LAND APPLICATION OF POULTRY WASTES: IMPLICATIONS FOR WATER QUALITY AND AGROECOSYSTEM MANAGEMENT

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INTRODUCTION

Increases in consumer demand for low-cholesterol protein products has led to a tremendous expansion in poultry production in recent years. In 1991, the combined value of production from poultry was $14.7 billion (USDA 1991). Broiler chicken (*Gallus gallus*) production in the U.S. currently exceeds six billion birds per year and constitutes approximately 40 to 50% of total farm income in the top broiler producing states (USDA 1991). Nearly 60% of broiler production is concentrated in the southern states of Alabama, Arkansas, Georgia, and North Carolina (USDA 1991). Associated with poultry production is an enormous quantity of waste in the form of broiler litter (manure and sawdust, peanut hulls, or other bedding material), laying hen manure from egg production, and dead birds associated with mortalities from all types of operations. Alabama and Arkansas alone generated more than 4.5 million Mg of broiler litter in 1990 (Wood 1992). In Alabama, Arkansas, Georgia, and North Carolina an estimated 2 million Mg of manure from laying hens was disposed of in 1991 (Sims et al. 1989; USDA 1991). Edwards and Daniel (1992) estimate that roughly 38 kg day^{-1} of dead birds (at an average mortality of 3-5%) require disposal from a single house near the end of a production cycle. Recently, poultry producers have initiated co-composting of poultry mortalities and poultry litter, which generates a nutrient-bearing material amenable to land application (Cummins et al. 1992).

Although poultry waste has been shown to be an effective nutrient source for crop production (Flynn et al. 1993; Wood et al. 1992), land application of these materials can promote degradation of water quality (Liebhardt et al. 1979; Ritter and Chirnside 1984). The potential for environmental contamination is especially enhanced in regions of highly concentrated production. For instance, in the Sand Mountain region of northern Alabama, Blount, Cullman, Dekalb, and Marshall counties account for nearly 43% of the state's broiler production; in fact, Cullman is now estimated to be the top broiler producing county in the U.S. (AASS 1992). Due to transportation costs which exceed broiler litter nutrient value within relative short hauling distances, disposal practices over the past 25 to 30 years have likely produced an oversupply of nutrients in agricultural soils. Preliminary studies in the region suggest that nitrate-nitrogen (NO_3-N) concentrations exceeding the recommended limit of 10 mg L^{-1} (U.S. EPA 1976) in some aquifers and lake eutrophication from phosphorus (P) in run-off may be attributable to land disposal of broiler litter (Anonymous 1986). While priority is typically given to potential environmental impacts of N and P, poultry wastes are also sources of metals such as copper (Cu) and zinc (Zn), which are important to environmental concerns.

Elevated NO_3 concentrations in groundwater supplies used for human and/or livestock consumption constitute a serious health hazard. Methemoglobinemia (blue baby syndrome), cancer, and respiratory illness are among the major human health problems associated with ingestion of high levels of NO_3 in drinking water (Stevenson 1986). Fetal abortions in livestock can result from intake of water containing elevated NO_3 concentrations (Stevenson 1986). Additionally, excess N in bio-available NO_3 and ammonium-N (NH_4-N) forms can lead to eutrophication of surface waters (Stevenson 1986). Elevated levels of P in surface soils can lead to increased levels of biologically available P that can be transported in runoff to surface waters (Sharpley and Menzel 1987). The most available form of P to algae in aquatic environments is soluble P (Sharpley and Menzel 1987). Eutrophication of surface waters leads to reduction in its quality for use for fisheries, recreation, industry, or drinking (Sharpley and Menzel 1987).

Despite centuries-old experience with manures as nutrient sources for plant growth and an extensive literature concerned with NO_3 accumulation from heavy manure application (Elliot and Stevenson 1977; Smith and Peterson 1982), a rational basis for manure management is not in widespread use. As the greatest fraction of N or P contained in poultry wastes is in organic forms (Peperzak et al. 1959; Wood and Hall 1991; Cummins et al. 1992), the bio-availability of each is governed largely by the rate and extent of microbial mediated processes (Stevenson 1986). The organic N in manures have been characterized as having fractions which are rapidly mineralizable, near-term mineralizable, and very slowly mineralizable (Chescheir et al. 1986). While little research has investigated modes by which various organic P in manures becomes bio-available, it may be assumed that manure-P is analogous to soil organic P which has been generally categorized into labile, or more readily available, and non-labile pools (Stevenson 1986). Because the majority of N and P contained in poultry wastes are in forms not immediately available to biota, a knowledge of the quantity and quality of bio-available pools and how they are affected by agroecosystem management is essential to the formulation of application practices (rates and timing) which are designed to avoid ground and surface water contamination (Edwards and Daniels 1992). Research showing these elements to have a high potential for near and long-term degradation of water quality has created an urgent need for scientifically sound waste-management recommendations. Given that projections for poultry production in the U.S. indicate continued rapid expansion, research addressing the impacts of land application of poultry waste on environmentally related soil properties and processes is critical to the vitality of the industry itself and to environmental concerns of the community at large.

