PERCOLATE CONCENTRATIONS OF NITROGEN AND PHOSPHORUS IN POULTRY LITTER-APPLIED-SOILS OF EASTERN OKLAHOMA

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CHAPTER I

INTRODUCTION

Poultry production in eastern Oklahoma has risen significantly in the last five years. Along with this production is the increasing accumulation of poultry waste. Application of poultry waste or litter (manure plus an absorbing material) on pasture and cropland is the primary method of disposal. Poultry litter application in this region is concentrated in both upland and lowland areas.

The region is a dissected plateau with gently sloped uplands, steep side slopes, and narrow stream and river valleys (lowlands). Poultry application areas initiate or at least contribute to recharge of streams and lakes. Nitrogen and phosphorus are major plant nutrients found in poultry litter. These two elements have been established as consistent factors in controlling undesirable algal growth in lakes and streams, with phosphorus identified as the nutrient most likely to control such growth. Surface-applied poultry litter can contribute to increased amounts of nitrogen and phosphorus in percolates from soils of eastern Oklahoma. Soil percolates will eventually contribute to stream and lake quality.

This research was part of a project with a primary objective of determining whether there is leaching of nitrogen (N), phosphorus (P), and arsenic (As) through the soil following poultry litter application. The project was funded by the United States Department of

Agriculture/Soil Conservation Service as a part of cooperative report number 2045 entitled Risk to Water Quality/Soils of Eastern Oklahoma.

The objectives of this study include: (1) Development and implementation of field and laboratory research to determine the contribution of surface-applied poultry litter to nitrogen and phosphorus percolation through soils, and (2) Determination of the forms (i.e. soluble organic or inorganic) of N and P in soil percolates.

This research examined the effect of various poultry litter loading rates (on unclipped tall fescue pasture) have on nitrogen and phosphorus concentrations in soil percolates. Two soils having a long-term history of poultry litter application were used. The two soils were: (1) Baxter Fine, mixed, mesic Typic Paleudalf, and (2) Stigler Fine, mixed, thermic Aquic Paleudalf. The experimental sites in which these soils were described, sampled, and monitored with lysimeters were located in Delaware County, Oklahoma. This research consisted of a laboratory and field study. The laboratory study involved the use of large intact soil columns. Percolation of the soils was conducted in a temperature and light regulated room. The field study utilized porous ceramic cup or "suction" lysimeters and zero-tension or "pan" lysimeters. From these studies and in conjunction with a surface-runoff study by the agricultural engineering department, poultry litter loading rates will be established for poultry growers in this area.

CHAPTER II

LITERATURE REVIEW

Introduction

Prior to the early 1950's, farm manure was considered an indispensable resource. Farm manure's nutrient content and ability to maintain soil organic matter levels were important in overall farm management (Salter and Schollenberger, 1939; Oniani et al., 1973).

In spite of some of the advantages of farm manure, there are disadvantages, too. Odors, flies, and nutrient losses are usual problems. Nutrient leaching from farm manure may not represent a significant loss for plant growth but may adversely affect ground water quality. Farmers usually have an abundant supply of manure, or commercial fertilizers for crop production. Leaching losses take on a different perspective when assessing environmental quality. Poultry manure percolate is suspected to cause degradation of water quality in the Illinois River and consequently Tenkiller Ferry Lake (Gakstatter and Katko, 1986). Loss of nutrients by percolation is a significant pathway for fertilization of lakes (Biggar and Corey, 1969).

Nitrogen (N) and phosphorus (P) are two essential plant nutrient elements from poultry manure considered in nutrient loss to the environment. Arsenic (As) may also pose environmental health problems, when poultry manure is added to soils. Nitrate pollution has received considerable recent attention in the United States. Although greatly influenced by water volume and mean depth, Vollenweider (1968) fixed the eutrophic threshold values at 0.3 mg L^{-1} for nitrate in flowing streams. Poultry litter percolate has caused nitrate concentrations in the ground water to exceed EPA drinking water standards of 10 mg L^{-1} (CFR-40 141.62 1991 ed.) (Robertson, 1977; Liebhardt et al., 1979; Bachman, 1984; Ritter and Chirnside, 1984; Ritter, 1989).

There is no recommended drinking water standard for phosphorus. In addition, no established limiting P concentration value has been set for algal growth in natural waters. Some research has suggested 0.03 mg L^{-1} DIP (dissolved inorganic P) as the upper limit for controlling algal growth in natural waters (Sawyer, 1947; Vollenweider, 1968).

A concentration of 10.08 kg N ha^{-1} ("available NO_3-N" or "residual NO_3-N" extracted with dilute $CaSO_4$) and 17.92 Kg P ha^{-1} (an"index value" which will not account for the plant available P and is determined by using Mehlich 3 extraction) was typical for soils in the A horizon from non-poultry litter-applied-pastureland located in the Battle Branch subbasin of Delaware County, Oklahoma (Jackson, 1992).

Arsenic from poultry manure may also pose a soil disposal problem. High As levels in soils may result in growth reduction and crop failure (Adriano, 1986). Arsenic in soil and water can reach phytotoxic levels (Adriano, 1986). Although arsenic is not a limiting nutrient for algal growth, Sharpley et al. (1991) stated that he found residual amounts in poultry litter-applied soils but claimed no increase in As from litter application. Calvert (1975) reported that As is used as a poultry feed additive to control coccidiosis and to promote chick growth. The United States Environmental Protection Agency has set 0.05 mg L^{-1} as the primary drinking water standard for As. For irrigated crops, the limit in water is 0.10 mg L^{-1} (40-C.F.R. 141.62, 1991). Arsenic levels of untreated soils located in the Battle Branch Subbasin (approximately 0 to 50 cm depth) were below the 6 mg Kg^{-1} detection limit (Sharpley et al., 1990).

The following topics provide a better understanding of the impact of poultry litter disposal on ground water quality. Major topics include: (1) chemistry and bioavailability of nitrogen and phosphorus in natural waters (2) arsenic water chemistry (3) chemistry and bioavailability of nitrogen and phosphorus in soil (4) arsenic soil chemistry (5) processes affecting nutrient concentration changes in soil percolates (6) measurement of phosphorus transport through soil, (7) poultry litter, (8) fate of nitrogen and phosphorus from poultry litter, and (9) effects of poultry waste loading rates.

Chemistry and Bioavailability of Nitrogen and Phosphorus in Natural Waters

Phosphorus

Understanding land disposal problems of poultry litter requires a knowledge of the detectable forms of phosphorus present in water, and which forms cause accelerated eutrophication.

Phosphorus occurs in natural water as "phosphates" more specifically, orthophosphate (PO_4^{3-}). Orthophosphate is fully oxidized. Orthophosphates can exist inorganically as $H_2PO^-_4$ and HPO_4^{2-}. Under certain conditions they may exist as a condensed or polyphosphate. Phosphates can also exist in organic forms (embodied into organic compounds). Phosphorus enters organisms as orthophosphate although it becomes polyphosphate when assimilated into the organic structure

(Henderson-Sellers and Markland 1987; Hem, 1989). Inorganic and organic forms can be either dissolved or undissolved (sediment, particulate). Neither organic nor inorganic phosphorus is very soluble (Hem, 1989).

Phosphorus controls biological activity in streams and lakes. Different forms of P may change the rate of biological activity. Biggar and Corey (1969) stated that dissolved inorganic P is directly available for biological utilization. Solid particulate matter contains a large portion of P, only a small amount will dissolve when the sediment is placed in stream water (Taylor, 1967).

Sonzongni et al. (1982) found that potentially bioavailable P in tributaries generally does not exceed 60% of the total P and is often considerably less. The potentially bioavailable P corresponded to the dissolved inorganic P (DIP) plus the fraction of particulate inorganic P obtained by extraction with 0.1N NaOH.

Hergert et al. (1981) found that soluble inorganic phosphorus was the predominate form of phosphorus in soil drainage tile flow during most of the year following heavy soil applications of dairy manure. Although phosphorus losses in tile flow are small, this form is readily available to organisms.

Nitrogen

Nitrogen occurs in natural water as nitrite or nitrate anions (NO_2^- and NO_3^-), in cationic form as ammonium (NH_4^+), at intermediate oxidation states as a part of organic solutes, and as elemental nitrogen. Since nitrate is stable under oxidizing conditions at pH>3 (Bohn et al., 1985), it is the predominant form present in flowing streams.

Medine and Porcella (1981) reported that there are three major forms of nitrogen present in water:

- (1) Gaseous N (N_2, N_2O, and NO)
- (2) Dissolved N
  - (a) inorganic compounds
  - (b) organic compounds (i.e. amino acids, peptides, polypeptides), dissolved albumin and other organic compounds
- (3) N in suspension
  - (a) inorganic compounds adsorbed on particles
  - (b) organic detritus and organic compounds adsorbed on particles.

Various forms of nitrogen in water cannot be used to the same extent by plants (Fig. 1). It is not known which of the two inorganic forms of nitrogen (NH_4^+ and NO_3^-) is preferred by plankton algae. In culture, the two sources are, as a general rule, used to roughly the same extent (Ryding and Rast, 1989). Nitrate is clearly preferred by Botryococcus Braunii (Chu 1942), whereas according to Gerloff (1969) Chlorella absorbs only ammonium (from ammonium salts), even if nitrate is present. A certain preference for NH_3 is to be expected in theory, since NO_3^- requires energy for its reduction. However, effective plankton algae preference for one or the other ion in nature certainly depends on the biological makeup of the plankton.

	Organic N	(NH_3-N)	(NO_3-N)	N_2
Some bacteria and eumycetes, some species of Euglena	X			
Some bacteria and Eumycetes	X	X		
Most bacteria, Eumycetes, algae and higher plants	X	X	X	
Some bacteria and blue-green algae	X	X	X	X

Fig. 1. Use of different forms of nitrogen.

Elemental nitrogen is fixed by Cyanophyceae, a blue-green algae (Provasoli, 1969). However, algae bloom formation is caused most frequently by three blue-green algae which are not nitrogen fixing, i.e. Aphanaizomenon flosaquae, Microcystis aeruginosa, and Oscillatoria rubescens (Paerl and Ustach, 1982).

Arsenic Water Chemistry

Arsenic, in small amounts can be toxic to flora and fauna. Arsenic is ubiquitous in the biosphere. (Adriano, 1986; Hem, 1989). The stable forms of Arsenic (As) in natural water are arsenate (As(V)) or arsenite (As(III)) oxyanions. Arsenate as $H_2AsO_4^-$ is the prevailing form of arsenic between pH 3 and pH 7. Between pH 7 and pH 11 $HAsO_4^{2-}$ is the predominant form. Slight reducing conditions will promote arsenite, $HAsO_2$(Aq), formation (Hem, 1989).

Hem (1989) citing Pierce and Moore (1980) and Kopayashi and Lee (1978) reports that arsenic adsorption or precipitation by hydrous iron oxide seem to be major inorganic factors in maintaining concentrations of arsenic at very low levels in natural water (Hem, 1989). Braman and Foreback (1973) reported that dimethyl arsenic acid (a derivative of arsenic as a result of biologically mediated methylation) is difficult to oxidize and maybe a major part of the dissolved arsenic in surface water. The importance of biochemical processes relating to arsenic in natural waters is still being studied (Hem, 1989).

Chemistry and Bioavailability of Nitrogen and Phosphorus in Soil

Nitrogen

Since nitrate is stable under oxidizing conditions at $pH>3$ (Bohn et al., 1985), it is the predominant form present in soil. Most nitrogen in soils is in the undissolved organic form (incorporated into organic matter). As much as 95% or more of the nitrogen may be in the organic form. About half the organic fraction is in the form of amino compounds. Protein is present generally as coatings on organic matter (i.e. galactose amine + glucose amine = 5-10% of total N). The remainder of the organic nitrogen could be in the cyclic compounds (Biggar and Corey, 1969).

The conversion of organic nitrogen compounds to mineral forms, a process referred to as mineralization, encompasses two distinct microbial processes (1) ammonification, in which bacteria and hydrolysis decompose organic nitrogen to form ammonium-N (NH_4^+), and (2) nitrification, in which ammonia is oxidized by Nitrosomonas bacteria to nitrite (NO_2^-), and the genus Nitrobacter further oxidizes (if under areable conditions) the resulting nitrite to nitrate (NO_3^-). Although some reduction (NO_3^- --> gaseous products) may also take place, algae and higher plants rapidly assimilate the NO_3^-. A small part of this nitrate, not assimilated by plants, may be readily transported by surface and ground water (Barthomew and Clark, 1965; Brady, 1984; Bohn et al., 1985).

