the loblolly pine plantation were arranged in 2.4 x 2.4 m spacings. All of the trees in the pine plantation and silvipasture areas of the research site were planted in 1987. The exact time of establishment of the grass pasture is unknown.

Because this particular site was not originally established as a replicated experiment, it was assumed that the establishment of plots based on soil condition and landscape position was adequate and that differences would occur as a result of litter treatment levels. Nine (20.5 x 22.7 m) gross plots were established in each of the vegetative systems. These nine plots were subdivided into 3 blocks based on proximity, slope, soil profile characteristics and vegetation condition. All data and measurements were collected from smaller net plots, which were created by leaving a 3.6 x 3.6 m buffer within each treatment plot.

The three litter application rates were randomly assigned to the three plots within each of these blocks within each vegetation type. Application rates were: 0 Mg ha^{-1}, 11.2 Mg ha^{-1} (5 tons/acre), or 33.6 Mg ha^{-1} (15 tons/acre). These rates were selected based on typical application rates and expectations for nitrate movement from EPIC modeling completed by the National Agroforest Research Center.

The low application rate was within the range of recommended litter application rates to pastures of 9 to 11 Mg ha^{-1}. Nitrogen loading at this application rate was expected to be between 200 and 300 kg ha^{-1}, which is within the range of inorganic N additions typically applied to commercial mid-rotation loblolly pine stands throughout much of the Southeast. This application rate was not expected to promote N movement below the root zone.

Mid-rotation pine plantations are fertilized periodically at 3 to 5 year intervals. The high application rate represents the cumulative loading expected over a 3-year period under normal pasture application applied to a pine plantation at one time so as to correspond to an equivalent annual application. Thus, it is much higher than a typical single application and was expected to promote N movement below the root zone.

It should be noted that this design was superimposed upon existing vegetation conditions. With this design, comparisons among litter application rates within vegetation types could be analyzed using appropriate GLM. However, comparisons among vegetation types could not be similarly analyzed since randomization of vegetation systems upon the site was impossible. Furthermore, some of the pre-treatment analyses showed that differences existed among vegetation systems. Consequently, information is provided on mean characteristics and variability only.

Poultry Litter Application

Poultry litter was delivered to the research site by Sargent Nutrients Inc., from Murrayville, Georgia, and applied to the plots the first week of November, 1998. Two Bobcat ® front-end loaders moved litter to each plot where rakes and shovels were used to spread the litter evenly within each plot at the assigned application rates.

Litter Characteristics

Moisture contents were determined by drying litter samples for 48 hours at 65°C. Litter pH was measured in a 1:5 litter and deionized water suspension using an Orion Research 520A pH meter (Orion Research, Boston, MA). Total N and P were determined following acid digest procedure No. TA4-0323-00 (Official Methods of the AOAC) and analyzed on an Alpkem FS 3000 autoanalyzer (OI Analytical, College Station, Texas). Nitrate-N and NH_4-N were also determined colorimetrically using the same autoanalyzer after litter samples were shaken in 40 mL of 2*M* KCL for 30 minutes and filtered through No.42 Whatman filter paper. The salicylate method was used for NH_4-N determination and cadmium reduction for NO_3-N detection (Methods of Soil Analysis, 1996).

Known tissue standards (NIST Standard Reference Material, Gaithersburg, MD), one or more laboratory blanks and 10% sample duplications were included for each set of samples prepared for analysis to ensure quality. If standard tissue or duplicate samples varied by more than 5%, samples were rerun. Analytical instrument QC standards (Environmental Resource Associates, Arvada, CO) were also used for each analytical run to ensure instrument quality. These quality assurance procedures were followed for all laboratory analyses conducted during this research project.

Soil Sampling

During July 1998, pre-treatment soil samples from depth increments of 0-10 cm, 10-20 cm, 20-40 cm, 40-80 cm and 80-100 cm were collected using a 7.5 cm diameter bucket auger. Soil samples from four different holes per plot were composited for each depth increment. Acid digestion procedure No. TA4-0323-00 (Official Methods of Analysis of the AOAC) was used to digest soil for N and P. Industrial Method No. 325-74W was used for N and Industrial Method No. 327-74W for P detection for the Technicon Autoanalyzer II (Bran and Luebbe Analyzing Technologies, Buffalo Grove, IN).

Five months after the poultry litter was applied (April 1999), post-treatment soil samples were collected for comparison. These soil samples were analyzed using the same methods.

Soil Solution Sampling

A total of 63 ceramic cup lysimeters were constructed and installed at a depth of 1 meter during the winter of 1998. Two lysimeters were placed in each pasture and pine plantation plot. Each silvipasture plot was instrumented with 3 lysimeters, one at each of the following locations: within the row of trees (40-60% pine canopy cover), between the fescue and the trees (20-40% pine canopy cover), and in the middle of the fescue lanes (0% pine canopy cover). Soil water samples were collected in Nalgene bottles, and transported to the laboratory for analysis. Digestion procedures for Total N and Total P were followed using standard methods from the U.S. EPA's Standard Methods for the Examination of Water and Wastewater (1998). All water samples were analyzed using a Technicon Autoanalyzer II (Bran and Luebbe Analyzing Technologies, Buffalo Grove, IN). The automated phenate method was used for NH_4-N determination and the cadmium reduction method was used for analysis of NO_3-N (U.S. EPA Standard Methods, 1998). These samples were also analyzed for copper, arsenic, boron and zinc using U.S. EPA method 200.8 on a Perkin Elmer Elan 6000 (Perkin Elmer Instruments, Shelton, CT).

Sampling was conducted for 10 consecutive months after poultry litter was applied, however, due to the lack of rainfall, most sampling periods failed to produce sufficient sample numbers and/or volume for analyses. Soil solution samples were successfully retrieved and analyzed only during February, March and April of 1999.

Gaseous Loss

The gas flux portion of the study began immediately following the poultry litter application. Monitoring of ammonia and nitrous oxide was done using a modified version of the large static gas chambers described by Dulohery (1993). The bases for these gas chambers were 0.5 x 1.0 m in dimension and were constructed from stainless steel. The tops of the chambers were constructed from Plexiglass® and measured 100 cm long, 50 cm wide and 20 cm tall. Each contained a battery operated fan (Sunon™ model ST1208PTSI) and a sample port with a septum. Chambers were modified from those described by Dulohery (1993) by placing impermeable weather-stripping in the chamber bases to eliminate the use of water for creating a seal with the chamber tops. Early laboratory investigations using these chambers indicated that the water was trapping ammonia, which resulted in low and erratic recovery rates. Stainless steel hooks were welded to the sides of each base to secure cords around the chamber tops to the bases, ensuring a good seal. Immediately after poultry litter application, the chamber bases were installed. The pasture and pine plantation had 3 bases installed, one for each treatment level. The silvipasture had a total of 9 bases, 3 bases for each treatment level-one within each of the 3 levels of canopy cover within each plot.

Denitrification

Since denitrification requires anoxic conditions, sampling for nitrous oxide was to be done following several major rain events (2.5 cm or greater) between November 1998 and July 1999. Due to the lack of rainfall during the study, actual sampling periods were rare, producing only four sets of samples. During each sampling period, the Plexiglass® chamber tops were carried to each base and placed within the troughs. Two cords were placed around each chamber top and secured in the stainless steel hooks on the bases, creating an airtight seal. Each chamber was covered with a plastic reflective material to prevent temperature increases in the enclosed space. Fans were then turned on to evenly distribute air within the chambers, and the first set of samples was immediately withdrawn from the septa in the sampling ports. When a chamber was being sampled, 3 ml of gas was withdrawn using a hypodermic needle and placed in a 2 ml glass serum vial. Samples were withdrawn again at 60 and 90 minutes to test for linearity. The glass vials were placed in a cooler for storage until returned to the laboratory for analysis.