The objectives of the work reported herein were to:

1) Determine the effect of long-term land application of poultry wastes to pastures in the Sand Mountain region of Alabama on selected environmentally related soil chemical properties.
2) Determine the impact of poultry wastes on surface water quality.
3) Determine management effects on soil processes, such as nutrient transformations and leaching, as related to water quality.

Long-term Effects

An investigation of the impacts of long-term land application of broiler litter on soil chemical properties was made in the Sand Mountain region of northern Alabama (Kingery et al. 1994). The four counties selected for sampling, Blount, Cullman, Dekalb, and Marshall, are the major broiler producing counties in Alabama (AASS 1990); one of these (Cullman) is among the top broiler producing counties in the U.S. (Molnar and Wu 1989). From each county, three pairs of sites were chosen that consisted of long-term (15 to 28 yr) littered and non-littered pastures on matching soil series and maintained under perennial tall fescue. In each of four major broiler producing counties, 3 pairs of sites consisting of long-term (15 to 28 yr) littered and non-littered fields on matching soil series and maintained under perennial tall fescue (*Festuca arundinacea* Schreb.) were sampled. All samples were collected just prior to the 1991 application of broiler litter or to other fertilizer or lime applications. Soil cores were taken to 3 m or lithic contact and depth-incremented samples (0 to 15, 15 to 30, and each subsequent 30 cm interval) were analyzed for soil NO_3-N and acid extractable P. Soil NO_3-N was extracted with 2*M* KCl, followed by measurement via standard colorimetric procedures (Keeney and Nelson 1982) on a Lachat autoanalyzer (Lachat QuickChem Systems, Milwaukee, WI). Phosphorus determinations were made by extracting soil samples with a dilute double acid solution (Southern Coop. Series 1983) followed by inductively-coupled argon plasma spectroscopy (ICAP 9000, Thermo Jarrell Ash, Franklin, MA).

For littered pastures, application rates of broiler litter ranged from 6 to 22 Mg ha^{-1} yr^{-1} and the number of years of continuous application ranged from 15 to 28 years. These application practices are representative of the region as a whole (Molnar and Wu 1989). Litter is most often applied to land directly from broiler housing in solid form with a spreader (Molnar and Wu 1989). In a survey of Alabama broiler operations, Stephenson and McCaskey (1990) found that litter as dry matter contained an average of 4.0% N, 1.56% P, and 2.32% potassium (K) as well as lesser quantities of calcium (Ca), magnesium (Mg), manganese (Mn), copper (Cu), and zinc (Zn).

Depth distribution of soil NO_3-N concentrations (Figure 1) clearly demonstrate an impact due to long-term broiler litter application. Though littered pastures had higher NO_3-N concentrations than non-littered pastures at shallower depths (Figure 1), the differences are not considered to be of practical significance. Greater NO_3-N concentrations in littered v. non-littered soils initiating at about 100 cm depth and extending over the remainder of the depths indicate appreciable leaching to or near bedrock. These concentration vs. depth profiles for littered pasture soils are consistent with depletion in the upper part of the profile due to plant uptake and leaching to lower depths of NO_3-N in excess of tall fescue requirements. Because soils were sampled just prior to the current year's application of litter, i.e., at the end of approximately one year of microbial breakdown of litter and plant uptake, the NO_3-N observed below the rooting zone probably represents NO_3-N that exceeded crop needs. Little information is available on soil distribution at depths below the rooting zone for poultry manure applied to pastures. Though Cooper et al. (1984) found significant leaching of NO_3-N under conventional corn production to a depth of 6 m, poultry manure application rates were more than 4 times the highest rates encountered in this study.

Profile distributions of extractable P (Figure 1) indicate both accumulation and some downward movement in littered soils as compared to non-littered soils to a depth of approximately 60 cm. Long-term land application of broiler litter increased soil P concentrations to more than 6 times that of non-littered soils in the 0 to 60 cm depth interval. Phosphorus concentrations measured in the 0 to 15 cm depth in litter sites have a rating of "extremely high" according to the Auburn University Soil Testing Laboratory. Phosphorus concentrations of 25 mg kg^{-1} in the 0 to 15 cm depth are considered adequate for most crops on these soils (Cope et al. 1981). Few studies have investigated the profile distribution of P from long-term application of poultry wastes. However, greater extractable P under litter amended pastures in the Sand Mountain region of Alabama is consistent with other findings on land application of poultry manure (Field et al. 1985; Reddy et al. 1980). The relatively deep movement of P (Figure 1) may indicate leaching of applied P that has exceeded both plant P requirements and the P adsorption capacity of these sandy-textured soils (Barrow 1980). Reddy et al. (1980) observed that P adsorption capacity of soils was reduced with increased poultry waste application rates. Studies by Field et al. (1985) suggested that application rates of poultry manure in excess of normal fertilization rates increased the mobility of P. Their findings support the deduction from our results that P loading from litter application has exceeded tall fescue requirements of pastures in the Sand Mountain region of Alabama.