Phosphorus

Unlike nitrogen, phosphorus is not a significant component of the atmosphere. The phosphorus cycle is not open to the atmosphere. Phosphorus is a major component of some rocks and is therefore often referred to as "rockbound". Among the rockbound elements it is the scarcest in proportion to biological demand (Chang, 1940). Three basic forms of inorganic phosphorus may exist in unfertilized soils: (1) apatite (apatite is a mineral with variable elemental composition, but does contain calcium phosphate or $Ca_n(PO_4)_x$ with variable amounts of OH, Cl and F) includes specific compounds such as fluorapatite $[Ca_3(PO_4)_2]_3CaF_2$ or $Ca_5(PO_4)3F$ (most common formula of the fluorapatites), chlorapatite $[Ca_3(PO_4)_2]_3CaCl_2$ or $Ca_5(PO_4)_3Cl$ (most common formula of the chlorapatites) and hydroxylapatite $Ca_5(PO_4)_3OH$. Many gradations exist between hydroxylapatite and those of fluorapatite and chlorapatite, depending on how much OH substitutes for F or Cl in the crystal structure. Other substitutions are possible in the apatite structure: OH, CO_3 and SO_4 for PO_4 and cations like Mn, Y, Sr for Ca (Deer et al., 1966; Krauskopf, 1979). (2) phosphorus adsorbed on the surfaces of iron (Fe), aluminum (Al) and calcium (Ca) components (nonoccluded). (3) phosphorus present within the matrixes of Fe and Al components (occluded) (Seyers and Walker, 1969; Williams and Walker, 1969). Iron and aluminum phosphates are the most abundant inorganic forms of phosphate in acid soils. Calcium phosphates are the abundant inorganic phosphate forms in alkaline soils (Reddy et al., 1980).

Various reactions can take place when phosphorus comes in contact with soil particles. Adsorption is believed to be the primary process during the initial rapid reaction with soil particulates. This reaction takes place within the first four hours (Singh and Jones, 1976). Singh and Jones (1976) proposed that phosphorus is adsorbed by anion exchange, and replaces hydroxyl ions in organic matter. It is assumed that with time the P is transformed into less available iron and aluminum phosphates, as well as incorporated into the organic matter. The next reaction is precipitation to relatively insoluble phosphate (Sawhney and Hill, 1975; Singh and Jones, 1976).

Because phosphorus is relatively immobile in soil water, P lost from agricultural lands occurs by sediment suspended load in surface runoff (Holt et al., 1970; Miller, 1979; Brown et al., 1989). Tile flow from agricultural land usually carries small amounts of sediment, consequently dissolved P may be the major fraction of P present. In several studies P concentrations in drainage water from tiles ranged between 0.01-0.30 mg P L^{-1} and losses ranged from 0.02-0.50 kg P ha^{-1} per year (Johnson et al., 1976, Bolton, et al., 1970; Erickson and Ellis, 1971).

Additions of organic matter to the soil may either increase or decrease the immediate availability of soil P. Increased P availability is attributed to organic acids (derived from organic matter decomposition) that complex Fe and Al and block P adsorption sites (Singh and Jones, 1976). Decreased P availability (observed for residues with low P contents) is attributed to microbial assimilation (Singh and Jones, 1976). Long term addition of organic matter increases total availability of soil P (Hergert et al., 1981).

Some studies have found that large additions of animal manures to the soil typically result in increased P availability and decreased P adsorption (Singh and Jones, 1976; Reddy et al., 1980). Some researchers, in fact, have found significant P concentrations in their soil percolates as a result of organic waste additions (Erickson and Ellis, 1971; Bielby et al., 1973; Duxbury and Peverly, 1978; Miller, 1979; Raez, 1979; Hergert et al., 1981; Reddy, 1983). These studies concluded that transport of P in the soil profile is dependent on the rate of P application, type of waste, and P adsorption and precipitation reactions with soil.

Hergert (1975) rejected the hypothesis that since there was an increase in concentration of P in the soil tile flow from plots treated with 448 Mg ha^{-1} of dairy manure, then the concentration of P in the subsoil should increase substantially. Extractable P from the subsoil of such plots indicated only small increases. Hence, the mechanism controlling P movement, which results in increases in tile flow concentrations, was not related to mass movement of P into the subsoil.

Organic phosphorus compounds move more readily than inorganic P in soils (Hannapel et al., 1964). Hergert (1975), rejected the hypothesis that organic P compounds derived from manure may be percolating through the soil but end up hydrolyzing to inorganic P during the analysis.

Arsenic Soil Chemistry

Arsenic is a toxic and ubiquitous element in nature. Background levels of arsenic, in soils, have been surveyed by several researchers. Adriano citing Shacklette and Boernger (1984) and Berrow and Reaves (1984) reported mean As content of 7.2 and 10 mg kg^{-1} respectively, in soils across the United States. Adriano (1986) citing Vinogradov (1959), reported that the As levels of soils of the Russian Plain were generally uniform at 1 to 10 mg Kg^{-1}, with a mean As level of 3.6 mg kg^{-1}. Fergusson (1990) citing Ure and Berrow (1982) reported a mean As level of 5-10 mg Kg^{-1} for soils world-wide which were not contaminated.

Arsenic occurs frequently in nature in the pentavalent state as arsenate (AsO_4^{3-}) (Fergusson, 1990). Adriano (1986) cited Deul and Swoboda (1972), stating that there is the possibility of As reduction to arsenite (AsO_2^-) under moderately reducing conditions. Arsenite is a very toxic As compound. Braman and Foreback (1973) stated that arsenite was 25 times more potent than that of dimethylarsenic acid.

Soils strongly retain both H_3AsO_4 and $HAsO_2$ which are weak acids. Arsenic resembles phosphorus chemistry. Arsenic is fixed in soil in the iron, aluminum and calcium fractions; iron and aluminum hydroxides being the most fixation effective. Hence, Fe and Al have a greater role than Ca in the fixation process of As (Elkhatib et al., 1984). This is because iron and aluminum arsenate have lower solubility products as compared to calcium arsenate (Wauchope and McDowell, 1984; Elkhatib et al., 1984). The amount of sorption of As relates to the As concentration, time, and the iron and manganese content of the soil. In acidic soils, the main forms of As are aluminum and iron arsenates $AlAsO_4$ and $FeAsO_4$, whereas, in alkaline and calcareous soils, the main form is $Ca_3(AsO_4)_2$ (Tammes and de Lint, 1969).

Livesey and Huang (1981) found that As retention by the soils (with dilute As concentration) did not proceed through the precipitation of sparingly soluble arsenate compounds. Arsenate retention evidently proceeds through adsorption mechanisms (Livesey and Huang, 1981). The adsorption maxima, of the soils which were studied, were not related to acidity and the contents of inorganic C (Livesey and Huang, 1981). These adsorption maximas were found to be related to the iron concentration in the soil. More specifically they were, linearly related to amounts of ammonium oxalate-extractable Fe. Chloride, nitrate, and sulfate present at concentrations usually present in saline soils have little effect on the adsorption of As. They also found that phosphate substantially suppresses As adsorption by the soils, and the extent of this suppression varies between soils.

Under moderately reducing conditions (poorly drained soils) a greater proportion of As(III) compared to As(V) increased the mobility of arsenic. The reduced state of As(III) has been reported to have a 4 to 10 times greater dissolution rate in soils than the oxidized state of As(V) (Fergusson, 1990). In strongly reducing conditions arsenic sulfide As_2S is stable in soils (Bohn et al., 1985).

Bacteria also play an important role in the chemistry of soil arsenic. The oxidation of As(III) to As(V) is accelerated by bacteria. Methanogenic bacteria, under reduced environments, can reduce arsenate (V) to an arsenite (III) methylated compound. These can be further methylated or reduced to other compounds. (Adriano, 1986; Fergusson 1990).

Tammes and de Lint (1969), and also Steevens et al. (1972) have demonstrated that a substantial amount of As can be transported with soil percolates, especially in soils of coarser texture.

Factors Affecting Nutrient Concentration Changes in Soil Percolates

Since some of the N, P and K in raw poultry manure is water soluble, then poultry manure-applied-soil has the potential to percolate such nutrients. Poultry manure is also biologically active when mixed with the soil or when applied during periods of high humidity and warm temperatures. Variation in the percolation of N and P is probably due to a combination of factors such as soil and water management practices, the rate of fertilization, the composition and depth of the soil and the nature of the underlying rock (Graves, 1986; Issacs and Harris, 1987).

An important process affecting the movement and distribution of soluble materials through soil is mixing between the resident soil solution and invading water from surface (Biggar and Corey, 1969). Hence, mixing will determine the concentration changes that occur as a function of both resident time and direction of flow. The consequence of mixing is: (1) dissolved constituents can move independently of the solvent, and (2) hydraulic conductivity cannot describe processes that are responsible for mixing on a microscopic scale. Residence time is the rate of movement of nutrients through the profile. Residence time has an important bearing on the nutrient concentration-water flow relationship. Kinetic factors are involved in the interaction of PO_4^{3-} with soil mineral components or the labile phosphorus pool (Duxbury and Peverly, 1978).

Reduction might affect DIP concentrations in soil percolates. Reduction of an acid soil after flooding tends to increase inorganic P concentration in soil solution (Patrick et al., 1973). Exactly the opposite effects were noted for calcareous soils by Hergert (1975).

Hergert (1975) found that the DIP concentrations in his tile flow did not increase with reduction but actually decreased. He thought that the actual mechanism controlling this decrease in DIP concentrations in tile flow from calcareous soils may be related to the production of Fe as a result of reduction.

* Hergert et al. (1981), using calcareous soils applied with dairy manure, concluded that the concentration of P in the tile flow depended upon three major variables:

$CaCO_3$

(1) the concentration of P in the soil solution within the
    plow layer
(2) the path of water movement to the tile
(3) the salt and/or Ca concentration of the soil solution.

Measurement of Phosphorus Transport Through Soil

The ability of P sorption capacity to predict retention or movement of phosphorus may not be as precise as once thought (Bartlett and James, 1980). The use of P sorption capacity for such predictions requires assumptions such as the amount of soil mixing and contact time needed for equilibrium to be reached (standard mixing time is 24 hours). Channelizations can occur in soil with considerable water flow occurring in the macropores (White, 1985). As a result of channelization, only the ped faces and channel surfaces may be contacting the applied waste water solution. In addition, waste water flow through the macropores and cracks may surpass time necessary for equilibrium to be reached (Thomas and Phillips, 1979; White, 1985). Both assumptions may lead to underestimation of P movement through soil.

Large (>15 cm in diameter) undisturbed core samples provide a representation of the field situation (Bartlett and James, 1980). Accurate sampling is achieved with undisturbed columns because: (1) the complex micro, meso, and macropore structures are preserved, (2) relatively large cores will enable the researcher to avoid boundary flow conditions at or near saturation flow levels which smaller diameter cores are susceptible to (Lewis et al., 1990), (3) biological communities are not destroyed, and (4) rock fragments are included in soil fabric. Lewis et al. (1990) devised a method for collecting large intact cores from stony soils by excavating free-standing pedestals carefully trimming to the required diameter.

Poultry Litter

Introduction

The term "poultry waste" is used as a general term, which may or may not include both poultry manure plus an absorbing material, collectively called poultry litter, or solely poultry manure. The term "poultry litter" is sometimes used loosely to express poultry manure, however, most researchers recently involved with this waste usually will not use the term litter for manure. They will use the term "litter" in the collective sense (manure plus an absorbing material) (Carr, 1989). The term most often used for the absorbing material is "bedding". The term "poultry" may include layers and broilers (Issacs and Harris, 1987).

Composition

Management practices, undoubtedly, influence the amount, as well as, the composition of poultry manure and the bedding used. These practices vary widely even within a county or community (Perkins et al., 1964). This wide variation was not noticed by Soil Conservationists in this region of Oklahoma (Walker, 1991). Most, if not all, of the poultry growers had soil-floored houses. Materials most often used for bedding in eastern Oklahoma are oak bark, pine shavings, wheat straw and rice hulls (Walker, 1990). Earlier research (Perkins, et al, 1964) showed that in soil-floored houses, soil material may constitute up to 25 per cent of the total amount of floor litter.

Poultry litter and poultry manure content is reported either on a dry weight and/or a wet weight basis. Chemical analyses of broiler manure reveal that it contains, on a dry weight basis, an average of 4.11% N, 1.45% P, 2.18 % K (Hileman 1971). Hileman (1971) also stated that the N, P and K in the raw manure is water soluble, revealing 92%, 86% and 98%, respectively. Beegle (1988) found that 25% of the nitrogen in poultry manure was organic and essentially 75% was soluble uric acid or urea nitrogen.

Issacs and Harris (1987) reported the nutrient content of poultry litter. Values for total N, available N, P_2O_5, K_2O in poultry litter (Table 1) are provided by Issacs and Harris (1987). These values account for storage losses, and are given in terms of wet weight of litter as applied to land.

Table 1. Nutrient content of poultry litter

	(mg Kg^{-1})			
Type	Total N	Avail.N	P_2O_5	K_2O
Broiler Total Cleanout	40,000	25,000	40,000	22,000
Broiler Crust	22,000	12,000	18,000	12,000
Layers	20,000	12,000	10,000	5,000

Sharpley et al. (1991) used an average of values reported in the literature for N, P, and K in poultry litter, which were 45,000 15,000, and 18,500 mg Kg^{-1} respectively.

Fate of Nitrogen and Phosphorus From Poultry Litter

Perkins et al. (1964) found the average availability of total P in broiler manure to be 94.1% (citrate soluble). These researchers thought that rock phosphate, used as a mineral source for chickens, may account for part of the unavailable P in manure. Also, they thought that P may be contained in the organic matter which may be slowly available during decomposition.