N_2:N_2O Ratio

The atmosphere has a large background level of N_2, which makes it very difficult to estimate concentration changes in the field. The acetylene inhibition technique was used to provide information on the ratio of N_2 to N_2O produced in the field (Tiedje, 1982). Soil cores were collected at the same time that chambers were being sampled for nitrous oxide. Soil cores were sampled using 15 cm thin-walled polyvinyl chloride pipes (PVC). The PVC pipes were hammered into the ground near the chambers with a rubber mallet and then removed with the soil cores intact. The bottom of each pipe was covered with a PVC cap and the tops were covered with plastic wrap and a rubber band. The soil cores were transported back to the laboratory in a cooler and refrigerated overnight. Soil (at 5 cm depth) and air temperatures were measured using a Taylor™ model 5367 thermometer at this time.

The next day, the plastic wrap was removed from the cores and replaced with rubber stoppers. Each stopper contained a sampling port with a septum. Each soil core tube was equilibrated with the atmospheric pressure by inserting a stainless steel hypodermic needle into each septum. Each core was then incubated at the temperature recorded in the field for 5 hours in a Precision ™ TS-31213-AN-10 Model 816 Low Temperature Incubator (Precision Scientific Group, GCA Corporation, Chicago, IL). After the incubation period, 3 ml of gas was removed from each soil core and stored in a 2 ml glass serum vial for analysis. All soil cores were then opened and aerated. The rubber stoppers were then replaced and soil cores were equilibrated to atmospheric pressure as described above. At this time, 10% of the headspace from each core was removed and replaced with acetylene gas. The soil cores were incubated again for

5-hours and re-sampled. Samples were analyzed using a Shimadzu GC-14A gas chromatograph (Shimadzu Scientific Instruments, Columbia, MD, using a 10-port valve with a sample loop of fixed 2 ml volume. As described by Meding (1999), the column arrangement consisted of 91 cm of Porapak N with 80/100 mesh, in series with a 305 cm Poropak Q with 100/120 mesh. A (Ni_{63}) electron capture detector was used with a 95:5 Argon to methane carrier gas mixture flowing at 40 ml min^{-1}, column temperature of 70°C and detector temperature of 340°C. The ratios of N_2 to N_2O from these soil core incubations were used to calculate denitrification from field sampling.

When the incubation period was over and samples were obtained, the head-space volume from each intact soil core was measured. A Tensimeter™ (Soil Measurement Systems, Tucson, AZ) was used to measure the pressure within each core before the injection of a known volume of air (30ml) and after the injection to measure the change in pressure. The following equation [Eq 1] was used to calculate the head-space volume for each individual core:

$$\text{Head-space (ml)} = (V_i - P_1)(P_1 - P_2)^{-1} \qquad \textbf{[Eq 1]}$$

Where:

V_i = volume of injected air (ml)

P_1 = initial pressure inside soil core tube, before injection of air (mbar)

P_2 = final pressure inside soil core tube, after injection of air (mbar)

Ammonia Volatilization

Sampling for ammonia volatilization was conducted during two sampling periods. Initially, samples were collected daily for the first 14 days following the November 1998 litter application and twice per week for two months after that. Samples were collected from chambers using procedures previously described for nitrous oxide sampling and ammonia gas determined by gas chromatography. Results from this initial sampling were not reliable and no results are reported.

A second, short-term sampling was conducted in early June 1999. For this second sampling period, which corresponded to warmer temperatures when maximum volatilization should occur, litter was applied to the area beneath the chambers at the same rates utilized in the initial study and samples were collected immediately following application, and at 4, 48, 72 and 96 hours after application. Collection was also scheduled for a 24-hour interval but due to rain, this sample was not obtained. Glass dishes containing 150 ml of 0.1-M sulfuric acid were placed within each chamber at the designated time of collection for 60 minutes to trap the NH_3 gas . NH_4-N concentrations in the acid solutions were determined using the automated phenate method on a Technicon Autoanalyzer II (Bran and Luebbe Analyzing Technologies, Buffalo Grove, IN).

Vegetation Analysis

Initial stem diameters and total tree heights were measured in July 1998 in the pine plantation and silvipasture plots prior to litter application. Diameter was measured at breast height with a Spencer diameter tape to the nearest 0.1 cm. Tree height was measured using a Suunto clinometer to the nearest foot, then converted to meters. Trees were re-measured in the winter of 2001 (3 years after application) in order to monitor tree response to each treatment level. Individual stem diameters and heights were converted to stem volumes using an inside bark merchantable volume equation [Eq 2] for loblolly pines in the Piedmont region (Pienaar et al., 1987). Final volumes expressed in cubic feet in the original equation were converted to cubic meters.

$$VIB_m = 0.00171199\ D^{1.870407}\ H^{1.110322} - 0.00210729(D_m^{3.437603}/D^{1.437603})(H-4.5) \qquad \textbf{[Eq 2]}$$

Where:

VIB_m= inside bark merchantable volume (ft^3)

D= dbh (inches)

D_m= minimum merchantable top diameter (2 in)

H= total tree height (feet)

Pine foliage samples were collected for nutrient analysis in April 1999, 5 months after poultry litter application. The needles were taken from the first flush of growth on the primary lateral branches, from the upper one-third of dominant and co-dominant trees. Fescue grass samples were also collected from 1-m^2 plots established in the pasture and silvipasture. Foliar samples were digested using methods described in Isaac and Johnson (1976). Total N and P detection was done on a Technicon Autoanalyzer II (Bran and Luebbe Analyzing Technologies, Buffalo Grove, IN). Samples were digested and analyzed for K, Ca and Mg as described by Isaac and Johnson (1975). These three elements were detected using a Perkin Elmer AAnalyst 100 (Perkin Elmer Instruments, Shelton, CT).

Statistical Analyses

Statistical analyses were performed using the Statistical Analysis System GLM procedure (SAS Institute, Inc. 1999) for a two-factor experiment (vegetation system and litter application rate) allocated to split-plots (litter rate) within randomized main plots (vegetation system). This statistical treatment assumed that vegetation system (pasture, pine plantation and silvipasture), which constituted main plots, could be treated as if they were randomly assigned within the study area. Poultry litter treatment rate (0, 11.2 and 33.6 Mg ha^{-1}) were split plots randomly assigned within these main plots. Duncan's multiple range test was used to compare treatment differences when significant differences (a= 0.05) were indicated by GLM. Differences in soil nutrient conditions among vegetation systems in the absence of poultry litter treatment were tested by sampling all experimental plots prior to litter application.

Although available information indicates that the pine plantation and silvipasture were established within a single pre-existing pasture, there is no information that indicates if any randomization was applied in selection of the areas to receive each vegetation system. Organization of areas within the landscape indicates that areas selected to receive different vegetation systems were likely selected based on operational convenience. Thus, differences in soil conditions among vegetation systems may be the result of initial differences in the site or a function of the vegetation system and differential management of these systems since establishment. It was assumed that effects of litter application and the interaction of litter application with vegetation system are due to vegetation system and not due to differences in initial site conditions, but this assumption could not be independently tested.

CHAPTER 4

RESULTS

Poultry Litter Characteristics

The characteristics of poultry litter applied to the research site in November 1998 (Litter 1) and the litter used in the short-term volatilization study in June 1999 (Litter 2) are presented in Table 1. Litter used in the second short-term NH_3 volatilization test had slightly higher N and P concentrations than the litter used in the field application. Both were within the range typically reported for poultry litter (Edwards and Daniel, 1992).