Though it remains to be determined, it is likely that current application practices can result in NO_3-N concentration in excess of the recommended 10 mg L^{-1} limit (U.S. EPA 1976). Elevated concentrations of P found in littered soils can increase amounts of P transported in surface runoff. In runoff from grassland, most of the P may be transported in soluble forms which are biologically available to surface water biota (Sharpley and Menzel 1987). These findings indicate that long-term land application of broiler litter at present rates has created the potential for adverse environmental effects in the Sand Mountain region.

Impacts on Surface Water Quality

In a study conducted in Alabama, Hall (1993) measured nutrients in runoff water from soils that had received different rates of poultry wastes. Broiler litter was applied at rates of 9 (BL9) and 18 Mg ha^{-1} (BL18) to sites situated on either 2 or 4% slope. Mineral fertilizer (F) was applied to sites with the same slopes according to soil test recommendations. Runoff samples were collected after each runoff producing rainfall event during March 1991 to March 1993. Total Kjeldahl N was measured in unfiltered runoff water, and NO_3-N and ammonium-N (NH_4-N) were measured in filtered runoff. Total P was measured in both sediment and runoff water.

During the first year of the study, organic N (difference between total Kjeldahl N and NH_4-N) losses were affected by soil amendment (Table 1). Organic N losses on the 2% slope were greater under BL18 than F and runoff loss from BL9 equivalent to F and BL18 treatments. These findings were similar to other studies where mass loss of poultry waste constituents in runoff water were shown to increase linearly with application rate (Edwards and Daniel 1993). Dissolved P (DP) (P which passed through a 0.45 μm filter) and total P (TP) (sum of dissolved P and sediment P) losses from both 2 and 4% slopes were also affected by soil amendment (Table 1). Greater losses of DP and TP were observed with poultry waste applications as compared to mineral fertilizer. This result was attributed to the greater application rate of P in BL18 (610 kg P_2O_5 ha^{-1}) and BL9 (305 kg P_2O_5 ha^{-1}) compared to the F treatment (50 kg P_2O_5 ha^{-1}).

During the second year of the study, Hall (1993) found greater mass losses of inorganic N (sum of NO_3-N and NH_4-N) and total N (sum of organic and inorganic N) in runoff on the 4% slope from BL18 than from BL9 and F (Table 1). Soil amendment applications affected runoff losses of DP on both slopes and TP on 2% slopes (Table 1). Poultry wastes applied at 18 Mg ha^{-1} resulted in greater DP losses on both slopes and TP on the 4% slope. The previously mentioned application rate of P was cited as the explanation for these findings.

The following discussion relative to nutrient concentrations pertains to time course runoff events as compared to the total nutrient mass mentioned above (data not presented due to space limitations). Hall (1993) found that on several occasions during the first year, NO_3-N levels rose above 5.3 mg L^{-1} for poultry waste and mineral fertilizer amendments. This is considered a minimum requirement of N essential for growth and reproduction of algae (Greeson 1969). However, Sawyer (1947) and Vollenweider (1968) have implicated concentrations as low as 0.3 mg L^{-1} of NO_3-N as a critical level expected to promote aquatic plant growth in lakes. These and higher concentrations are often encountered in discharge waters from unfertilized non-agricultural watersheds caused by mineralization of soil organic matter (Römkens et al. 1973). Concentrations of NO_3-N lost in edge of field runoff on both slopes for each amendment exceeded 0.3 mg L^{-1} on most occasions, indicating that all treatments may be contributing to eutrophication via NO_3-N losses in surface runoff. During 1992-1993, a high of 68.1 mg NO_3-N L^{-1} was measured under BL18 and was nearly seven times the highest NO_3-N concentration lost in runoff in the first year. These findings support Hall's (1993) conclusion that residual N can make a substantial contribution to runoff nutrient concentrations.

On most occasions, concentrations of TKN, NO_3-N, NH_4-N, and organic N lost in runoff edge of field losses in both years of the study exceeded the critical range of N (trace quantities to 5.3 mg L^{-1}) required for growth and reproduction of algae (Greeson 1969).