The nitrogen in manure, like urea fertilizer, has a significant potential for loss of nitrogen through volatilization. Urea is rapidly converted to ammonia and free to volatilize into the atmosphere. (Beegle, 1988).

Despite the volatilization of nitrogen, potential nitrate contamination in ground water from poultry litter may occur from storage of uncovered poultry litter near poultry houses or from land application of high levels of poultry litter (Ritter, 1989). Poultry litter can cause high nitrate concentrations in the ground water (Robertson, 1977; Liebhardt et al., 1979; Bachman, 1984; Ritter and Chirnside, 1989). In southern Delaware, Robertson (1977) found nitrate concentrations above 10 mg L^{1-} N in 41 of 95 wells sampled, and that higher nitrate levels were commonly detected in areas near poultry operations. Ritter and Chirnside (1984) found that 32% of the wells sampled in coastal Sussex County, Delaware had average nitrate concentrations above 10 mg L^{-1}. The highest nitrate concentrations occurred in areas with intensive concentration of broiler production or intensive crop production with excessively drained soils. They found in several areas that nitrate concentrations in the ground water decreased as the distance from poultry houses increased.

Bachman (1984) analyzed nitrate data from 604 wells tapping the Columbia aquifer on the Delmarva Peninsula in eastern Maryland. Higher nitrate concentrations were found at sites with urban and agricultural land uses and moderately drained soils compared to natural areas. Water from wells near poultry houses had the highest median nitrate concentrations of 9.7 mg L^{-1}.

Effects of Poultry Waste Loading Rates

Jackson et al (1977) used rates of 0, 22.4, 44.8, 89.6, and 134.4 Mg ha^{-1} (dry weight basis) of broiler litter on unclipped Kentucky-31 fescue for 2 years. During the 2-year period the plots received 0, 89, 179.2, 358.4 and 537.6 Mg ha^{-1} of broiler litter. The soil was a Cecil sandy loam in the Southern Piedmont (Georgia). They found that litter residue remaining at the soil surface contained appreciable nitrogen which may be released for later crop production, or for movement with percolating water. Jackson et al (1977) also reported an appreciable increase on soil nitrogen infiltration at litter rates greater than 22.4 Mg ha^{-1}. Total N content differed only slightly between years at all rates in the 107 cm profile.

Perkins et al. (1968) examined residual effects of broiler manure, incorporated into the soil by plowing, at rates of 0, 18 and 36 Mg ha^{-1}. Residual effects were detected on available P during a 42-month period after application on a Cecil sandy loam (Table 2). The soils possessed initially low values for P but they increased considerably following manure applications. Although the P values had decreased from the maximum after 42 months, the soil which received the 36 Mg ha^{-1} application rate continued to have highest levels of P.

Table 2. Phosphorus values as influenced by a single application of different rates of broiler manure for corn grown on Cecil sand loam, Athens, GA, 1959.

Month after manure applications	Broiler manure (Mg ha^{-1})		
	0	18	36
Kg ha^{-1}			
0	24.6	24.6	24.6
6	33.6	67.2	212.8
18	28.0	84.0	168.0
30	17.9	95.2	151.2
42	12.3	72.8	106.4

Bielby et al. (1973) applied liquid poultry manure on a Guelph sandy loam which was developed from a stony calcareous till. Applications were made when the soils were frozen and snow covered. The amounts of phosphorus applied from the manure were 0, 190, 377 and 566

Kg ha^{-1}. Over the period of 3 years, the P in all four treatments was equivalent to 50, 408, 1,240, and 1,590 Kg ha^{-1}. At the third year the percolates contained the equivalent of 0.35, 0.65, 0.38 and 0.35 Kg ha^{-1} P for the four treatments, with corresponding P concentrations of 0.029, 0.057, 0.033, and 0.034 mg L^{-1} respectively. Although abnormally large amounts of P were applied, the DIP concentrations in the percolates were not correspondingly large. The averaged concentration of DIP in the percolates nearly equaled or surpassed the upper limit (for controlling algal growth in natural waters) of 0.03 mg L^{-1}.

Liebhardt et al. (1979) applied poultry litter to corn plots on an Evesboro loamy sand soil in Delaware at rates of 0, 13, 27, 54 and 179 Mg ha^{-1}. Nitrate concentrations in the ground water ranged from 65 to 174 mg L^{-1} at the 3 m depth, for the highest application rate. On plots where no litter was applied, the nitrate concentration in the ground water ranged from 7 to 15 mg N L^{-1} . Liebhardt et al. (1979) found that as the rate of poultry litter applications increased, so did the concentration of nitrates in the groundwater.

CHAPTER III

MATERIALS AND METHODS

Site Overview

Soil Type Used and Site History of Poultry Manure Application

Two soil types amended with poultry waste in Eastern Oklahoma, were used for this study. The two soils were: (1) Baxter (Fine, mixed, mesic Typic Paleudalf), and (2) Stigler (Fine, mixed thermic Aquic Paleudalf). The surface texture for Baxter was a cherty silt loam and for Stigler a silt loam. Baxter soils had an approximate annual poultry litter application (spring and fall) rate of 7.8 Mg ha^{-1} for the last twelve years. Stigler soils had an approximate annual litter application (spring only) rate of 4.5 Mg ha^{-1} for the last thirteen years.

Location and Selection

The two experimental sites, the first containing the Stigler soil and the other containing the Baxter soil, were described, sampled, and monitored with lysimeters and located in Delaware County, Oklahoma (Fig. 2). Tall fescue pastures with slopes less than 3% were selected as crop management. Tall fescue pasture is a major land-use unit within the

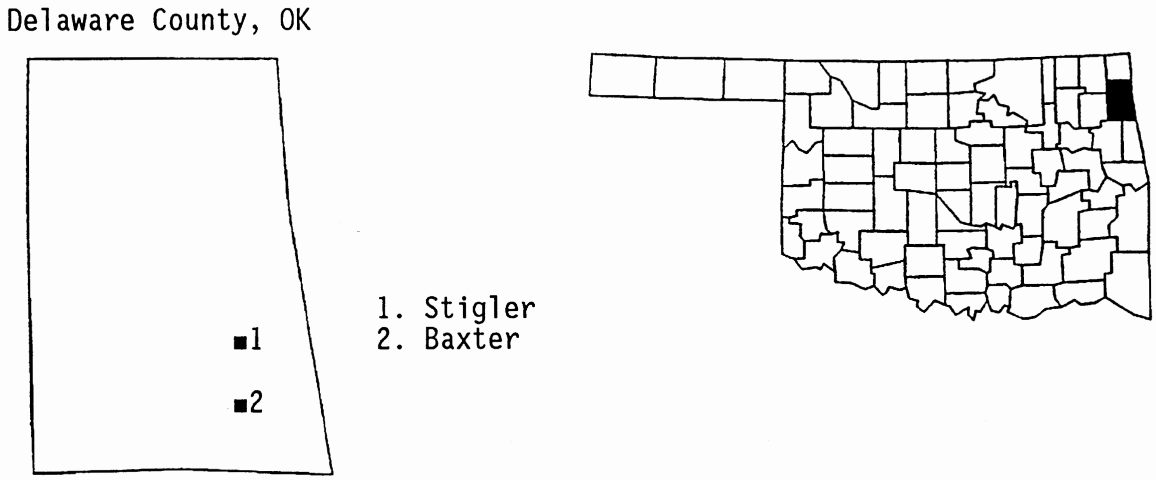

Fig. 2. Location of the experimental sites in Delaware County, Oklahoma (Sharpley et al., 1991).

poultry producing area. Baxter and Stigler are typical soils within these pastures.

Profile Description

Profile descriptions on Baxter and Stigler soils with and without a history of poultry litter application (eg. Baxter poultry manure and Baxter no manure) are presented in Table 3. The soil profile description for the unmanured site was located in a wooded area adjacent to the tall fescue pasture used to apply poultry litter. The soil profile description for the manured site was made within the middle of the field. The poultry litter applied was composed of chicken manure and bedding (pine shavings).

The Baxter soil is characterized by a strongly acid cherty silt loam (15-35% chert) surface layer (0-18 cm). The subsurface layer (18-36 cm) is a cherty silty clay loam. Below 36 cm the texture ranges

Table 3. Soil profile descriptions.

Horizon	Depth* (cm)	Color moist	Structure	Texture‡	Consistence	Boundary	Special Features
Baxter (no manure)							
A	0-3	7.5YR4/2	2,c,gr	SiL	L	A,S	M,f,m+c roots
E	3-10	10YR6/4	2,sbk	SiL	vfr	a,w	Co,f+m roots
EB	10-18	7.5YR5/6	2,c,sbk	SiL	fr	g,w	M,f+c roots
2Bt1	18-37	5YR4/6	2,c,sbk	SiCL	fr	g,w	Co,f,m+c roots; Co, f, dt 7.5YR5/6 mottles; 10% gravels
2Bt2	37-60	7.5YR4/6	2,c,sbk	CbSiCL	fr	c,w	F,f,m roots; 30% cobbles, 15% gravels
3BC	60-75	7.5YR6/4	1,f,sbk	GrSiCL	fr	c,w	M,f,dt 10YR5/3 mottles; 20% cobbles, 60% gravels
3Cr	75+	10.5YR6/2	m	CbSiL	fi	--	M,f,dt 7.5YR5/6 mottles; 60% cobbles; 30% gravels
Baxter (poultry manure)							
Ap1	0-3	10YR2/3	2,f,sbk	SiL	fr	c,s	M,f+m roots
Ap2	3-18	10YR4/3	2m,sbk	SiL	fr	a,s	M,f+m roots
BA	18-36	7.5YR4/6	2,m,sbk	SiL	fr	c,s	M,f+m roots
2Bt1	36-48	5-7.5YR 4/6	2,c,pr/ 3,f,sbk	GSiCL	fr	c,s	Co,f+m roots; chert + tripoli-like chert of 1-2 cm thick, 2.5YR5/8
2Bt2	48-62	7.5YR5/6	3,f,abk	VGC	fi	c,w	Co,f+m roots; M,m,dt 7.5YR5/2 mottles; chert of 1-2 cm thick, 25 YR5/8
3Cr	62-78+	1.5YR5/4	m	EChC	eh	--	F,f roots

NOTE: The structure is controlled by angular chert fragments in the 6th horizon; chert has many thin joints filled with clay.

Table 3. Soil profile descriptions. (Con't)

Horizon	Depth* (cm)	Color moist	Structure	Texture‡	Consistence	Boundary	Special Features
Stigler (no manure)							
A	15	10YR3/2	1,f,sbk	SiL	fr	cl,s	Loess; M,f-m+c roots.
E	30	10YR4/3	2,f,sbk	SiL	fr	cl,s	Alluvium; M,f-m+c roots.
2Bt1	53	10YR6/4	2,f,sbk abk	SiCL	fr	cl,s	Alluvium; M,f+m roots; F, thin discount. clay coatings on peds.
2Bt3	91	10YR5/3	3,m,sbk	SiC	fi	a,i	Alluvium; Co, f roots; Co, thin cont. clay coatings on peds; Co, m, ft 7.5YR5/6 mottles; F,f+m, Mn-Fe (black) concretions + coatings.
2Bt4	142	7.5YR5/4	2,c,pr/ 1,m,abk	SiCL	fi	g,s	Alluvium; F,f roots; M, thick cont. clay coatings on peds; F,f,dt 7.6YR5/6 mottles; Co, m, Mn-Fe (black) concretions + coatings; Co, c, 7.5YR5/4 tongues.
2Bt5							
Stigler (poultry manure)							
A	3	10YR6/2/ 10YR4/2	2,f,pl	SiL	l	a,s	M,vf + f roots; cf + vf roots.
Ad	24	10YR6/2/ 10YR4/2	2,c,pl	SiL	vh	a,s	M,f (<1cm diam. Fe stains; 10YR7/8); Co, f+vf roots; F,m roots.
E	46	10YR7/2/ 10YR5/4	2,m,sbk	SiL	fr	g,w	M,f+m(<1-3cm diam. Fe stains; 10YR7/8) Co,r+sr, f gravels at base; Co,f+vf roots.
Btg1	61	10YR6/3/ 10YR4/3	1m,pr/ 2m,sbk	SiC	fr	g,w	Co,v+vf roots; M,m,pr 2.5YR3/8 mottles. F,r+sr,f (2-4cm) gravels.
Btgh2	81	2.5YR4/8/ 10YR2/2	3mpr/ 3f,bk	C	fr	c,w	F,vf roots; F,r+sr (2-4cm) gravels; M,f,pr 10YR3/16 + 5YR5/6 + 2.5Y6/2 mottles.
Btgh3	94+	10YR2/2/ 7.5YR3/4	1cpr	SiC	fi		M,f+m 10R3/16 + 5YR5/6 + 2.5Y6/2 mottles F,f roots; f,r+sr fine gravels.