Soil

Significant differences in surface soil nutrient concentrations existed among vegetation systems prior to poultry litter application (1998 sampling). Total N concentrations averaged across all soil depths were greater in the pasture (650 ug/g) than in either the silvipasture (374 ug/g) or pine plantation (328 ug/g). Pre-treatment soil P concentrations were high for all vegetation systems, indicating historical use of the area as field and improved pasture. Concentrations of soil P averaged across all depths ranged from a high of 350 ug/g in the silvipasture to 297 ug/g in the pine plantation and 248 ug/g in the pasture.

Soil N concentrations before poultry litter application (July 1998) and 5-months after application (April 1999) are summarized by depth in Table 2. In general, N concentrations were greater in the surface soils and declined below the 10-20 cm depth

Table 1: Selected characteristics of poultry litter and total loading at low application rate.

	Litter Characteristics									Total Loading at Low Rate (11.2 Mg ha^{-1})					
	Total N	Total P	NO_3-N	NH_4-N	As	B	Cu	Zn	pH	Total N	Total P	As	B	Cu	Zn
	------g kg^{-1}------		-------------------mg kg^{-1}----------------------						-su-	------kg ha^{-1}-----		--------g ha^{-1}--------			
Litter 1[§]	31.0	11.2	1.5	4.2	5.01	121	318	409	8.15	374	125	56	1355	3562	4580
	(.55)[†]	(.21)	(.01)	(.05)	(.34)	(5.1)	(7.2)	(7.0)	(.02)						
Litter 2[£]	49.4	15.0	1.6	3.2	5.46	126	335	428	8.32	553	168	61	1411	3752	4794
	(.21)	(.14)	(.02)	(.03)	(.75)	(9.6)	(4.5)	(2.6)	(.04)						

[§] Litter 1 was applied to research site in November 1998.

[£] Litter 2 was used during short-term volatilization experiment in June 1999.

[†] Standard deviation based on 8 replications.

Table 2: Soil nitrogen concentrations by depth before poultry litter application in July 1998 (Pre) and 5-months after application in April 1999 (Post) to a Georgia Piedmont soil.

	Pine Plantation			Silvipasture			Pasture		
Depth	High	Low	Control	High	Low	Control	High	Low	Control
	---------------ug/g-------------			---------------ug/g-------------			---------------ug/g-------------		
0-10 cm									
Pre	837 (199)[†]	915 (121)	578 (260)	745 (136)	808 (134)	617 (255)	1037 (13)	2258 (1123)	2308 (1249)
Post	867 (254)	1232 (405)	764 (182)	1902 (925)	766 (206)	915 (54)	749 (19)	846 (24)	618 (143)
10-20cm									
Pre	464 (89)	352 (64)	456 (51)	580 (34)	523 (98)	706 (117)	660 (94)	652 (107)	707 (28)
Post	510 (132)	581 (96)	417 (49)	966 (312)	737 (248)	605 (26)	550 (141)	557 (12)	400 (63)
20-40cm									
Pre	213 (31)	249 (44)	255 (76)	280 (21)	267 (33)	399 (72)	459 (51)	397 (22)	366 (44)
Post	231 (58)	338 (55)	275 (91)	539 (124)	330 (14)	382 (92)	258 (100)	233 (69)	272 (86)
40-80cm									
Pre	78 (17)	99 (14)	111 (9)	151(18)	121 (22)	133 (23)	224 (28)	251 (66)	173 (39)
Post	147 (46)	160 (32)	113 (19)	177 (18)	152 (20)	183 (11)	102 (23)	424 (223)	162 (53)
80-100cm									
Pre	80 (5)	74 (11)	88 (13)	98 (25)	98 (12)	95 (14)	115 (54)	171 (47)	98 (8)
Post	55 (10)	84 (7)	89 (4)	108 (18)	117 (4)	122 (8)	189 (97)	53 (11)	84 (38)

[†] Standard error of the mean (n=3)

Table 3: Soil phosphorus concentrations by depth before poultry litter application in July 1998 (Pre) and 5-months after application in April 1999 (Post) to a Georgia Piedmont soil.

	Pine Plantation			Silvipasture			Pasture		
Depth	High	Low	Control	High	Low	Control	High	Low	Control
	---------------ug/g------------------			---------------ug/g------------------			---------------ug/g------------------		
0-10 cm									
Pre	341 (71)[†]	331 (54)	269 (80)	396 (22)	338 (25)	322 (54)	461 (86)	407 (33)	418 (14)
Post	433 (78)	416 (64)	387 (23)	478 (30)	448 (68)	420 (23)	380 (80)	523 (34)	377 (35)
10-20cm									
Pre	293 (73)	283 (75)	233 (74)	316 (12)	325 (58)	317 (43)	338 (64)	309 (33)	303 (60)
Post	396 (74)	363 (36)	381 (54)	374 (45)	389 (65)	367 (41)	332 (66)	367 (19)	335 (39)
20-40cm									
Pre	248 (69)	255 (53)	304 (58)	303 (32)	371 (115)	232 (15)	213 (24)	190 (30)	166 (6)
Post	392 (73)	330 (32)	399 (67)	367 (15)	399 (83)	371 (62)	271 (38)	283 (22)	283 (22)
40-80cm									
Pre	303 (71)	280 (77)	331 (86)	342 (93)	495 (219)	323 (91)	161 (15)	184 (23)	146 (9)
Post	402 (65)	358 (42)	449 (107)	386 (56)	468 (147)	382 (84)	228 (27)	248 (9)	222 (6)
80-100cm									
Pre	368 (45)	298 (67)	343 (103)	426 (167)	427 (100)	325 (126)	204 (18)	153 (29)	144 (11)
Post	533 (45)	353 (43)	415 (94)	418 (61)	440 (127)	395 (103)	215 (49)	212 (12)	234 (6)

[†] Standard error of the mean (n=3)

increment for all treatments. Variability of soil N was high within the experimental area and no clear pattern was consistently observed associated with application rates. Pasture soils had higher N concentrations in the surface 20 cm than the silvipasture or pine plantation prior to poultry litter application, perhaps, indicating differences in management history and animal use. However, there were no significant differences between application rates or vegetation types after poultry litter was applied. Pasture soil N concentrations were much lower in these samples suggesting that the initial samples were abnormally high.

Phosphorus concentrations in soil beneath all vegetation systems were relatively high, reflecting past agricultural use and fertilization of the area (Table 3). In pine plantation and silvipasture surface soils, P concentrations tended to follow the pattern of high>low>control, but variability was high and differences were generally non-significant. No clear soil P pattern was observed in the pasture. Statistical analyses indicated that the pasture had significantly less P than silvipasture or pine plantation after litter application. While P uptake and removal during haying would be expected to reduce soil P in pastures, it is unlikely that this would be observed over the short 5-month period between the two samples.

Pre-treatment soil pH averages across all depths were significantly different with pasture averaging 5.23 and the pine plantation and silvipasture averaging 5.05 and 5.03, respectively. Average post-treatment soil pH across depths in the pine plantation (4.98) was significantly higher than pH in the silvipasture (5.18) and pasture (5.23) but did not differ among application rates.

Soil Solution

The first year following poultry litter application was dry and very few monthly sampling periods actually produced leachate. The first successful collection of leachate was in February, three months after application. Samples were also retrieved in March and April. To determine the influence of spatial differences in vegetation within the silvipasture, lysimeters were placed within tree rows (under 40-60% pine canopy cover), in the middle of the fescue lanes (0% pine canopy cover) and midway between the two (20-40% pine canopy cover). No clear pattern in soil solution concentrations was evident (Table 4) and overall averages are presented in this report.