Due to low concentrations and scarcity in surface waters, P is generally considered to be more important than N in accelerating eutrophication. Hall (1993) found that total P concentrations in runoff during 1991-1992 were not significantly affected by soil amendment on either slope. Inorganic P concentrations between 0.002 and 0.09 mg L^{-1} are considered necessary to support algae growth in lake water. Phosphorus levels within this range are often encountered in discharge waters from unfertilized non-agricultural watersheds and in surface waters draining geological formations high in P (Römkens et al. 1973). Hall (1993) showed that poultry waste applications of 18 Mg ha^{-1} resulted in higher losses of dissolved P in runoff than either 9 Mg ha^{-1} or mineral fertilizer applications. Higher sediment P concentrations from BL18 may contribute to deposition and subsequent nutrient supply. In addition, concentrations of DP, TP, and sediment P in runoff from all treatments consistently exceeded the critical range of inorganic P expected to promote growth and reproduction of algae.

It was concluded from this study that concentrations of all nutrients in runoff from all treatments doubled during the second year due to residual effects and provided more than adequate levels to support algal growth. The findings of Hall (1993) indicate that nutrient concentrations in runoff from residual effects of poultry wastes pose a potential for degradation of surface water quality.

Management Effects

Kingery and Wood (1994) conducted a study to examine N and P mineralization/release in soils previously maintained for two years under conventional or strip-tillage systems and commercial or broiler litter fertility regimes. Tillage systems investigated were strip (or conservation) and conventional tillage, with various soil nutrient amendments that included: no fertilizer, commercial fertilizer, and broiler litter. Broiler litter was broadcast pre-plant at a rate of 9 Mg ha^{-1} on a fresh weight basis, and commercial fertilizer was applied at rates to match the total elemental content of N, P, K, and Zn in the broiler litter. Soil organic C and total N were determined by dry combustion. Inorganic N was measured via standard colorimetric procedures (Keeney and Nelson 1982). Soil organic N was calculated as the difference between total and inorganic N. Available P was measured in dilute double acid soil extracts (South. Coop. Ser. 1983). Soil organic P was determined as the difference in P from ignited and unignited samples (Olsen and Sommers 1982).

Tillage and fertility management effects on N and P mineralization/release were studied by laboratory incubation using the procedure of Nadelhoffer (1990). Measurement of N mineralization and P release were made following initiation of incubation at 1, 3, 5, 7, and 10 days, weekly through day 35, and every other week through day 254. Modeling cumulative mineralization or release was performed by regression of cumulative C, N, or P and time (days).

There were no significant effects due to either tillage or soil amendment regimes for soil organic C and double acid extractable P (data not shown). For soils maintained under conventional tillage, we observed a slight trend toward higher concentrations of soil organic N as compared to strip-till. Conventional tillage also resulted in an average of approximately 60% greater concentrations of soil organic P than for strip-till (data not shown). We suggest that the higher soil organic P concentrations observed under conventional, as compared to strip, tillage may be manifestation of available P from amendments and crop residues, supplied to a larger portion of the soil microbial population, and subsequent incorporation into biomass.

Nitrogen mineralization during laboratory incubation reflected the influence of previous tillage-fertilizer practices (Figure 2). For example, the greatest cumulative N mineralization occurred in soils maintained under strip-till and amended with broiler litter was approximately 47% greater than N mineralized from soils where broiler litter was applied under conventional tillage

(Figure 2). These results imply that even though two years of conventional tillage had likely promoted slightly larger total soil organic N concentrations, strip till management may have resulted in a larger labile N fraction.

Approximately 0.4 mg kg^{-1} more inorganic P was released during the 254-day incubation from strip-till as compared to conventionally tilled soils (Figure 3). In addition, two years of prior soil amendments had differential effects on cumulative P released (Figure 4). Greater cumulative P was released from both commercially fertilized and broiler litter amended soils than from soils receiving no fertilizer. Commercial fertilizer and broiler litter-P applications promoted a larger pool of easily extractable P (0.01 *M* $CaCl_2$ extractant) than was found in control plots despite similar double-acid extractable P levels in pre-incubated soils (data not shown).

These results provide evidence that organic matter processes in a southeastern U.S. soil can be influenced by relatively short duration agroecosystem management. It has been demonstrated that the quantity of ions potentially mobilized via microbial activity cannot be predicted from measurement of total concentrations alone. The impact of agroecosystem management on the quantity and quality of nutrient pools must be considered in order to insure environmentally sound utilization of organic materials such as poultry waste.