1 = weak, 2 = moderate, 3 = strong, f = fine, m = medium, c = coarse, gr = granular, sbk = subangular blocky, abk = angular blocky, pr = prismatic, ma = massive, pl = platy, fr = friable, fi = firm, h = hard, l = loose, cl = clear, g = gradual, a = abrupt, s = smooth, w = wavy, i = irregular, M = many, Co = common, f = few, ft = faint, dt = distinct, pt = prominent.

‡ Results are derived from averages of data for three soil profile samples from each location.

* Depth from ground surface to the bottom of the horizon.

from heavy cherty silty clay loam to cherty clay. This soil is well drained.

The Stigler soil is characterized by a silt loam surface layer (0-24 cm). The subsoil (24-90 cm) is a silty clay loam which is firm and very firm in consistence. This soil is somewhat poorly drained.

Methods of Soil Analysis

Physical Property Soil Characterization

Physical properties of the Baxter and Stigler soil profiles are presented in Table 4. The percent moisture content of soil samples was determined gravimetrically after oven drying (Gardner, 1986). Soil samples were air dried prior to particle size analysis. Particle size analysis was determine by the pipette method (Gee and Bauder, 1986). Three additional soil clods were taken from each horizon, coated with saran, (clod method) and bulk density determined (Blake and Hartge, 1986).

Chemical Property Soil Characterization

Chemical properties of the different soil profiles are presented in Table 5. Disposition graphs were developed from the data in Table 5 to help explain differences in nutrient amount and/or concentration in percolates of the Baxter and Stigler soils (see App. A). Air-dried subsamples from particle size analysis was ground to pass a 2 mm sieve, and stored in seal containers for chemical analysis. The pH of the soil samples was measured with a glass electrode using a 1:1 water to soil ratio (wt/wt), followed by addition of $CaCl_2$ and pH again determined in

Table 4. Particle size analysis, bulk density (B.D.) and gravimetric water content (θm) air-dry at room temperature for the soils studied.†

Horizon	Depth cm	2.0 - 1.0	1.0 - .5	.5 - .25	.25 - .1	.1 - .05	2.0 - .05	.05 - .002	.002>	Texture	(g/cm^3)	%
					Baxter (no manure)							
A	0-3	2.0	2.0	1.0	1.1	2.0	7.8	76.0	16.1	SiL	1.48	2.8
E	3-10	0.9	1.7	1.1	1.2	1.8	6.7	80.9	12.3	SiL	1.48	1.2
EB	10-18	0.8	1.5	0.9	1.3	1.1	5.5	75.9	18.5	SiL	1.53	1.5
2Bt1	18-37	1.1	1.0	0.7	0.9	1.4	5.0	61.9	33.1	SiCL	1.56	3.2
2Bt2	37-60	2.0	1.1	0.7	1.0	1.9	6.6	58.5	35.0	cbSiCL	1.57	3.7
3BC	60-75	10.6	3.4	1.6	1.6	2.6	19.7	59.2	21.0	GrSiL	1.62	2.3
3Cr	75+	8.8	3.2	1.5	1.7	2.7	18.0	59.1	22.8	cbSiL	1.62	2.3
					Baxter (poultry manure)							
Ap1	0-3	2.3	1.9	1.4	1.7	2.7	9.8	78.4	11.8	SiL	1.44	1.6
Ap2	3-18	3.0	2.0	1.4	1.6	2.6	10.6	77.3	12.1	SiL	1.44	1.1
BA	18-36	1.8	1.8	1.3	1.5	2.5	8.8	79.4	11.8	SiL	1.42	1.3
2Bt1	36-48	3.0	1.7	1.2	1.5	2.2	9.5	70.7	19.8	GSiL	1.57	2.9
2Bt2	48-62	8.4	3.1	1.3	1.4	2.2	16.4	53.7	29.9	VGSiCL	1.54	2.7
3Cr	78+	9.3	5.1	2.7	2.8	3.2	23.0	50.9	26.2	EChSiL		
					Stigler (no manure)‡							
A	0-15	0.7	0.7	0.7	0.9	1.4	4.1	81.3	14.5	SiL	1.28	2.6
E	15-30	2.1	2.3	1.2	1.1	1.3	8.0	75.4	16.7	SiL	1.36	1.6
2Bt1	30-53	2.2	1.6	1.0	1.2	0.2	5.6	76.3	18.1	SiL	1.47	1.7
2Bt2	53	2.3	1.3	1.0	1.4	0.9	6.8	70.1	23.2	SiCL	1.55	2.2
2Bt3	69	1.3	1.0	0.8	1.5	2.0	6.5	61.8	31.8	SiCL	1.63	3.5
2Bt4	142	0.5	0.6	0.7	1.6	2.4	5.6	66.5	28.0	SiL	1.66	2.4

Table 4. Particle size analysis, bulk density (B.D.) and gravimetric water content (θm) air-dry at room temperature for the soils studied.† (Con't)

Horizon	Depth cm	2.0 - 1.0	1.0 - .5	.5 - .25	.25 - .1	.1 - .05	2.0 - .05	.05 - .002	.002>	Texture	(glcm^3)	%
2Bt5	211	1.9	0.8	0.7	1.5	0.6	6.4	67.6	25.9	SiCL	1.71	2.3
*	211	0.5	0.7	0.7	1.5	1.1	4.1	60.7	35.1	SiCL		3.7
2Bt6	244	5.2	1.7	0.9	1.6	0.7	9.9	61.2	27.1		1.77	2.3
					<u>Stigler (poultry manure)</u>							
A	3	1.0	0.8	0.5	0.6	1.7	4.6	75.6	19.8	SiL		
Ad	24	0.7	0.6	0.5	0.7	1.9	4.3	76.4	19.2	SiL	132	1.8
E	46	2.7	1.5	0.7	0.9	1.8	7.5	69.1	23.1	SiL	1.43	1.8
Btg1	61	0.4	0.4	0.2	0.4	1.5	2.8	41.2	56.0	SiC	1.42	5.0
Btgh2	81	1.1	0.5	0.2	0.5	1.3	3.5	36.6	59.9	C	1.53	6.3
Btgh3	94+	0.8	0.4	0.3	0.6	1.8	3.9	42.2	54.0	SiC	1.50	5.9

† Results are averaged of data for three profile samples from each location.

‡ Data from Sharpley et al. (1991.

* Depth from ground surface to the bottom of the horizon.

Table 5. Organic C, total N, nitrate N, total P, C:N ratio, C:P ratio, electrical conductivity (EC) and pH of the Baxter and Stigler soils.‡

Horizon	Depth* ave.	range	Organic C	Total N	Nitrate N	Total P	C:N ratio	C:P ratio	EC mmhos	pH cm^{-1}
	-- cm --		gkg^{-1}	------ mg Kg^{-1} ------						
				Baxter (no manure)						
A	2	0-36	1.0	700	4.0	328	87	185	0.5	5.2
E	7	3-10	9.0	1000	5.0	161	9	55	0.2	4.9
EB	14	10-18	4.5	100	3.5	157	45	28	0.1	5.9
2Bt1	28	18-37	3.0	200	3.5	181	15	16	0.1	6.2
2Bt2	49	37-60	3.0	150	4.0	163	20	20	0.1	6.8
		60-75+	3.0							
				Baxter (poultry manure)						
Ap1	2	0-3	16.0	350	3.5	694	45	23		
Ap2	11	3-18	11.0	950	5.0	406	11	27	0.3	6.8
BA	27	18-36	15.0	1050	4.5	227	14	65	0.2	6.6
2Bt1	42	36-48	29.0	300	4.0	339	96	85	0.1	6.2
2Bt2	55	48-62+	27.0	200	4.0	145	135	185	0.1	5.8
				Stigler (no manure)‡						
A	8	0-15	43.9	2297	34.5	352	19	124	**	5.3
E	23	15-30	6.2	562	5.1	196	11	31	**	4.2
2Bt1	42	30-53	3.4	462	5.2	207	7	16	**	4.3
2Bt2	63	53-69	2.0	416	3.4	180	4	11	**	4.0
2Bt3	80	69-91+	2.5	492	0.0	204	5	12	**	4.9
				Stigler (poultry manure)						
A		0-3								
Ad	14	3-24	18.0	1000	6.0	458	18	39	0.2	5.7
E	35	24-46	18.0	3300	5.0	281	5	63	0.1	5.7
Btg1	54	46-61	50.0	1750	7.5	266	28	187	0.1	5.9
Btgh2	71	61-81	44.5	400	4.0	30	111	147	0.1	6.2
Btgh3	88	81-94+	59.0	450	5.0	221	131	266	0.1	6.1

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† Results are averages of data for three soil profile samples from each location.

‡ Data from Sharpley et al. (1991).

* Depth range (eg. from ground surface to the bottom of the horizon) and average depth (eq. middle horizon).

** Data not available.

a final solution (0.01 M $CaCl_2$): soil ratio of 2:1 (SCS, 1984). A saturated paste (soil and water) measured with a conductivity bridge was used to determine the electrical conductivity (EC) in mmhos cm^{-1} at 25 °C (SCS, 1984). Total carbon was determined by dry combustion method with induction furnace (Nelson and Sommers, 1986). No lime or coal was identified within the soils.

Analysis of N and P in Soils

The following methods were used for the chemical analyses of N and P from the soil.

Total N (TN): determined by a semimicro Kjeldahl procedure (Bremner and Mulvaney, 1982);

Residual Nitrate-N (NO_3-N): determined as follows:

(1) 0.01 M $CaSO_4$ extraction

(2) Cd reduction and automated colorimetric determination of NO_2^- by the modified Griess and Ilosvay method described by Keeney and Nelson (1982);

Total Phosphorus (TP): determined by perchloric acid digestion (Olsen and Sommers, 1982)

Field Study

Introduction

The objective of the field study was to provide information on percolate N and P concentrations produced by natural precipitation compared to the laboratory study. If N and P concentrations from the laboratory and field soil percolates correlate, better conclusions can be drawn from such combined information compared to using laboratory data alone.

Two types of lysimeters were utilized in the field study, a pan (or zero tension) lysimeter and a porous ceramic cup (or suction) lysimeter. Eight plots were selected for the Baxter and eight for the Stigler soil. Each plot had one porous cup lysimeter and one pan lysimeter. It was necessary to construct a fence around all plots to keep out livestock and other animals. Application of broiler litter for all plots was done on November 13, 1991.

Construction of Pan Lysimeter

The pan lysimeter (Fig. 3) was a modified version of one used by

Fig. 3. Implementation of a pan lysimeter.

Jordan (1990). Each pan lysimeter was made by modifying a two-liter polypropylene bottle. All joints, rubber stopper, and flexible tubing were attached using hot glue. One third of the bottle was cut out, inverted, and placed inside the same bottle. Before placement of the inverted section, 0.64 cm diameter vinyl tubing was inserted through a stopper, at the neck of bottle, and down along the sides into the collecting chamber. Next, a small hole (0.6 - 0.7 cm in diameter) was

Fig. 4. Suction lysimeter next to a pan lysimeter at a study site.

made on the previously cut inverted section of the bottle to allow passage of water into the lower collection chamber. This hole was cut near the neck area of the bottle. A grid was fabricated by cutting 0.5 cm wide strips of polypropylene and attached with hot glue to the top of the cut-out bottle. Finally, glass wool was placed in the inverted portion to help prevent soil contamination of collected water and to help prevent obstruction of the cut-out hole by soil.

Selection of Plot Locations and Implementation of Lysimeters and Borders

All field research plots were located immediately adjacent to soil sampling pits. Lysimeters were implemented at each site where intact soil columns had been sampled. Eight pan lysimeters were implemented at the bottom of the A horizon for both soil types (Fig. 3). Eight suction lysimeters were placed at the depth of a soil column (thus, 50 cm depth below ground surface for the Baxter and 90 cm depth below ground surface for the Stigler (Fig. 4)). Borders for the plots (to limit run-off) were created by making an incision in the soil with a knife. Landscaping border was then inserted in the cuts.

Litter Treatment

Poultry litter was applied similarly to that applied by poultry growers in this region. Litter was applied in a solid form. Farmers disk their litter while it is still in the poultry house to break up the poultry crust (creating a finer bedding for the poultry later) and then store it near the house before field application. The litter is taken from a storage pile to the field and applied using a manure spreader.

The litter for this study was applied to field plots at rates of 0, 9, 18, and 36 Mg ha^{-1}.

Weather Monitoring and Percolate Sampling Time

Weather forecasts and field conditions were monitored closely to determine proper times for sampling. The landowners (Baxter soil site: Jack Smith of Route 1 Box 260, Colcord, OK 74338 and Stigler soil site: Howard Woods of Route 1 Box 346, Jay, OK 74346) for the Baxter and Stigler soil sites were provided with a U.S. Weather Bureau raingage. Monitoring of weather conditions was necessary for determining sampling times. Immediately prior to litter treatment (same day), percolates from both suction and pan lysimeters were sampled and emptied if necessary. The day after each rainfall event the lysimeters at both sites were sampled (Fig. 5).

Fig. 5. Percolate sampling from field plots.