Although the number of samples collected was much smaller than had been anticipated, a pattern was observed in N concentrations measured. Where significant differences existed, they were associated with main effects of vegetation type or application rate. Summaries of average Total N detected in soil solution are presented in Table 5 and Table 6. Although no significant differences between vegetation type or application rate existed in March, during April the pine plantation had significantly more Total N in soil solution than either the pasture or silvipasture (1.19 mg L^{-1} vs. 0.39 and 0.36 mg L^{-1}, respectively). Generally, Total N concentrations were greater in high treatment level plots than in low or control plots, but statistical significance occurred only in February.

No significant differences in the amount of Total P in soil solution among the vegetation systems or poultry litter application rates existed in February or March (Table 5 and Table 6). During April, soil solution from the pine plantation had a significantly greater P concentration than the silvipasture or pasture (0.32 mg L^{-1} vs. 0.12 and 0.07 mg

L^{-1}, respectively). Although not significant, the high application rate resulted in higher P levels in soil solution than the low rate or control during all three months.

Average concentrations of NO_3-N and NH_4-N detected in soil solution samples in February, March and April are summarized in Tables 7 and 8. In February, the NO_3-N concentrations from the high application plots were significantly higher than the control plots (4.79 vs. 0.07 mg L^{-1}). In March, this same pattern existed with NO_3-N concentrations of soil solution from plots receiving the high application level still significantly higher than in the control plots (5.98 vs. 0.05 mg L^{-1}). The pine plantation had more than twice the NO_3 -N levels of the silvipasture or pasture during February and March, but these differences were not statistically significant. However, in April NO_3-N in soil solution had increased in the pine plantation with an average concentration of 16.0 mg L^{-1}, which was significantly greater than either silvipasture or pasture systems. High application plots were also significantly greater with NO_3-N concentrations averaging 9.01 mg L^{-1}.

During February, soil solution from the pine plantation plots had significantly more NH_4-N than the pasture or silvipasture plots (0.56 mg L^{-1} vs.0.02 and 0.02 mg L^{-1}, respectively). By March, NH_4-N levels were no longer significantly different in the pine plantation plots. In April, NH_4-N levels under the pine plantation were again significantly greater than the silvipasture or pasture plots (0.65 mg L^{-1} vs. 0.14 and 0.11 mg L^{-1}, respectively).

Arsenic, B, Cu and Zn concentrations were measured in soil solution samples only during February and March. Tables 9 and 10 summarize the trace element

Table 4: Average soil solution concentrations (n=3) from lysimeters placed in silvipasture at three different levels of canopy cover over a 3-month sampling period.

			Lysimeter Position		
Application Rate	Constituent	Detection Limit	Out (0% canopy)	Mid (20-40% canopy)	In (40-60% canopy)
		--------------------------------mg L^{-1}	------------------------------		
High	NO_3-N	0.005	4.96	7.68	1.67
	NH_4-N	0.005	0.08	0.15	0.05
	Total N	0.01	0.42	0.41	0.44
	Total P	0.01	0.11	0.06	0.06
Low	NO_3-N	0.005	0.40	0.58	0.93
	NH_4-N	0.005	0.03	0.08	0.07
	Total N	0.01	0.45	0.87	0.49
	Total P	0.01	0.04	0.22	0.05
Control	NO_3-N	0.005	0.05	0.01	0.01
	NH_4-N	0.005	0.04	0.04	0.07
	Total N	0.01	0.44	0.42	0.42
	Total P	0.01	0.05	0.07	0.07

[1] Dissimilar superscripts indicate significant differences among litter application rates within each month (Duncan's multiple range test a= 0.05).

Table 5: Average Total N and P concentrations in soil solution at 1-m depth among vegetation types in spring 1999 following November 1998 poultry litter application.

	Total N			Total P		
	Plantation	Silvipasture	Pasture	Plantation	Silvipasture	Pasture
	--------- mg L^{-1}---------			--------- mg L^{-1}---------		
February	1.82	0.52	0.64	0.04	0.03	0.03
March	1.37	0.56	0.46	0.15	0.04	0.04
April	1.19^{a}[1]	0.36^{b}	0.39^{b}	0.32^{a}	0.12^{b}	0.07^{b}

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[1] Dissimilar superscripts indicate significant differences among vegetation types within each month (Duncan's multiple range test a= 0.05).

Table 6: Average Total N and P concentrations in soil solution at 1-m depth among litter application rates in spring 1999 following November 1998 poultry litter application.

	Total N			Total P		
	High	Low	Control	High	Low	Control
	---------- mg L^{-1}-----------			---------- mg L^{-1}-----------		
February	1.04^{a}[1]	0.63^{b}	0.61^{b}	0.03	0.03	0.03
March	1.00	0.70	0.49	0.11	0.05	0.03
April	0.67	0.43	0.33	0.20	0.10	0.09

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[1] Dissimilar superscripts indicate significant differences among litter application rates within each month (Duncan's multiple range test a= 0.05).

Table 7: Average NO_3-N and NH_4-N concentrations in soil solution at 1-m depth within vegetation types in spring 1999 following November 1998 poultry litter application.

	NO_3-N			NH_4-N		
	Plantation	Silvipasture	Pasture	Plantation	Silvipasture	Pasture
	----------- mg L^{-1}-------------			----------- mg L^{-1}-------------		
February	3.46	1.74	1.10	0.56^{a}	0.02^{b}	0.02^{b}
March	4.77	1.59	1.51	0.06	0.05	0.04
April	16.0^{a}[1]	2.21^{b}	0.57^{b}	0.65^{a}	0.14^{b}	0.11^{b}

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[1] Dissimilar superscripts indicate significant differences among vegetation types within each month (Duncan's multiple range test a= 0.05).

Table 8: Average NO_3-N and NH_4-N concentrations in soil solution at 1-m depth among litter application rates in spring 1999 following November 1998 poultry litter application.

	NO_3-N			NH_4-N		
	High	Low	Control	High	Low	Control
	---------- mg L^{-1}----------			---------- mg L^{-1}----------		
February	4.79^{a1}	1.11^{ab}	0.07^{b}	0.32	0.04	0.04
March	5.98^{a}	1.38^{ab}	0.05^{b}	0.09	0.04	0.03
April	9.01^{a}	1.13^{b}	0.01^{b}	0.37	0.11	0.10

[1] Dissimilar superscripts indicate significant differences among litter application rates within each month (Duncan's multiple range test a= 0.05).

concentrations from samples collected during these two months. Generally, only main effects were significant. Concentrations of As beneath the pine plantation were significantly higher than the pasture or silvipasture during both months. The high application rate (0.34 ug L^{-1}) resulted in significantly more As in soil solution than the control plots (0.07 ug L^{-1}) during February. During March, a significant interaction between application rate and vegetation type existed for As levels. In the silvipasture and pasture, As concentrations were higher in plots receiving litter than in the control, but there was little difference between the two rates. In the pine plantation, much higher As concentrations occurred from the high litter rate than the low rate and both were greater than the control.

Copper concentrations were significantly higher in the pine plantation than the silvipasture or pasture in February. No significant differences in soil solution Zn or B concentrations were observed among any application rates or vegetation types during either month.

Table 9: Average concentrations of trace elements at 1-m depth among vegetation types in February and March 1999 lysimeter samples.