Future Research Needs

From the above discussion it is apparent that a large measure of the disposal problem could be solved by removing poultry wastes from poultry production areas for utilization in areas of intensive row crop production. However, due to the cost restrictions in moving poultry wastes, it is anticipated that most poultry wastes will be land-applied to pastureland near poultry production facilities. An aspect of poultry waste management that has received very little attention is the impact of grazing on water quality. Activities associated with animal production systems on grazed land are a major contributor to physical, chemical, and biological changes in watershed structure and function. Estimates are that these activities account for approximately 25% of the nonpoint source pollution associated with U.S. agriculture. Where grazing has reduced plant and residue cover, sealing of soil surfaces via raindrop impact and hoof compaction may reduce infiltration and increase erosion and runoff (Archer and Smeins 1991). Graf (1985) reported that ephemeral drainage found in grazed watersheds can be sources of excessive sediment in perennial stream flow. No information is currently available relative to the contribution similar features and processes make to sediment and other pollutant loads in perennial streams of grazed watersheds in the southeastern U.S., however, the contribution is probably significant. In fact, erosion control has been identified by the National Resource Inventory (USDA 1987) as one of the top three management issues on the 75 million hectares of grazed pasture in the Southern Region.

Vegetation type can also be an important variable in agroecosystems where poultry wastes are being land-applied. Research has shown that vegetation type affects the amount and structure of associated cover on grazed lands, thereby impacting infiltration rate and other hydrologic properties (Black et al. 1986; Thurlow et al. 1986). For example, the amount of cover, and hence the rate of infiltration, is usually greatest under trees and shrubs, followed in decreasing order by bunchgrass, sodgrass, and bare ground. Drainage channels in grazed pastures are often left to be colonized by planted forage species. Two of the most important perennial warm-season grasses used for pasture in the southeast, bahiagrass and bermudagrass, are sodgrasses. When exposed to the same rainfall amount and intensity, interill erosion has been shown to be up to 7x greater for this grass type than for bunchgrass (Blackburn et al. 1986). The influence of various bunchgrass species, including native species, in vegetative buffer or filter strips for erosion control and enhancement of runoff and groundwater quality has not been examined for use in land-application/grazing agroecosystems.

Despite the problems associated with poultry wastes cited above, land application offers the most practical means for management of the large amounts of poultry waste produced. For this reason it is essential that application rate guidelines be developed that maximize the alignment between optimum agricultural productivity and maintenance of water quality.

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Table 1. Mean N and P losses in runoff as affected by soil amendment during 1991-1993.

Parameter	Year‡	Slope(%)	Soil Amendment† F	BL9	BL18
			------------------kg ha^{-1}------------------		
			Dissolved Nutrients		
Organic N	1	2	1.39	2.68	3.81
Organic N	1	4	2.16	2.83	6.00
P	1	2	0.44	0.77	0.90
Inorganic N	2	4	4.90	3.40	8.23
P	2	2	0.31	0.43	0.99
P	2	4	0.22	0.47	1.21
			Total Nutrients¶		
P	1	4	0.94	1.15	3.14
N	2	4	6.01	4.60	9.45
P	2	2	0.56	0.70	1.32

†F=mineral fertilizer; BL9=9 Mg broiler litter ha^{-1}; BL18=18 Mg broiler litter ha^{-1}
‡1=March 1991-March 1992; 2=March 1992-March 1993
¶Total nutrients=sum of sediment and dissolved nutrients