Laboratory Study

Introduction

Intact soil columns were sampled from the field and used for the laboratory percolation study. Several problems were encountered and solved prior to or during sampling. These problems included maintaining intactness of the undisturbed soil columns, their subsequent retrieval from the soil pit, design and construction of transport rack and laboratory holding rack, and treatment of column bottoms for clear (no suspended soil particles) percolate.

Sampling Procedure

Eight intact soil columns were retrieved from each of the two soils types, Baxter and Stigler. Before excavation of any soil, the specific column location was marked with irrigation flags. Obtaining or creating a free standing pedestal of soil was accomplished by excavating soil around the marked area until a free standing column approximately 30 cm in diameter was formed. Using a large sharp knife, the column was further shaped to a 20.3 cm diameter column. The Baxter soil column height was 50 cm (Fig. 6) while the Stigler soil column height was 90 cm (Fig. 7). Saran resin of the type used by Brasher et al. (1966) was then applied to the entire exposed soil surface of the standing columns using a paint brush. After the applied resin had dried, a 25.4 cm PVC pipe, which was previously sanded on the inside, was carefully positioned over the column. A 3.4-3.8 cm space was created between the PVC and the column. Next, a triple expanding polyurethane foam was injected in this space. Injection of foam was accomplished by two

Fig. 6. Baxter soil as a free standing column.

methods. On the shorter Baxter soil columns foam was injected within the 3.4-3.8 cm space between the PVC and the column using a 47 cm vinyl hose extension taped to a dal rod. On the longer Stigler soil columns, pre-drilled holes were made in the PVC and the foam was injected through these holes.

The foam was then allowed to fully expand and cure overnight. On the day following curing, the top of the column was packed with styrofoam packing material then covered with a cap. Next, soil beneath the intact core was removed to enable the soil column to be rocked off its bottom. While the soil column was being rocked off its bottom, a second person held the soil beneath the column to prevent soil loss from

Fig. 7. Stigler soil as a free standing column.

column. The column was then inverted and encapsulized.

Column Transport

Once encapsulized the intact columns were carefully removed from the pit and placed on a transport rack (Fig. 8) and secured for transport. The rack held the soil columns at a 45 degree angle so as to lessen the chance of column disturbance while being transported.

The soil columns were prepared in the following manner before placing columns on laboratory racks. The column was inverted and the bottom endcap was removed. The neck and approximately 0.5 cm of the mouth from an 8mm funnel was countersinked in the center of each cap. The surface of the cap near the funnel was scored with a razor blade. The funnel was secured in place using hot glue on both sides of cap. Next, the cap was placed on the bottom of the column and filled with inert plastic beads. After the cap was completely filled with plastic beads, a small (volume of a 500 ml beaker) amount of glass wool was finally added to the cap. The column was set upright on a rack, and any exposed foam on the top of the column was trimmed.

Percolation of these intact soil columns was conducted in a

Fig. 8. Encapsulated intact soil columns on transport rack

Fig. 9. Intact columns in an upright position in the laboratory.

temperature and light regulated room (Fig. 9). The average diurnal temperature (day = 18.3 °C and night = 6.7 °C) and photo period (daylight = 13.5 hours and dark = 10.5 hours) for the month of April was used for both soils.

Saturated Hydraulic Conductivity Determination

Saturated hydraulic conductivity was determined on all the soil columns. Saturated conductivity (Ksat) values provide (1) information on hydrologic conditions among the samples (2) data to determine the best pairing sequence for replication on the litter loading rates, and

(3) data to determine the validity of any substantial increase in percolate volume as a result of water application.

The amount of water to apply per application for obtaining saturation in the soil columns was determined by dividing 10 applications for Baxter and 17 applications for Stigler into the total water volume (determined from bulk density and total porosity) for each soil. Columns were brought to saturation slowly by applying distilled water three times daily, early morning, mid-afternoon, and evening, to avoid creation of air pockets in the soil.

The Ksat was determined on the undisturbed soil cores by the drip method (Klute and Dirksen, 1986). By knowing the water volume, the length of the column, and the time interval of water volume collected, Darcey's Law (Klute and Dirksen, 1986) could then be used to calculate the saturated conductivity (Ksat) of the soil as shown:

$$\text{Ksat} = (Q \,/\, A \,.\, T)\,\frac{L}{\triangle H}$$

where: Q = volume of water collected or discharge rate (cm^3)

A = cross sectional area of soil (cm^2)

T = time period water was collected (sec.)

$\triangle$ H = change in hydraulic head

L = length of soil

Since the change in hydraulic head (< 1 mm) for both soils is insignificant compared to the length of the soil, then $\triangle H / L$ is assumed to be 1.0.

Manure Application

The columns were allowed to drain for approximately 2 days after the conductivity experiment before manure application. The columns were considered close to field capacity when they reached a drainage rate of approximately one drop of water every three hours. The columns were fertilized with poultry litter at rates of 0, 9, and 36 Mg ha^{-1}. Replication was performed for each rate.

Determination of Water Amounts to be Applied on Samples

The amount of water to apply on soil columns was determined by the average daily rainfall on each day in April at the closest reporting stations; Jay Tower, Jay OK and Kansas, OK (NOAA 1948 - 1991) for Stigler and Baxter soil respectively (App. B). However, for the first application of water, the columns received the record rainfall for April at each reporting stations (App. B). The month of April was chosen for the rainfall amounts used because (1) April is one of the two most common months (the other is March) for application of poultry litter in this region, and (2) April, having a higher rainfall than March, would represent a better upper limit of percolation during a rainfall period.

Analytical Procedures

Gross Broiler Litter Composition

The manure percentage in the litter was determined using five 35 g random subsamples from approximately 70 kg of broiler litter crust sampled in a broiler house at one of the field sites. Each 35 g sample was split into a 15 g sample for determining percent total solids and percent water, and a 20 g sample for determining percent bedding in litter.

Total solids and water for all five samples were determined in the following manner. First, 15 g of litter were placed in an aluminum dish and tared on an analytical balance. Next, the sample was placed in a 105 °C oven overnight. Finally, the dried sample was weighed the following day. Percent total solids and percent water in the litter could then be obtained from the difference in the initial or wet weight and the dry weight.

Percent bedding, on both wet and dry weight basis, was determined by placing the remaining portion (20 g) of the 35 g sample into a plastic shaker bottle then filling it with 200 ml of distilled water. The bottle was then capped and shaken for 1 hour (to bring into suspension most of the manure portion of the litter). This shaken solution was poured through a 500 micro-meter sieve (to separate the bedding material from solution) and rinsed for further separation. Next, the bedding material was removed from the sieve, placed in a previously weighed, numbered beaker, and placed in a 105 °C oven overnight. The following day the beaker plus bedding material was weighed. Dry bedding weight was obtained from the difference of the two weights. By knowing the dry bedding weight, the percent bedding weight on both wet and dry weight basis was determined from the total solids or from the initial (wet) litter weight.

The percolate water in each of the five bedding separations was collected in 400 ml beakers for subsequent chemical analysis of the manure. Percolate volumes for each of the five 400 ml beakers were measured, poured back into their beakers, and stirred thoroughly. Next, a 125 ml sample from each beaker was retrieved into a pre-acid washed 250 ml erlymeyer flask and covered with a pre-acid washed stopper.

Analysis of N,P, and As in Poultry Manure

Below are the methods used to determine N, P, and As in the poultry manure. The term "dissolved" is inferred as water soluble. Total Dissolved Arsenate (TD AsO_4): determined by the difference between the following two methods. The first method determined both total phosphate and arsenate as described by Olsen and Sommers (1982). The second method determined phosphate only. This second method was done by the adhesion of sodium bisulfite ($NaHSO_3$) to reduce AsO_4 to AsO_3 (arsenite) before the phosphomolybdate complex is formed and thereby excluding AsO4 in the determination, as described by Olsen and Sommers (1982); Total P (TP) and Total Dissolved P (TDP): perchloric acid ($HClO_4$) digestion followed by determination of dissolved P by measurement of reduced phosphomolybdate complex at 882 nm as described by Olsen and Sommers (1982); Dissolved Inorganic P (DIP): ascorbic acid method using sequential extraction with 0.5 M $NaHCO_3$ (pH 8.5) followed by determination of dissolved inorganic P by measurement of reduced phosphomolybdate complex at 882 nm as described by Watanabe and Olsen (1965); Dissolved Organic Phosphorus (DOP). Calculated as the difference between TDP and DIP; Total Dissolved NO_3-N: determined using a ion-selective electrode (ISE) or for $[cl^-] > 2$ ppm, by ion chromatography.

Preparation for Soil Percolate Storage

Biological communities in the soil percolates were destroyed with the addition of chloroform at 0.02 mg L^{-1} concentration. Soil percolates were then refrigerated at 7.0 °C until chemical analysis was performed.

Chemical Analysis of N and P in Soil Percolates

The following are the methods used for the chemical analysis of N and P in the column and lysimeter percolates. The term "dissolved" is inferred as water soluble. Total Dissolved Phosphorus (TDP): determined by perchloric acid method (APHA, 1980); Dissolved Inorganic Phosphorus (DIP): ascorbic acid method followed by determination of dissolved inorganic P by measurement of reduced phosphomolybdate complex at 882 nm as described by Watanabe and Olsen (1965); Dissolved Organic Phosphorus (DOP): The difference between TDP and DIP is defined as soluble organic phosphorus; Total Dissolved NO_3^-N (TD NO_3^-N): samples with concentrations <2 ppm were determined by an ion chromatograph. Samples with concentrations >2 ppm were determined by ion specific electrode (ISE).

Statistical Analysis on Data from N and P Concentrations Percolates

In cases where a response in nutrient percolate concentration or amount appeared to exist due to manuring, an analysis of variance test (using an F test) was used to determine if such a response actually existed. The results were assessed at a significance level of $P<0.05$ (Little and Hills, 1975).

Finally, there are no DIP or NO_3-N concentration standards for soil percolates. Therefore, the average DIP and NO_3-N concentration in the soil percolates of the unmanured soil columns and field plots on the first posttreatment sampling day served as a reference level when reviewing posttreatment data.

CHAPTER IV

RESULTS AND DISCUSSION

Poultry Litter Analysis

Gross compositional analyses of poultry litter (broiler manure plus bedding consisting of pine shavings) contains an average of 50% manure, 21% bedding, and 29% water. Nitrogen and phosphorus concentrations (dry-weight basis) of poultry manure are shown in Table 6. The total P (TP) in poultry manure of 15,289 mg Kg^{-1} is similar to the mean TP value of 15,500 mg Kg^{-1} reported by Sharpley et al. (1991). The total NO_3-N value of 32,530 mg Kg^{-1} was lower than the mean value of 45,800 mg Kg^{-1} reported by Sharpley et al. (1991), which may be due to storage losses of NO_3-N from volatilization and/or the type of poultry feed used. Total arsenate (TAs) in the manure was at residual (background soil levels) levels of less than 6 mg Kg^{-1}.

Determination of Saturated Hydraulic Conductivity

Baxter and Stigler soil percolate volumes were collected (see App. C) for saturated hydraulic conductivity (Ksat) determination. Saturated hydraulic conductivity (Ksat) values for six of the eight Baxter columns ranged from 2.83 to 12.6 cm hr^{-1} (App. D). Water channelled along the sides of two Baxter soil columns (at the soil-insulation interface and/or insulation-PVC container interface), and hence, Ksat values for these columns were not representative of the soil and were discarded.

Table 6. Nitrogen and phosphorus content of poultry manure (mg kg^{-1}).‡

	Dissolved inorganic P	Dissolved organic P	Total dissolved P	Total P in Suspension	Total P	Total dissolved NO_3-N	Total N in Suspension	Total N
Poultry manure (sampled from broiler house)	157.4	41.9	199.3	15,090.5	15,289.8	2,227.0	30,303.0	32,530.0
Poultry manure (average from literature)*	†	†	†	†	15,000.0**	†	†	45,800.0

† Data not available.
‡ Dry weight basis.
* Values from Sharpley et al., 1991.
** Includes bedding material.

Saturated hydraulic conductivity (Ksat) values for six of the eight Stigler columns ranged from 1.52 to 8.28 cm hr^{-1} (App. D). Water channelled along the sides of two Stigler soil columns and were also discarded.

A pairing (large Ksat values to small Ksat values) sequence for replication in the percolation experiment was determined for the Baxter and Stigler soils using the established Ksat values. The least difference in the coefficient of variation for Ksat values among the various pairings determined the pairing sequence used for both soil types (App. D).

The mean Ksat values (Baxter = 6.7 cm hr^{-1} and Stigler = 5.4 cm hr^{-1}) were large when compared with 0.5-1.6 cm hr^{-1} and <0.15 cm hr^{-1} for the least permeable layer of Baxter and Stigler soils respectively reported by Cole (1970). However, laboratory Ksat is often greater than field Ksat because macropores in the detached core are continuous vertically through the length of the sample (Lauren et al. 1988; Smettem, 1987). Lauren et al, (1988) found that detached Ksat values were approximately ten times greater than in situ Ksat values, for the entire soil profile. The average Ksat value for the Baxter and Stigler soils was somewhat lower than that reported by Logsdon et al, (1990). Logsdon et al, (1990) using undisturbed soil columns (Rossetta Fine-silty, mixed, mesic Typic Hapludalf) reported an average Ksat value of 18.1 cm hr^{-1} for a 13 cm column.