	Pine Plantation	Silvipasture	Pasture	EPA Criteria[£]
	---------------------------ug L^{-1}-------------------------------------			
February				
As	0.6^{a}[1]	0.1^{b}	0.1^{b}	360
B	11.6	12.0	9.6	750
Cu	6.6^{a}	1.5^{b}	1.6^{b}	34
Zn	55.6	105	69.7	65
March	---------------------------ug L^{-1}-------------------------------------			
As	1.6^{a}	0.2^{b}	0.1^{b}	360
B	43.8	9.7	18.8	750
Cu	12.9	6.0	0.84	34
Zn	39.4	53.2	42.0	65

[1] Dissimilar superscripts indicate significant differences among vegetation types within each month (Duncan's multiple range test a= 0.05).

[£] Concentration levels considered to be a surface water problem by TSC1292 Criteria Chart, EPA REG IV-Water Management Division.

Table 10: Average concentrations of trace elements at 1-m depth among litter application rates in February and March 1999 lysimeter samples.

	High	Low	Control	EPA Criteria[£]
	---------------------------ug L^{-1}-------------------------------------			
February				
As	0.34^{a}[1]	0.25^{a}	0.07^{b}	360
B	11.4	10.4	13.4	750
Cu	3.6	2.0	1.7	34
Zn	71.5	77.7	109	65
March	---------------------------ug L^{-1}-------------------------------------			
As	1.2	0.34	0.06	360
B	54.3	13.0	18.8	750
Cu	8.6	9.4	0.47	34
Zn	48.0	51.2	42.1	65

[1] Dissimilar superscripts indicate significant differences among application rates within each month (Duncan's multiple range test a= 0.05).

[£] Concentration levels considered to be a surface water problem by TSC1292 Criteria Chart, EPA REG IV-Water Management Division.

Gaseous Loss

Denitrification

Because precipitation amounts were below average during the whole year following litter application, only four sets of denitrification data were collected. Denitrification rates were influenced by poultry litter application rates and vegetation type (Table 11). During January, March and June, N_2 loss was greatest at the high application rate, followed by the low application rate and the control. No differences were observed among litter application rates in April. Clear differences did not occur among vegetation systems during any of the sampling periods. A high denitrification rate was observed in the pasture during the first sampling period, but this difference was not maintained during other sampling periods and it may have been spurious.

Volatilization

Ammonia volatilization was measured during a period of 96 hours during a short-term study conducted in early June. Samples were taken immediately following the application of poultry litter, then at 4 hours, 48 hours, 72 hours and 96 hours after application. Sampling was scheduled at 24 hours also, but due to rain, this was not possible. Volatilization rates from this short-term study are presented in Table 12.

In general, NH_3 volatilization rates in the pasture were higher than the pine plantation or silvipasture (Figures 2-4). Volatilization from the silvipasture was slightly higher than the pine plantation, probably due to an increase in temperature. The greatest concentration of ammonia was trapped immediately following litter application and then at 4 hours on the high and low treatment plots within all three vegetation types. Ammonia

Table 11: Denitrification after November 1998 poultry litter application.

		January		March		April		June	
Vegetation Type	Litter Rate	Air Temp	N Loss	Air Temp	N Loss	Air Temp	N Loss	Air Temp	N Loss
		C°	g ha^{-1} hr^{-1}	C°	g ha^{-1} hr^{-1}	C°	g ha^{-1} hr^{-1}	C°	g ha^{-1} hr^{-1}
Pine Plantation	High	13.8	3.0	21.6	3.0	31.4	0.2	33.5	2.3
	Low	13.8	1.0	21.6	0.5	31.4	0.2	33.5	1.1
	Control	13.8	0.3	21.6	0.2	31.4	0.2	33.5	0.2
Silvipasture	High	14.6	7.0	23.6	1.1	32.4	0.3	33.7	1.1
	Low	14.6	0.8	23.6	0.3	32.4	0.2	33.7	0.4
	Control	14.6	0.2	23.6	0.2	32.4	0.2	33.7	0.3
Pasture	High	16.4	337	25.1	1.3	33.1	0.3	34.1	2.7
	Low	16.4	0.9	25.1	0.4	33.1	0.3	34.1	0.8
	Control	16.4	0.4	25.1	0.3	33.1	0.2	34.1	0.3

Table 12. Average ammonia volatilization during short-term study in June 1999.

Vegetation Type	Treatment Level	Time 0	4 hours	48 hours	72 hours	96 hours	Total
		----------------g N ha^{-1} hr^{-1}				------------------	-kg N ha^{-1}-
Pasture	High	640	150	100	110	110	288.8
	Low	200	25	20	130	30	123.6
	Control	0.2	0.3	0.2	0.2	0.2	0.53
Silvipasture	High	210	60	20	100	60	110.7
	Low	60	30	20	70	10	77.6
	Control	0.3	0.3	0.2	0.2	0.2	0.53
Pine Plantation	High	100	50	20	410	60	297.4
	Low	240	70	8	110	50	132.4
	Control	0.3	0.3	0.2	0.2	0.3	0.48

levels dropped considerably at 48 hours in all low and high treatment plots due to rainfall that had occurred 24 hours after application. By 72 hours, volatile loss had increased again on all plots; however, the pine plantation had a much more dramatic spike than the pasture or silvipasture. By 96 hours, volatilization rates had decreased again in all three vegetation types.

With respect to application rates, the high treatment levels resulted in much greater volatilization rates than low treatment levels in the pasture and silvipasture. This pattern was not as clear in the pine plantation. Low application rates produced higher volatilization on some days and the high application rate produced greater volatilization on others. This inconsistency may be a function of greater variation in microsite conditions and airflow within the forest floor.

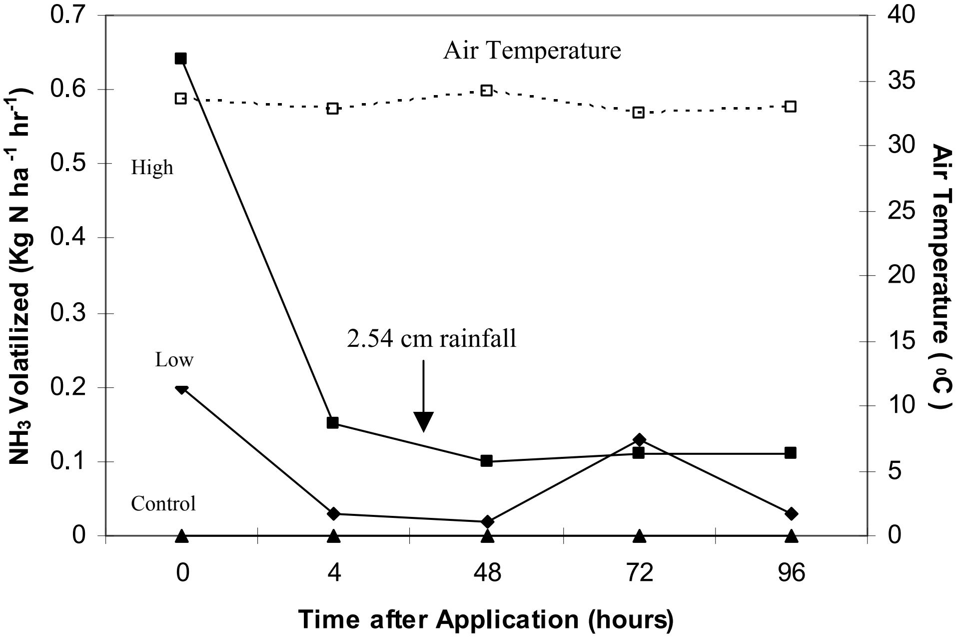

Figure 2: Ammonia volatilized from pasture after June 1999 poultry litter application.