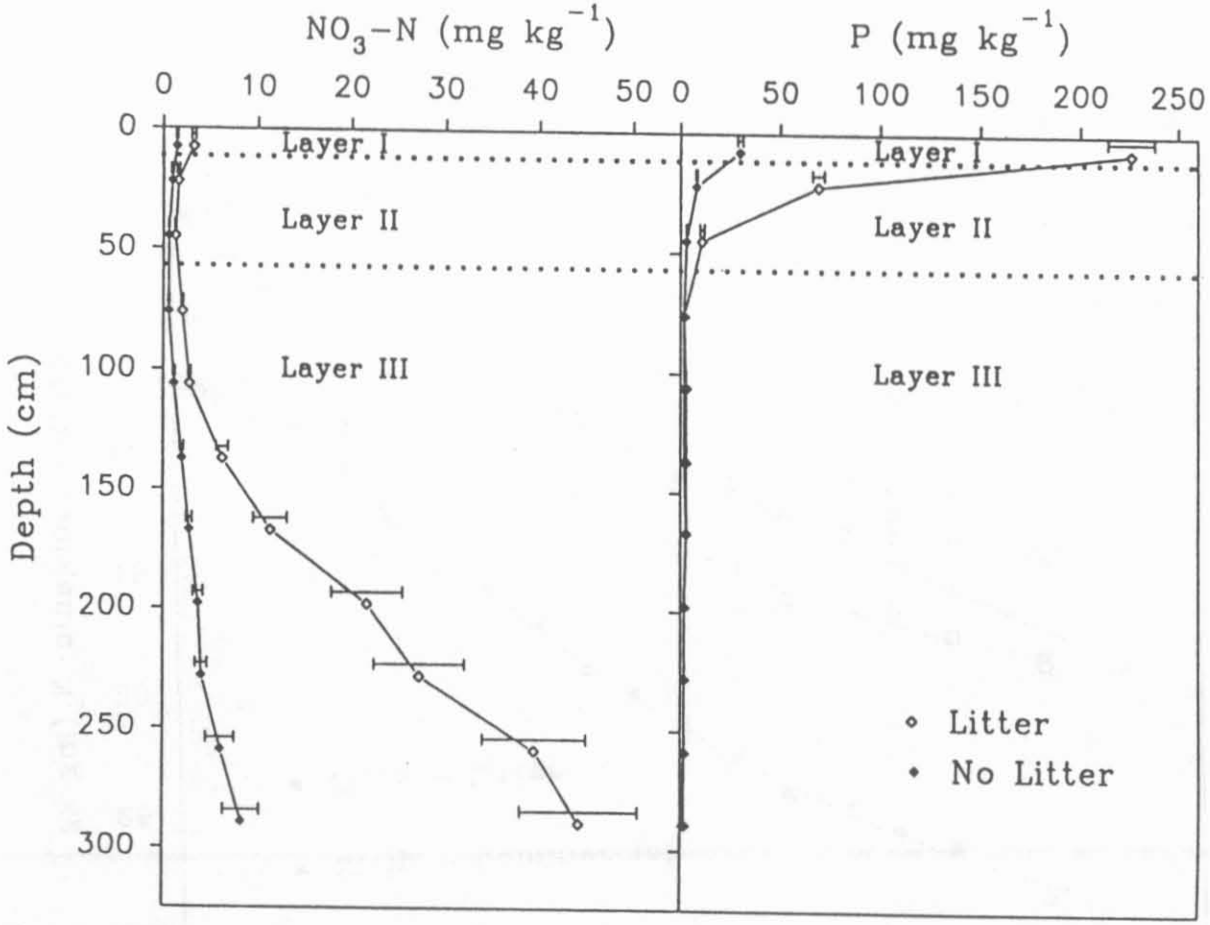

Figure 1. Depth distribution for NO_3-N and P from litter and no-litter pasture soils in the Sand Mountain region of Alabama. Bars are SE at each depth for the means of each treatment. LSD(0.05) for NO_3-N = 1.43 (Layer I), 0.52 (Layer II), and 2.47 (Layer III). LSD(0.05) for P = 114 (Layer I), 19 (Layer II); Layer III NS.