Percolate Volumes Collected From Percolation Experiment

Percolate volumes along with the amount of water applied for Baxter and Stigler soil columns are presented in Figure 10 and 11 respectively.

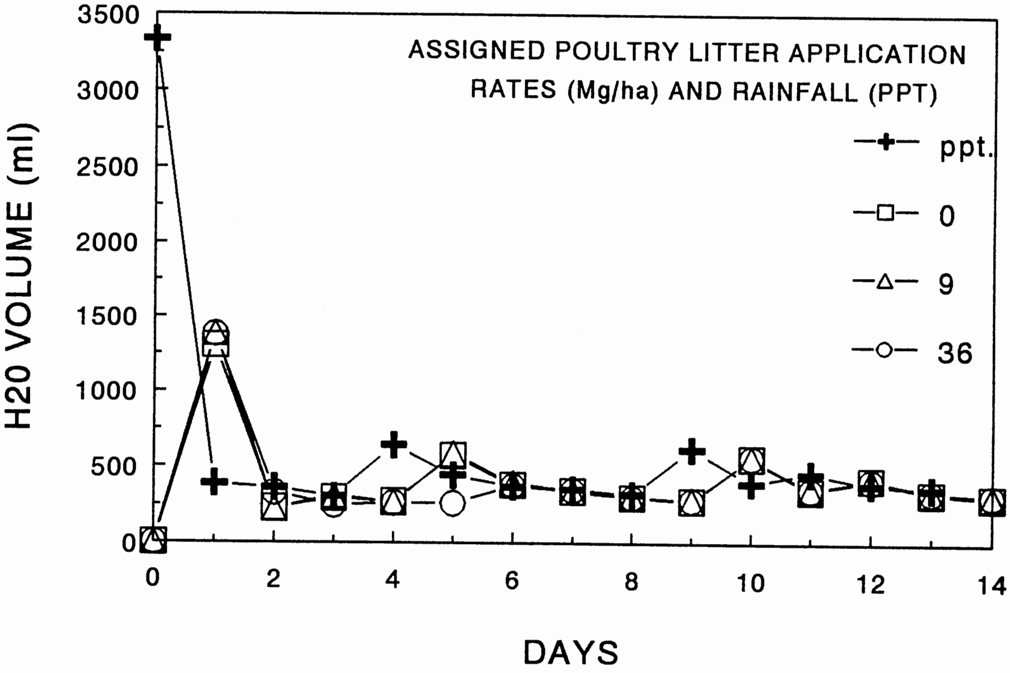

Fig. 10. Amount of artificial rainfall applied and percolate collected for Baxter soil columns.

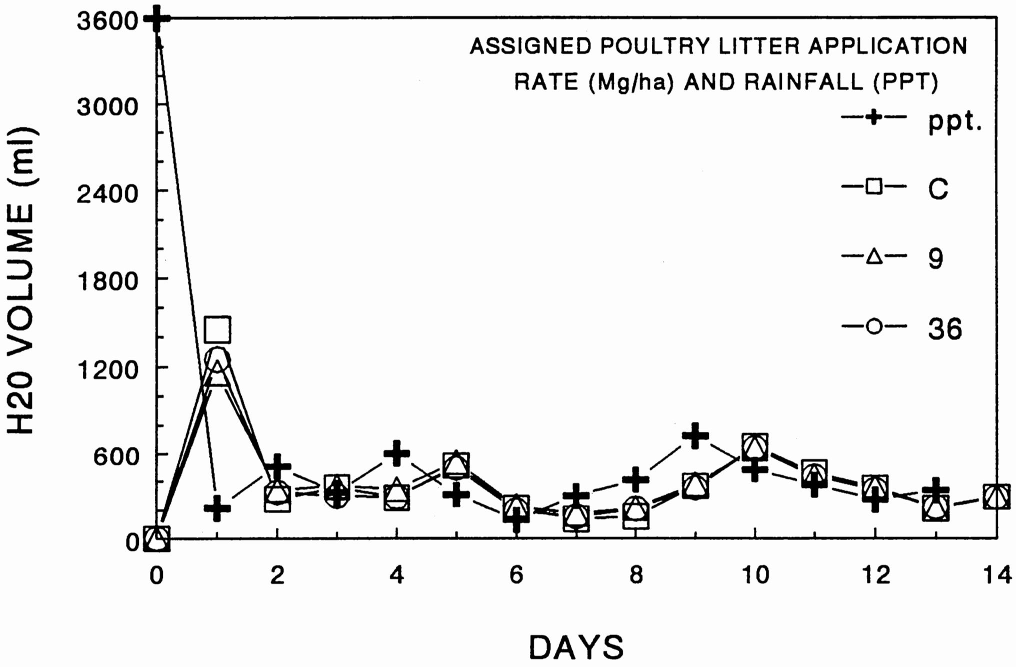

Fig. 11. Amount of artificial rainfall applied and percolate collected for Stigler soil columns.

There were significant increases in percolate volumes collected (within 24 hours) after a simulated record April rainfall (App. B: Baxter = 10.3 cm and Stigler = 11.1 cm) for the Baxter and Stigler soil columns. These sudden increases in percolate volume from a single rainfall are comparable to those reported by Hergert et al. (1981). Hergert et al. (1981) found, using tile placed at 60 cm in similar soils, that flow (which is positively correlated with volume) resulting from irrigation (17.4 cm) increased very rapidly (within 2 hours).

Nutrient Amounts and Concentrations in Percolates

Daily nutrient amounts and concentrations along with 14-day cumulative nutrient amounts in the Baxter and Stigler soil were determined (App. E). An analysis of variance (F test) was performed in cases where it appeared that there were increases in nutrient percolate amount and/or concentration due to increasing poultry litter application rate (App.I-K).

Concentration standards for DIP or NO_3-N for determining the pollution potential of soil percolates are not established. Therefore, the largest mean DIP and NO_3-N concentrations in the soil percolates of the unmanured soil columns and field plots on the first post-treatment sampling day served as a reference level when reviewing post-treatment DIP and NO_3-N concentrations.

Percolate Concentrations and Amounts of Phosphorus

Daily mean DIP concentrations and amounts for the Baxter soil column percolates are given in Figure 12 and 13 respectively. The DIP concentrations and amounts in Baxter soil column percolates were

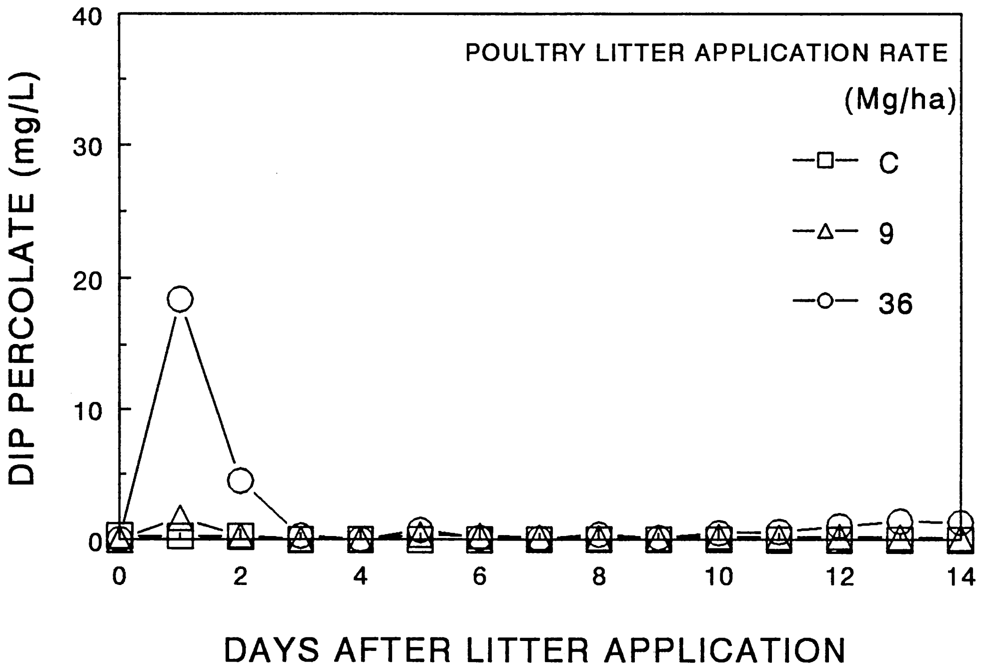

Fig. 12. Daily mean DIP concentration in percolates sampled from Baxter soil columns.

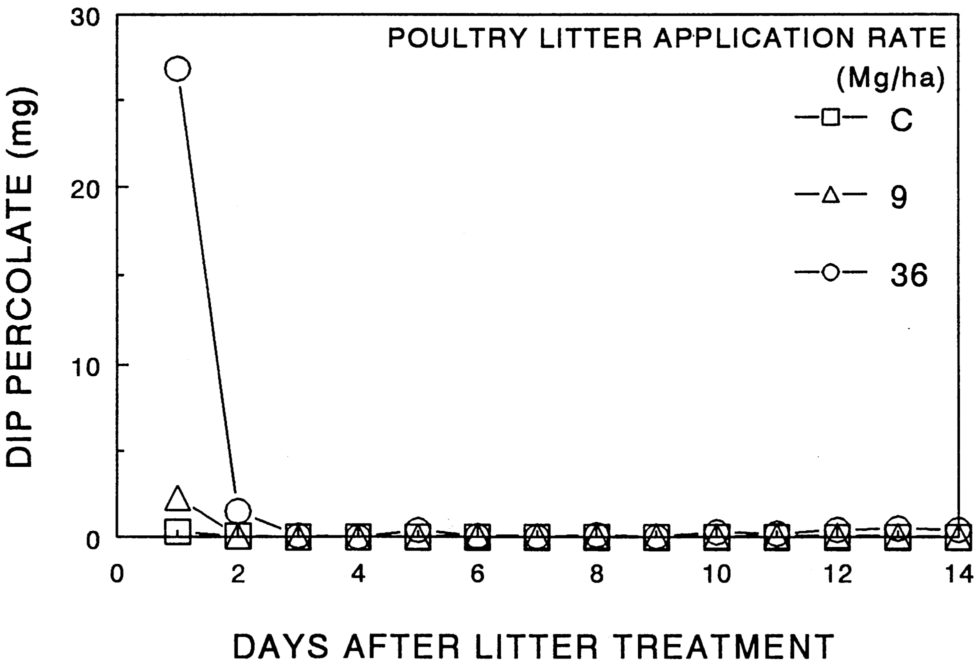

Fig. 13. Daily mean DIP amounts in percolates sampled from Baxter soil columns.

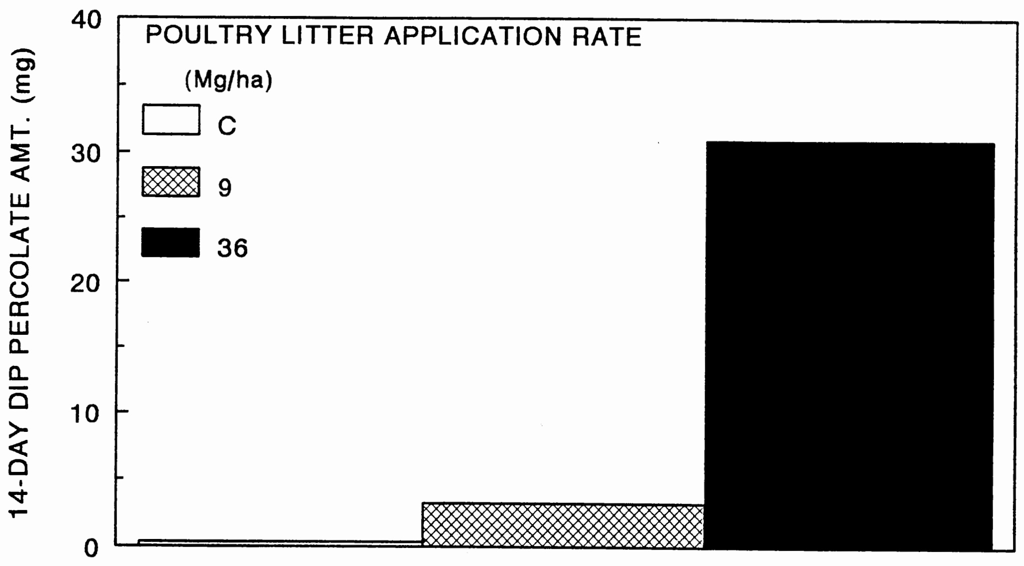

Fig. 14. Mean 14-day cumulative DIP units percolated from Baxter soil columns.

significantly different between the litter application rates for the first posttreatment sampling day. The concentration and amount of DIP increased with increasing litter application rate for the first posttreatment sampling day. The remaining sampling days showed that DIP concentration in Baxter soil column percolates were not significantly different between litter application rates. The largest mean DIP concentration reached on the first sampling day was 18.44 mg L^{-1} followed by 1.65 and 0.25 mg L^{-1} for the 36, 9, and 0 Mg ha^{-1} litter application respectively.