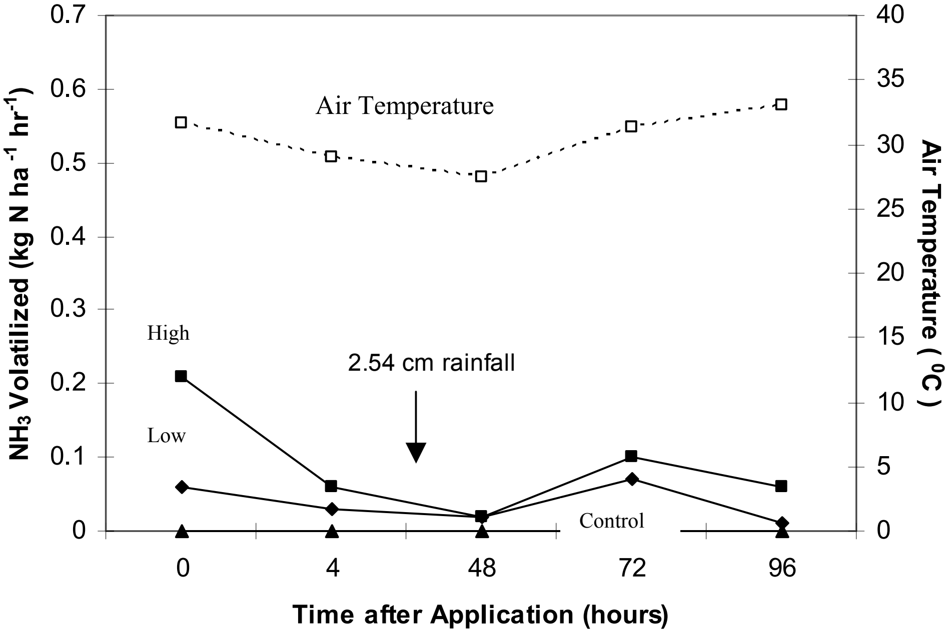

Figure 3: Ammonia volatilized from Silvipasture after June 1999 poultry litter application

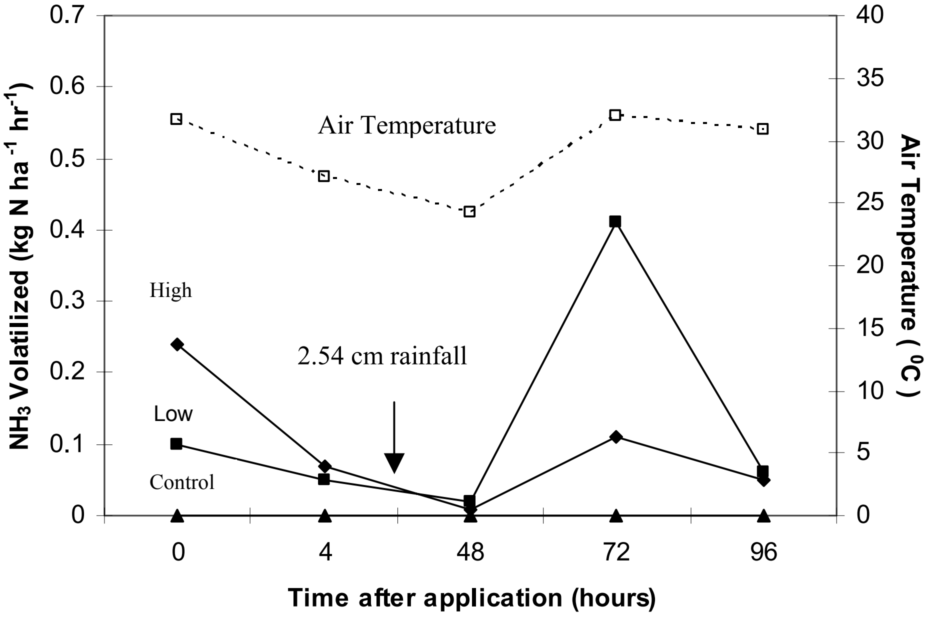

Figure 4: Ammonia volatilized from pine plantation after June 1999 poultry litter application.

Foliar nutrients

A foliar N content of 11.0 g kg^{-1} is considered sufficient for loblolly pine growth (Jokela et al., 1991). Foliar nutrient concentrations in the control plots indicated that the trees in the pine plantation and silvipasture were N deficient prior to litter application. There was a rapid response to litter application in both the silvipasture and the pine plantation (Table 13). Foliar N concentrations increased significantly on plots receiving the high rate of litter, averaging near the 11.0 g kg^{-1}level of sufficiency. Trees receiving the low rate of litter had increased, but did not reach 11.0 g kg^{-1}N content.

Generally, there were no interactions among vegetation type and application rate and main effects of the treatments are presented in Table 14. There was, however, an interaction between Ca concentration in pine foliage between vegetation type and application rate. In the silvipasture plots, Ca concentration increased with increasing application rate. In the pine plantation, there was no difference in foliar Ca concentration among rates. Because grass has a higher Ca demand than trees, more Ca is recycled in the silvipasture system and trees within that system will have an increased opportunity for Ca uptake. Foliar concentrations of P, K and Mg were not influenced by vegetation type or treatment levels.

Foliar nutrient concentration differences in fescue grass among vegetation types and application rates are summarized in Table 15 and Table 16. Fescue grass in the pasture and silvipasture plots had increased N and P concentrations after treatment; however, foliar N in the pasture grass was significantly greater than in silvipasture grass. Grass in the high and low application rate plots resulted in significantly higher average foliar N and P than control plots. Foliar Mg in pasture grass was significantly higher in the pasture than in the silvipasture and no significant differences between treatments or vegetation systems occurred in grass foliage K or Ca concentrations.

Tree Growth

In order to compare tree response to poultry litter application in the pine plantation and silvipasture systems, stem diameters and tree heights were measured after the third growing season following litter application. Average stem diameters and tree heights within each stand type and application rate are presented in Table 17. By the end of the third growing season, significant differences in stem diameter and tree height growth were attributable to vegetation system as well as poultry litter treatment levels.

Table 13: Nutrient concentrations in pine needles 5-months after poultry litter application from pine plantation and silvipasture.

		Pine Plantation	Silvipasture	Critical Concentration[§]
N	-g kg^{-1} -	9.2	9.4	11.0
P	------mg kg^{-1}------	2140	1480	1000
K		2500	2460	3500
Ca		2770^{a}	2340^{b}	1200
Mg		500	398	700

[1] Dissimilar superscripts indicate significant differences among vegetation types (Duncan's multiple range test a= 0.05).

[§] Critical concentrations for loblolly pine from Jokela et al., 1991.

Table 14: Nutrient concentrations in pine needles within different application rates 5-months after poultry litter application.

		High	Low	Control	Critical Concentration[§]
N	-g kg^{-1} -	10.9^{a1}	8.9^{b}	8.2^{b}	11.0
P	------mg kg^{-1}------	1590	1550	2290	1000
K		2590	2390	2460	3500
Ca		2790^{a}	2500^{b}	2370^{b}	1200
Mg		435	426	486	700

[1] Dissimilar superscripts indicate significant differences among application rates (Duncan's multiple range test a= 0.05).

[§] Critical concentrations for loblolly pine from Jokela et al., 1991.

Table 15: Nutrient concentrations in fescue grass 5-months after poultry litter application from silvipasture and pasture.

		Silvipasture	Pasture	Critical Concentration[§]
N	g kg^{-1}	22.8^{a}[1]	25.6^{b}	25.0
P	mg kg^{-1}	4030	3740	2000
K		21,700	21,400	22,000
Ca		4330	4730	NA[£]
Mg		1210^{a}	1500^{b}	2000[†]

[1] Dissimilar superscripts indicate significant differences among application rates (Duncan's multiple range test a= 0.05).