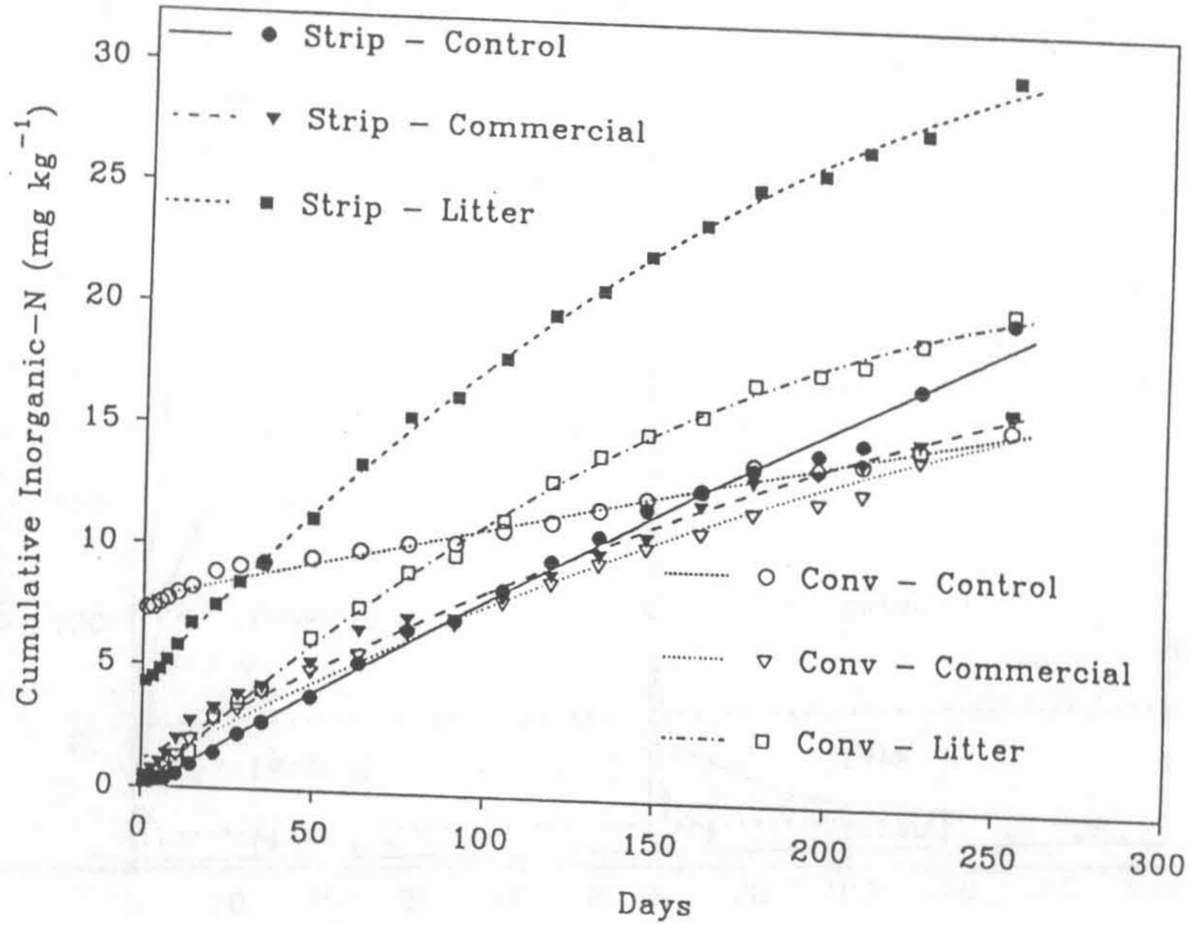

Figure 2. Cumulative N mineralization during laboratory incubation study as affected by tillage-soil amendment management. Strip and Conv - strip and conventional tillage; Control, Commercial and Litter - no fertilizer commercial fertilizer and broiler litter, respectively, applied in the field as soil amendment. Regression equations in Table 4 used to calculate lines representing predicted values.