The DIP amounts in the Baxter soil column percolates were significantly different between litter application rates on the first sampling day only (Fig. 13). The largest daily amount of DIP percolated was 26.82 mg followed by 2.36 mg and 0.32 mg for the 36, 9, and 0 Mg ha^{-1} poultry litter application respectively.

The control, 9 and 36 Mg ha^{-1} poultry litter treatments exhibited an increase in the mean 14 day-cumulative DIP percolated (Fig. 14). An increase in the mean 14-day cumulative DIP percolated was due to differences in DIP concentrations in the percolates and not differences in percolate volumes. All percolate volumes were essentially the same among the columns. The largest mean cumulative DIP amount percolated during a 14-day period was 30.88 mg in columns with 36 Mg ha^{-1} poultry litter treatment, followed by 3.2 mg and 0.3 mg for the 9 Mg ha^{-1} treatment and control respectively.

Research reports suggested 30 ppb as an upper limiting P concentration value for normal algal growth in natural surface waters (Sawyer, 1947; Vollenweider, 1968). Subsequent to reports by Sawyer (1947) and Vollenweider (1968), several studies (Fox and Kamprath, 1971; Zwerman et al., 1972; Bielby et al., 1973; Duxbury and Peverly, 1978; Kopayashi and Lee, 1978; Miller, 1979; Hergert et al., 1981) have used 30 ppb (0.03 mg L^{-1}) DIP as a pollution indicator for soil percolates. However, many factors (physical and chemical) may cause significant attenuation of DIP between where the soil percolate is sampled and the surface water of a stream or lake. Therefore, comparing DIP values found in this author's study to a reference value of 30 ppb would not be helpful in determining whether a pollution potential exist.

The DIP percolate concentrations sampled from pan lysimeters in the Baxter soil were not significantly different between litter application rates after each rainfall. The greatest mean DIP concentrations in the Baxter pan percolates across all litter application rates occurred after the first rainfall. The greatest mean DIP concentrations in Baxter pan percolates after the first rainfall were similar to that observed in the Baxter (laboratory) soil columns on the first posttreatment sampling day. The largest mean DIP concentration was 24.0 mg L^{-1} in the 36 Mg ha^{-1} poultry litter treatment, followed by 10.05, 1.27, and 1.04 mg L^{-1} for the 9, 18, and 0 Mg ha^{-1} litter application respectively.

No pretreatment Baxter soil percolates were sampled from the suction lysimeters due to lack of rainfall. Therefore, no response in DIP concentration from litter application could be observed on both post-treatment sampling dates. Mean DIP concentrations in the percolates of the suction lysimeters were considerably lower than the DIP concentration in the percolates of the pan lysimeters and laboratory columns. This may be due to a higher flow rate in the laboratory column and field pan percolates than in the suction lysimeter percolates. Hergert et al. (1981) reported a large increase in DIP concentration as rate of tile flow increased. This increase in DIP appeared to be a consequence of reduced Ca or salt concentration at high flow (Hergert et al. 1981). Another explanation for DIP concentration differences between the pan and suction percolates is that more attenuation of the DIP would occur as the water moved through the subsoil to the suction lysimeter. The largest mean DIP concentration reached in percolates sampled from suction lysimeters in the Baxter soil was 1.68 mg L^{-1} from the 36 Mg ha^{-1} poultry litter treatment plots after the second rainfall event.

Neither DIP amounts or concentrations in the Stigler soil column percolates exhibited any significant difference between litter application rates on any of the posttreatment sampling days(App. E). The largest mean DIP concentration reached on the first posttreatment day was 0.64 mg L^{-1} from the 9 Mg ha^{-1} poultry litter treatment (equivalent to 141.6 Kg DIP ha^{-1}).

Ranges for DIP concentration in Stigler soil column percolates were <0.005-0.64 mg L^{-1} and <0.005-0.09 mg L^{-1} for the 9 Mg ha^{-1} (141.6 Kg DIP ha^{-1}) and 36 Mg ha^{-1} (566.6 Kg DIP ha^{-1}) poultry litter treatments respectively.

The mean 14-day cumulative DIP amount percolated from the Baxter soil columns (30.88 mg) with a 36 Mg ha^{-1} poultry litter treatment was considerably greater than the mean 14-day cumulative DIP amount percolated from the Stigler soil columns (0.09 mg) with the same litter treatment. Baxter soil columns with a 9 Mg ha^{-1} poultry litter treatment percolated a mean of 3.25 mg DIP/14 days compared to 0.74 mg DIP/14 days from the Stigler soil columns. Baxter soil columns with no litter applied percolated 0.35 mg DIP/14 days compared to 0.43 mg DIP/14 days for the Stigler soil columns.

The DIP amount and concentration values in Stigler soil percolates were not expected to correlate closely with the DIP amount and concentration values in the Baxter soil percolates since (1) the Baxter is cherty and percolation water can pass through at a faster rate (Table 4), (2) Stigler soil has a higher clay content (Table 4), and (3) Stigler soil depth (1 m) was greater than Baxter soil depth (0.5 m) which contribute to increased adsorption differences between the soils due to the additional percolate contact with soil (Table 4). The chemical properties determined from the Baxter and Stigler soils were similar except for organic carbon (C). The stigler soil had a greater organic C content than the Baxter Soil. Hence, only organic C may explain differences in DIP amounts or concentrations from percolates of both soil types (Table 5).

Increased P retention due to organic residue application has been observed (Fokin and Chistova, 1964; Harter, 1969; Jackman, 1955; Larsen et al., 1959; Rennie and McKercher, 1958). However, several researchers have examined P sorption by soils in the presence of organic residues (Dalton et al., 1952; Gaur, 1969; Struthers and Sieling, 1950; Vyas, 1964), and concluded that during decomposition of organic residues, organic acids form stable complexes with Fe and Al, and consequently block P retention in soil. The negatively charged organic colloids have little ability to fix PO_4^{3-} (Fox and Kamprath, 1971) and any fixation probably involves the mineral components of the soil. More information is needed on the effect of animal waste application on P sorption by soils.

The DIP concentrations in the percolates sampled from the Stigler pan and suction lysimeters were irregular. Irregular trends may have been caused by the natural variability (soil factors such as structure, texture, clay and organic matter content, soil depth, etc.) between the control and treatments. Hergert et al. (1981) found that after 7 years of manuring (dairy manure) there was large variability in DIP concentrations among samples obtained weekly both from a given plot and among plots. A similar variation occurred between the Stigler soil columns.

Percolate Concentrations and Amounts of Nitrate-N

Daily mean NO_3-N amount and concentrations for the Baxter soil column percolates indicate neither NO_3-N amounts or concentrations in the Baxter soil column percolates were significantly different between litter application rates. Similar findings for NO_3-N concentrations were observed by Concannon and Genetelli (1971) using poultry litter solids at rates of 0 and 34 Mg ha^{-1} applied to 122 cm long soil (Adelphia and Lakewood) columns. However, Liebhardt et al. (1979) reported that as the rate (0, 25, 60, 121, and 400 Mg ha^{-1}) of poultry litter applications increased, so did the concentration of NO_3-N in the ground water.

An analysis of variance (linear regression) was performed on the rate of increase in daily mean NO_3-N percolate concentrations of the various surface-applied-litter Baxter soil columns verses a 4 day period which included a pretreatment day (App. K). There was a significant difference between the rate of increase in NO_3-N percolate concentration from the 9 and 36 Mg ha^{-1} poultry litter treatments and the rate of increase in NO_3-N percolate concentration from the control (Fig. 15). Although the daily mean NO_3-N concentrations in the Baxter soil column percolates on the pretreatment day followed an order of 9 Mg ha^{-1} > control > 36 Mg ha^{-1}, the increase in NO_3-N percolate concentration from surface applied poultry litter treatments were greater than the increase in NO_3-N percolate concentration from the control columns.

Daily mean NO_3-N percolate concentrations increased for the control and treatments after the second posttreatment day (Fig. 15). The control, 9, and 36 Mg litter ha^{-1} poultry litter applications reached their largest NO_3-N percolate concentrations of 29.25 mg L^{-1} (posttreat-

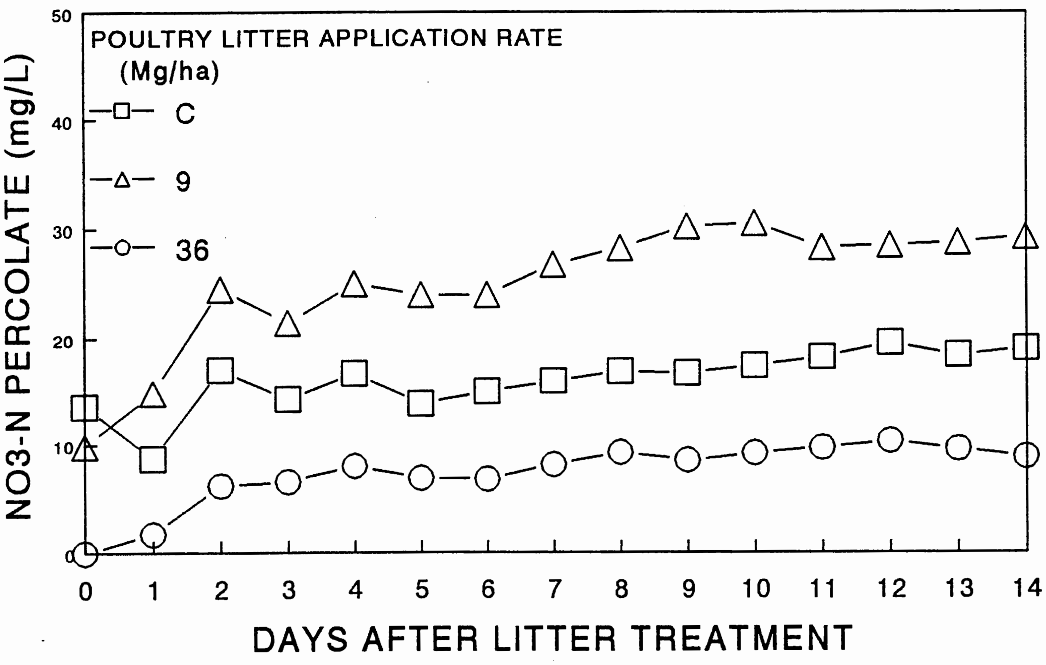

Fig. 15. Daily mean NO_3-N concentrations in percolates sampled from Baxter soil columns.

ment day 14), 30.5 mg L^{-1} (posttreatment day 10), and 10.32 mg L^{-1} (posttreatment day 14) respectively. Concannon and Genetelli (1971) found an increase in NO_3-N percolate concentrations over the posttreatment sampling period (one month). Increases in NO_3-N soil percolate concentrations during a 14-day period after surface application of manure may be due to a decrease in microbial denitrification over time (Bitzer and Sims, 1988). Gale and Gilmour (1988) reported that when poultry manure was incorporated in soil, net mineralization of N was completed within 7 days.

The mean 14-day NO_3-N concentration in the Baxter soil column percolates was 16.25, 26.02 and 7.84 mg L^{-1} for the control, 9, and 36

Mg ha^{-1} treatments respectively. Variation in mineralization of N in the Baxter soil may have caused the variability in the mean 14-day NO_3-N concentration between the various surface-applied poultry litter Baxter soil percolates.

There was no significant difference between cumulative NO_3-N amount in Baxter soil percolates from different litter application rates. The largest mean NO_3-N amount percolated for the 14 day period was 145.39 mg from the 9 Mg ha^{-1} treatment, followed by 86.55 mg in the controls and 39.8 mg from the 36 Mg ha^{-1} treatment. Cumulative NO_3-N variability in percolates from different litter application rates may be due to the vast N pool in the Baxter soil.

Field data indicated the NO_3-N concentrations in Baxter soil percolates from pan or suction lysimeters on both sampling dates were not significantly different between the different poultry litter applications. Mean NO_3-N percolate concentration from pan lysimeters after two rainfall events was 40.6, 4.4, 14.4, and 0.085 mg L^{-1} for the control, 9, 18, and 36 Mg ha^{-1} treatments respectively. Mean NO_3-N percolate concentration from suction lysimeters from two rainfall events was 52.4, 25.2, and 7.6 mg L^{-1} for the control, 9, and 36 Mg ha^{-1} treatments respectively. Suction lysimeters in the 18 Mg ha^{-1} plots were empty after the second rainfall, hence, data for the 18 Mg ha^{-1} poultry litter treatment was only available after the first rainfall of 6.1 cm. Concannon and Genetelli, (1973) found that NO_3-N soil percolate concentrations for the control and treatments were not significantly different between applications of dry poultry litter solids (0, 34, 67, and 101 Mg ha^{-1}) at the 5% level. Concannon and Genetelli, (1973) found NO_3-N percolate (sampled from pan lysimeters placed at 122 cm depth) concentrations of 23, 3, 14 and 25 mg L^{-1} respectively. The significance of the treatments used by Concannon and Genetelli, (1973) is that at 0, 34, 67, and 101 Mg ha^{-1} rates, dry poultry litter solids are unlikely to have a significant (at 5% level) effect on the NO_3-N concentration in percolates from soils used.