[§] Critical concentration levels for fescue grass from Lessman and Thom (2002).

[£] No generally accepted critical concentration.

[†] Mg concentrations less than this are considered inadequate for animal nutrition.

Table 16: Nutrient concentrations in fescue grass within different application rates 5-months after poultry litter application.

		High	Low	Control	Critical Concentration[§]
N	g kg^{-1}	32.0^{a}[1]	24.4^{b}	16.3^{c}	25.0
P	mg kg^{-1}	5050^{a}	4460^{b}	2140^{c}	2000
K		20,700	20,500	23,600	22,000
Ca		4410	4730	4450	NA[£]
Mg		1480	1320	1270	2000[†]

[1] Dissimilar superscripts indicate significant differences among application rates (Duncan's multiple range test a= 0.05).

[§] Critical concentration levels for fescue grass from Lessman and Thom (2002).

[£] No generally accepted critical concentration.

[†] Mg concentrations less than this are considered inadequate for animal nutrition.

Pine trees in the silvipasture had significantly greater average stem growth during the 3-year growing period at 3.38 cm 3-year^{-1}, while the pine plantation averaged about 2.26 cm 3-year^{-1} in stem diameter growth. Trees in the high litter application rate plots averaged a significantly greater diameter growth than trees in the control (3.00 cm 3-year^{-1} vs. 2.51 cm 3-year^{-1}). Height growth in the pine plantation was significantly greater than in the silvipasture (4.73 m 3-year^{-1} vs. 3.72 m 3-year^{-1}). The low application rate and control plots had significantly greater average tree height growth than the high poultry litter application rate. During this 3-year growing period, it appeared that trees receiving the higher treatment levels had increased significantly in their stem diameter, but not in height. Trees in the low treatment and control plots had a tendency to put more energy into height growth and less into their stem growth.

On an individual tree basis, increases in average merchantable wood volume (m^{3} tree^{-1} 3-year^{-1}) were significantly greater in the silvipasture than in the pine plantation over the 3-year growing period. Poultry litter application rates did not influence volume increases. Average merchantable wood volume (m^{3} ha^{-1}3-year^{-1}) was calculated for each stand type (Table 18) and results showed that overall average stand volumes increased in both the silvipasture and pine plantation (Figure 5). Poultry litter rates did not influence the volume increases. It is not clear why control plot volume increases were greater than low or treatment plot volume increases in the pine plantation. This could be a result of the initial lower average volume of plots selected for litter application or differences in mortality among treatments.

Table 17: Average tree characteristics in pine plantation and silvipasture before poultry litter application (1998) and following the third growing season after application (2001).

		1998				2001			
Vegetation Type	Rate	No. trees	Dbh	Ht.	Mer.[1] Volume	No. trees	Dbh	Ht.	Mer. Volume
		trees ha^{-1}	cm	m	m^3 $tree^{-1}$	trees ha^{-1}	cm	m	m^3 $tree^{-1}$
Pine Plantation	High	662	16.1	11.3	0.07	640	18.8	15.5	0.14
	Low	683	15.9	11.0	0.07	662	18.4	15.8	0.14
	Control	704	16.3	11.9	0.09	704	18.4	17.7	0.16
Silvipasture	High	314	16.8	11.1	0.08	301	20.8	15.0	0.17
	Low	339	15.9	10.7	0.07	314	19.8	14.6	0.15
	Control	289	16.9	11.2	0.08	264	20.7	15.3	0.17

[1] Inside merchantable bark volume [Eq 2]

Table 18: Initial merchantable stand volume (Pre-treatment) and merchantable stand volume 3-years after litter application (Post-treatment) in silvipasture and pine plantation.

	High		Low		Control	
	Pre-treatment	Post-treatment	Pre-treatment	Post-treatment	Pre-treatment	Post-treatment
	m^3 ha^{-1}	m^3 ha^{-1}	m^3 ha^{-1}	m^3 ha^{-1}	m^3 ha^{-1}	m^3 ha^{-1}
Silvipasture	102.3	204.8	96.2	186.8	92.3	178.3
Pine Plantation	113.0	215.9	115.2	227.1	134.2	250.6

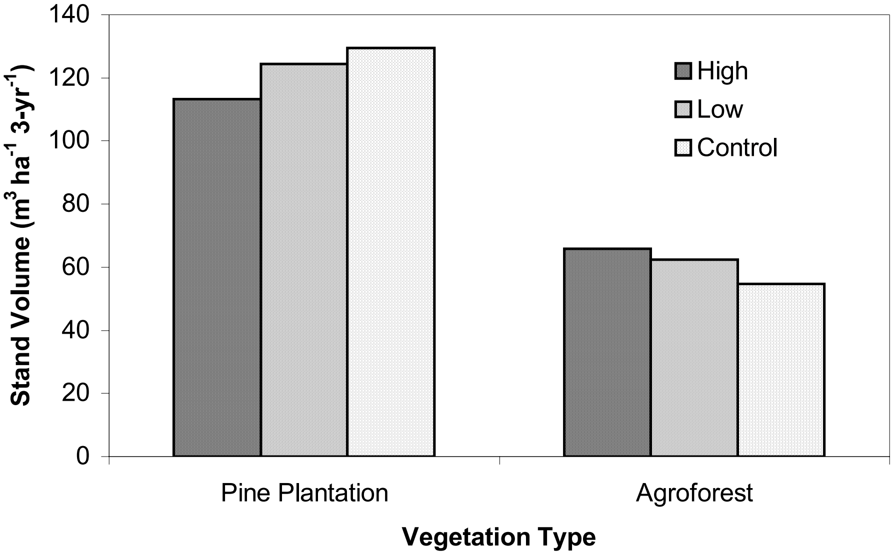

Figure 5: Comparison of total stand volume increases in silvipasture and pine plantation during the 3-year period following poultry litter application.

CHAPTER 5

DISCUSSION

Fate of Nitrogen

Ammonia volatilization represented the greatest short-term potential pathway of N loss after poultry litter application from all three vegetation types. Levels of litter application influenced volatilization rates with the greatest volatile losses occurring from high treatment plots. Volatilization from the pasture was higher than the silvipasture or pine plantation, probably as a result of warmer temperatures. A temporary decrease in volatilization was observed when a rainfall event occurred 24 hours after application. Ammonia loss increased again approximately 48 hours after the rainfall, which is consistent with volatilization patterns observed by Beauchamp et al. (1982). Volatilization rates decreased again in all treatments within each vegetation system by 96 hours after application. These results are consistent with previous work that showed that volatilization is highest immediately after application and can decrease to low levels within just a few days (Nathan and Malzer, 1994).

As expected, N loss through denitrification was much smaller than loss through volatilization. Denitrification was limited during this study due to the lack of precipitation necessary to create periodic ephemeral anaerobic microsites required for this biological process to occur on upland sites. Although denitrification rates were not influenced by vegetation type during any of the sampling periods, litter application rates did seem to have an affect as higher N_2 fluxes were observed from high treatment plots in

January and March. Denitrification rates from this study were consistent with results from upland sites reported by Meding (1999).

Soil solution samples were not available during the dry summer months when mineralization rates and plant uptake would be high. Soil solution samples were retrieved only during the winter months when leaching potential was high and exceeded evapotranspiration. According to Dodds et al. (1998), total nitrogen concentrations of less than 1.5 mg L^{-1} will prevent algal bloom growth in streams. Soil solution results showed that average total N concentrations exceeded this proposed limit in the pine plantation during February, indicating a potential for surface water contamination.