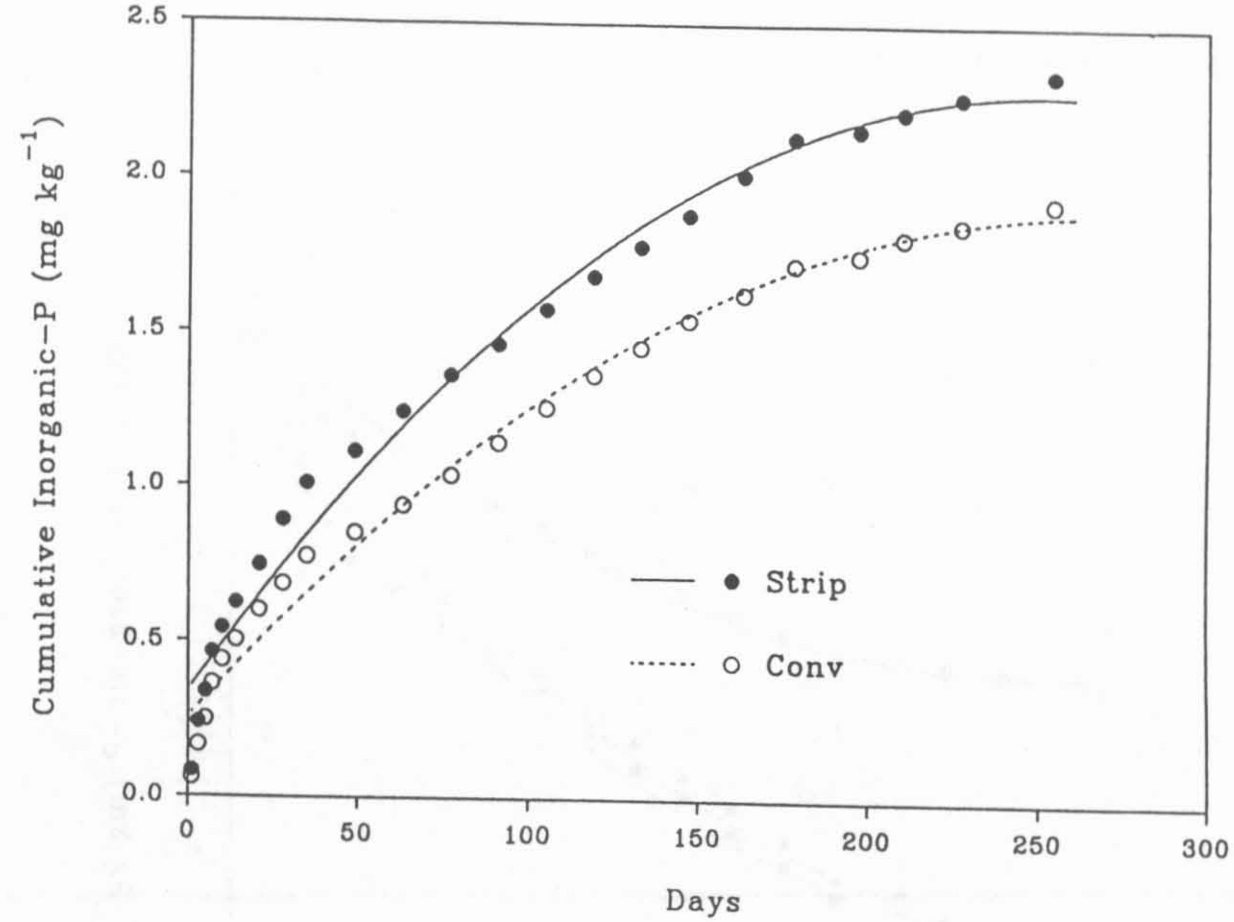

Figure 3. Cumulative P release during laboratory incubation study as affected by tillage. Strip and Conv - strip and conventional tillage.

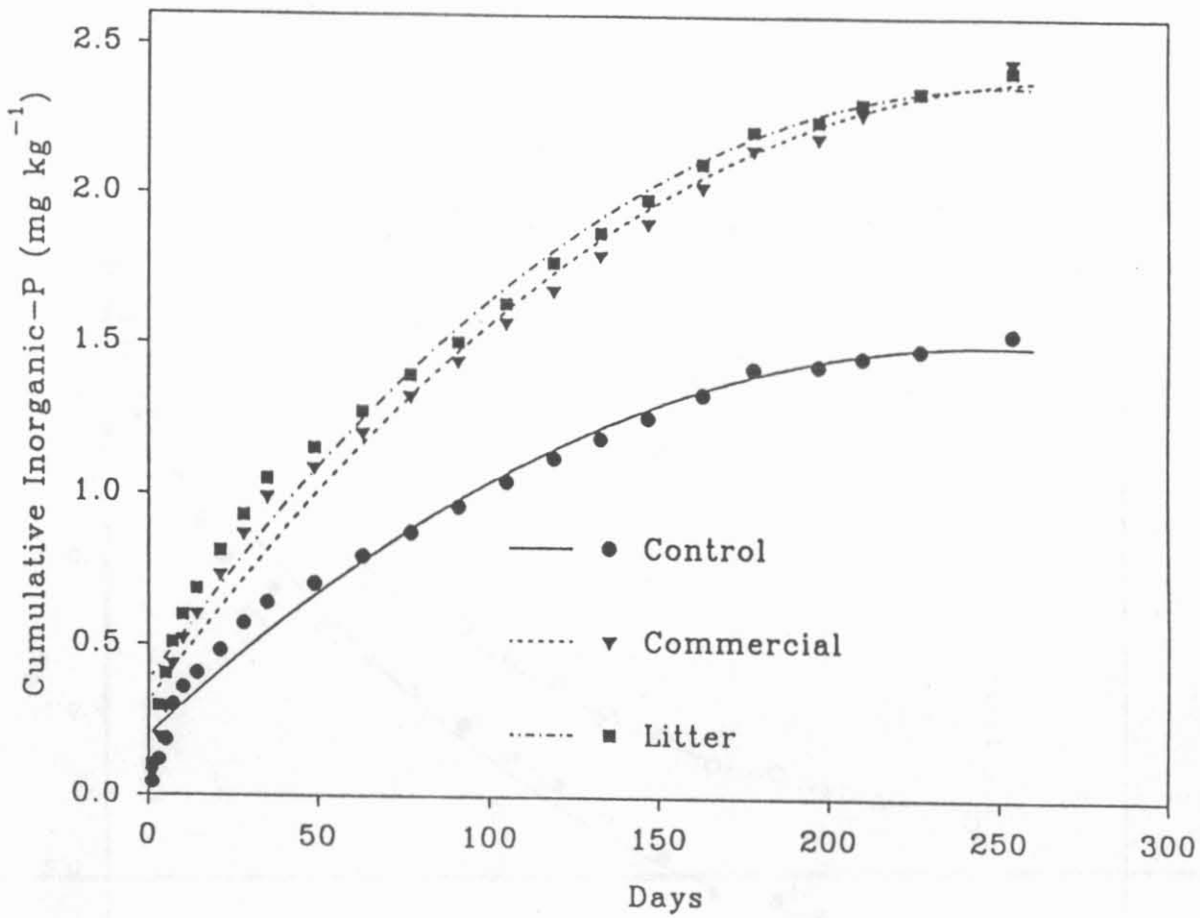

Figure 4. Cumulative P release during laboratory incubation study as affected by soil amendment management. Control, Commercial and Litter - no fertilizer commercial fertilizer and broiler litter, respectively, applied in the field as soil amendment.