Nitrate concentrations in soil solution were higher overall in the pine plantation than the silvipasture or pasture during all sampling periods. Previously, Browaldh (1995) showed that trees in an agroforestry system would reduce the potential for NO_3-N leaching because of an increased efficiency of N utilization. Loading to groundwater was not directly measured in this study; however, concentrations at 1-m depth were at least as high in the silvipasture as they were in the pasture. It seems unlikely that reductions in leachate volume would compensate for higher NO_3-N concentration. High litter application rates also resulted in significantly greater NO_3-N concentrations in soil solution. Although the EPA's drinking water standard of 10 mg L^{-1} was not exceeded during February or March, NO_3-N concentrations from the high litter application rates resulted in an average of 16.0 mg L^{-1} and the pine plantation plots almost exceeded this limit with an average of 9.0 mg L^{-1}. It is assumed that increased mineralization rates during the warmer months would have influenced a continuation of this trend of high

NO_3-N concentrations in soil solution in the pine plantation and in high treatment plots, although this could not be tested due to lack of rainfall to produce leachate.

The potential losses of N through leaching are likely to be small compared to NH_3 volatilization. If one assumes that all precipitation (38.6 cm) in excess of evapotranspiration (27.4 cm) leached during the months of February, March and April, and mean concentration of the leachate was 9.0 mg L^{-1} (the average observed) maximum NO_3-N loss would have been about 10 kg ha^{-1}.

Other Elements

Soil solution samples showed no significant difference in P concentrations resulting from levels of poultry litter applied during any of the sampling periods. The pine plantation had a higher concentration of P during April, perhaps as a consequence of lower soil pH and lower P fixation. Other possible explanations for higher P concentrations in the pine plantation could be lower uptake by pine trees resulting in greater residual P or increased P movement through the soil profile from large decomposed tree roots that leave channels or macropores for transport. Nevertheless, it does not appear that a one-time application of poultry litter, even at a high rate, would result in increased potential for soluble P loss from this site.

Total P concentrations that exceed 0.075 mg L^{-1} can result in surface water contamination, increasing the potential for growth of algal blooms (Dodds et al., 1998). Average P concentrations in soil solution observed in this study exceeded this 0.075 mg L^{-1}concentration in the pine plantation during March. In April, average P concentrations in all 3 vegetation types and in all 3 treatment levels exceeded this guideline indicating that potential P contamination of surface water could create an environmental concern. However, these soil solution concentrations do not necessarily represent concentrations of leachate leaving the site. Moreover, the high P levels detected on control plots which did not receive any poultry litter indicates that historical use of this site for agriculture may be responsible for these P levels and that poultry litter was not likely to be the source of the potential P contamination observed.

Arsenic, Cu and Zn were monitored in soil solution because these and other trace elements are often additives in poultry feed (Moore et al., 1995b), and because poultry do not absorb a majority of these elements during digestion, they are excreted in their waste, creating a potential for contamination (Sims and Wolf, 1994). Boron monitoring was also included in this study because high B concentrations have been associated with poultry waste as a result of boric acid use for insect control in poultry houses (Sims and Wolf, 1994). Results showed that B and Zn concentrations were not affected by this one-time poultry litter application in any of the vegetation types. Arsenic concentrations, however, were significantly higher in the high application plots during February and the pine plantation had significantly more As in soil solution during both February and March sampling periods. Copper concentrations were also high in the pine plantation during February. In general, poultry litter application did not increase a water contamination threat from As, B or Cu according to US EPA criteria (Table 9 and 10); however, average Zn concentrations did exceed contaminant levels based on these criteria in February in the silvipasture and pasture and on all treatment levels, including the control. High zinc concentrations occurring even on control plots indicates that elevated Zn concentrations were not a result of Zn applied in the poultry litter.

Nutrition and Tree Growth

Both fescue grass and pine benefited from litter application as evidenced by increased foliar N concentrations. High application rates of poultry litter increased foliar N contents significantly to levels near the 1.1% sufficiency required for loblolly pine growth (Table 14). Fescue samples from the silvipasture had significantly less foliar N concentrations than fescue in the pasture system (Table 15), which does not support that fescue productivity and nutrient uptake would improve with increased shade (Stritzke et al., 1976).

There was no apparent benefit to other nutrients applied in litter. No significant differences in foliar P, K or Mg concentrations in pine needles existed among application rates or vegetation type. Calcium content was significantly greater in pine trees in the silvipasture and in the high application rate plots, but this nutrient was above critical concentrations in all of the treatments. Fescue grass may have benefited from P in litter as concentrations of P were increased at the high litter application rates.

Individual pine tree growth in both plantation and silvipasture systems benefited slightly from poultry litter application, particularly at the high rate. The benefits of litter application showed different growth trends among trees in the two vegetation systems with the silvipasture stands increasing more significantly in average stem diameter and the pine plantation stands increasing more significantly in average height. This may be attributable to differences in stocking, stand densities and planting arrangement, as the silvipasture consisted of two, closely spaced rows of trees separated by wide lanes (9.15 m) of fescue grass. The silvipasture planting arrangement gives essentially every tree an edge effect in terms of competition for sunlight, whereas trees within plantation rows must “stretch” to compete vertically for sunlight.

Although overall average tree volumes in both the silvipasture and pine plantation increased from the poultry litter application, overall stand volume was not increased. It is not clear why tree volumes in the in the pine plantation control plots exceeded volume in the high and low treatment plots after three growing seasons. This pattern could be a result of the initial lower average stand volumes of plots selected for litter application or a result of fertilizing un-thinned pines, which has been associated with increased mortality in pine plantations. Also, no specific tree volume equations have been developed for trees grown in silvipastures, where growing conditions will influence different growth patterns among trees. This increases the potential for error in calculating tree volumes in the silvipasture accurately and makes it difficult to adequately compare tree volumes in the pine plantation to tree volumes in the silvipasture.

Silvipastures are the most common agroforestry system in the southern U.S. (Zinkhan and Mercer, 1997). Landowners receive no income during early years of pine plantations; however, silvipastures that incorporate the production of grazing cattle are an option to land management as a means to provide some annual income while trees are growing (Lewis et al., 1983).

In the southeastern U.S., approximately 150,000 ha of loblolly pine are fertilized annually to increase productivity (Zhang, 1996). Utilization of poultry litter to supply nutrients for tree productivity in loblolly pine plantations can offer an alternative to commercial fertilizers while also helping to resolve the issue of litter disposal. However, application rates in pine plantations would need to be lower than in pastures and silvipastures to avoid high NO_3-N leaching potential. Volatilization is a significant pathway for N loss following litter application, but difference among vegetation types are not large enough to suggest that volatile loss would be more important at determining rates than vegetation uptake. Additionally, these data don't provide evidence that support modeling results that show lower groundwater loading under silvipasture conditions than in pasture. Much lower leaching rates would be required in the silvipasture than in the pasture to offset the higher soil solution concentrations observed.

CHAPTER 6

CONCLUSIONS

Results from this study indicate that NO_3-N leaching potential will be similar in a pasture and silvipasture and less than leaching potential in a pine plantation following poultry litter application. Ammonia volatilization is relatively high immediately following litter application and likely to be a greater pathway of N loss than denitrification or leaching loss.

In the silvipasture, there was a significant increase in growth response to poultry litter application; however, no significant difference existed among litter application rates in the pine trees. The pine plantation did not respond to litter application on a stand level, even though foliar nutrient concentrations were initially low, and showed improvement after treatment with litter. This may be due to the fact that this stand was not thinned and had insufficient space to grow.

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