Laboratory data indicated neither NO_3-N concentrations or amounts in the Stigler soil percolates exhibited any significant difference between application rates. The largest mean NO_3-N concentration reached was 0.43 mg L^{-1} on day 8 in the 9 Mg ha^{-1} treatment followed by 0.08 (day 1) for the 36 Mg ha^{-1} treatment, and 0 mg L^{-1} for the control. The mean 14-day NO_3-N concentrations were <0.005, 0.106, and <0.005 mg L^{-1} for the 0, 9, and 36 Mg ha^{-1} treatments respectively. Nitrate-N concentrations in dairy manure soil percolates decrease at high flow suggesting a simple dilution and depletion effect (Hergert, 1975; Hergert et al. 1981). This dilution and depletion effect, along with various soil factors, such as a higher C:N ratio in the Stigler soil could explain the low NO_3-N concentrations in the Stigler soil percolates.

The largest mean NO_3-N amount percolated for the Stigler soil columns was 0.115 mg on day 5 in the 9 Mg ha^{-1} treatment followed by 0.065 mg (day 10) for the 36 Mg ha^{-1} treatment, and <0.005 mg for the control. The 14-day cumulative NO_3-N amounts were not significantly different between the litter application rates. The largest mean NO_3-N amount percolated over the 14 day period was 0.51 mg from the 9 Mg ha^{-1} poultry litter treatment followed by 0.3 mg from the 36 Mg ha^{-1} poultry litter treatment, and <0.005 mg from the control.

Field data indicated the NO_3-N concentrations in Stigler soil percolates from pan or suction lysimeters on both sampling dates were not significantly different between the different applications. Mean NO_3-N percolate concentration from pan lysimeters after two rainfall events was 4.08, 4.00, 3.10, and 0.03 mg L^{-1} for the control, 9, 18, and 36 Mg ha^{-1} poultry litter treatments. Mean NO_3-N percolate concentration from suction lysimeters after two rainfall events was 11.9, 11.05, 9.35, and 9.00 mg L^{-1} for the control, 9, 18 and 36 Mg ha^{-1} poultry litter treatments respectively.

The loss of NH_3 gas to microbial immobilization and a 13-14 year history of poultry litter application to the soil studied, could explain why NO_3-N concentrations in Baxter and Stigler soil percolates were not significantly different between the various application rates. Also, contamination of control and/or treatment plots could have occurred because of upward or lateral movement of waters within experimental plots. Lateral movement of water will occur from areas of low water potential to areas of high water potential (Zwerman et al, 1972; Miller, 1979). Since there were no monitoring wells or tensiometers installed, lateral movement could not be determined.

The chemical properties (total P, total N, nitrate-N, organic carbon, and pH) determined from the Baxter and Stigler soils were similar and could not explain the differences in NO_3-N amount and/or concentration from the percolates of these two soils (App. A). Physical properties (structure, texture, and rock content) of the Baxter and Stigler soils may have had an influence on NO_3-N amount and/or concentration (by affecting the residence time for NO_3-N) in the soil percolates of both soil types. The differences in physical properties between the Baxter and Stigler soils are presented in Table 4.

CHAPTER V

CONCLUSION

Mean DIP represented only 1% of the total P in the poultry manure, yet DIP was the predominant form of phosphorus in the soil percolates. Approximately 7% of the total N in the poultry manure was dissolved NO_3-N.

Surface-applied poultry litter contributes to increased amounts of DIP in Baxter soil column percolates. Soil percolate DIP amounts and concentration increased with increasing surface applied poultry litter applications on the first post-treatment day after (within 24 hours) a heavy rainfall (10.3 cm). Baxter soil applied with poultry litter at a rate of 9 to 36 Mg ha^{-1} just prior to a heavy rainfall, resulted in the movement of DIP into deeper soil layers along with percolating waters. Movement of DIP percolate in the Baxter soil may be due to the shallow soil depth of this soil and a relatively (compared to Stigler soil) low organic C content.

Once DIP is in the deeper soil layers it is susceptible to transport to ground water. Before using the Baxter soil for application of poultry wastes, serious consideration should be given to (1) time of poultry application, (2) application rate, and (3) the assimilatory capacity of the soil system.

Surface-applied poultry litter does not contribute to increased amounts and concentrations of NO_3-N in Baxter soil percolates or NO_3-N and DIP in Stigler soil percolates. However, both soils had a 13-14 year (biannual application between 8 and 10 Mg litter ha^{-1}) history of poultry litter application. Therefore, a one-time 6-month poultry litter surface application did not effect NO_3-N in Baxter soil percolates or NO_3-N and DIP in Stigler soil percolates great enough to show that increasing poultry litter surface application will cause a significant increase in amount or concentration of one or both nutrients in the percolates from these two soils.

Soil type is an important factor influencing the amount of DIP and NO_3-N in surface-applied poultry litter soil percolates. Soil properties eastern Oklahoma soils have a marked influence on the amount of DIP and NO_3-N in soil solution. These properties or variables include (a) clay content, (b) rock content, (c) soil structure, and (d) soil depth. Other factors may be involved in the complex mechanism producing variable amounts of DIP and NO_3-N in soil solution. These factors include (1) the DIP concentration in soil solution in the surface horizon, (2) the interaction of organic P and inorganic P in soil solution, (3) effects of microbial immobilization on maintaining NO_3-N in solution due to the loss of NH_4 gas, (4) effects of mineralization on maintaining NO_3-N and inorganic P in solution, and (5) organic matter content in soil.

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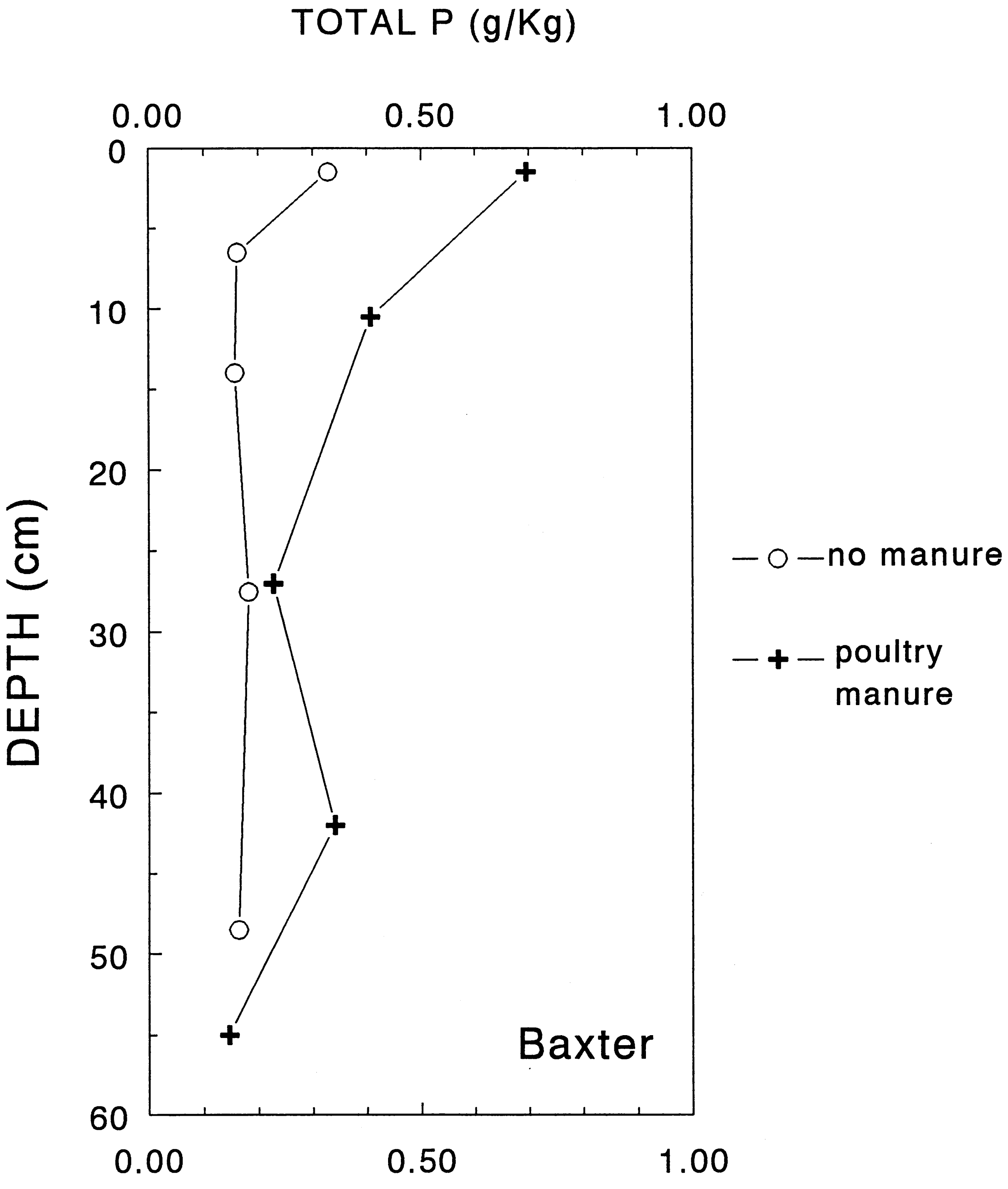
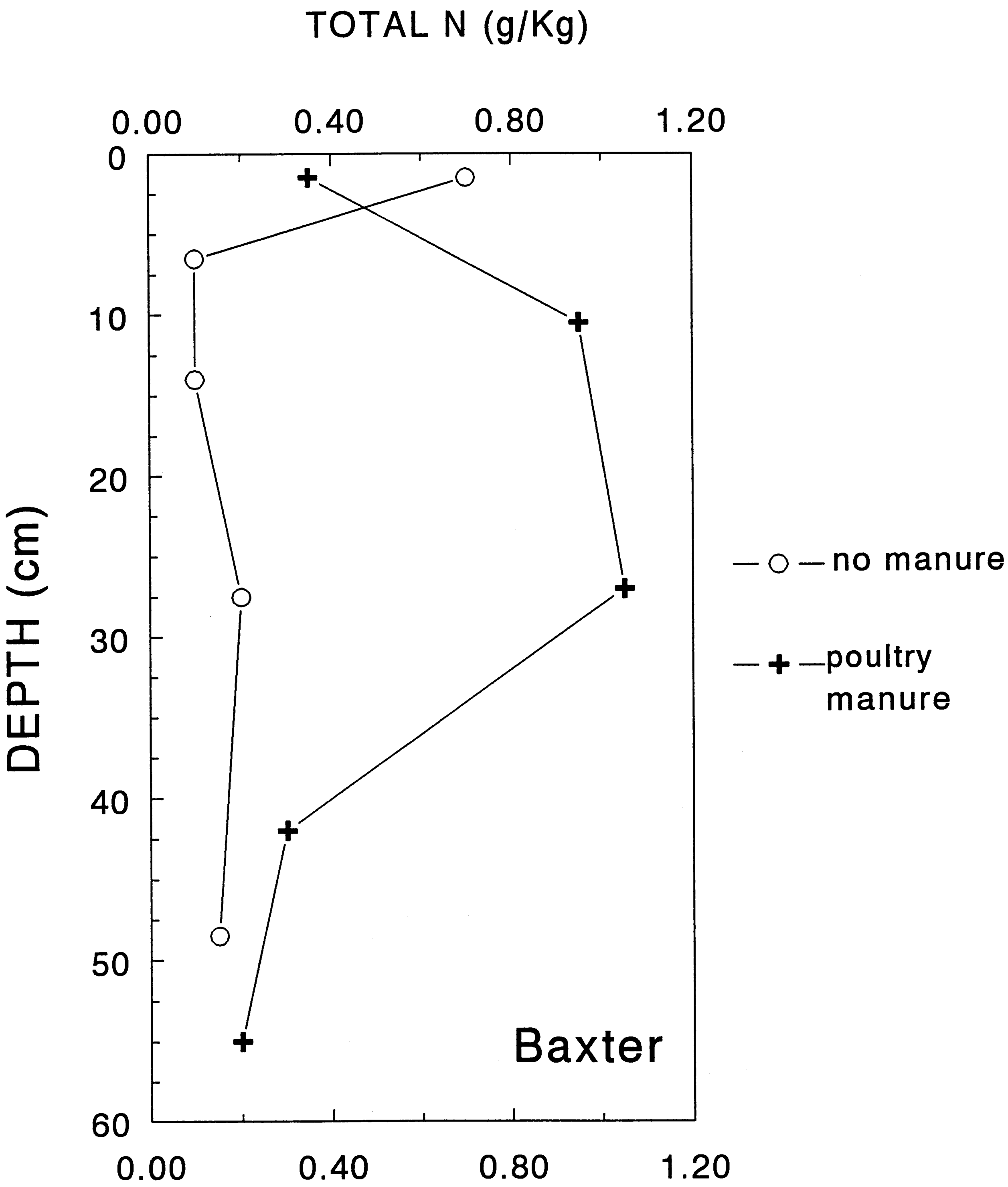
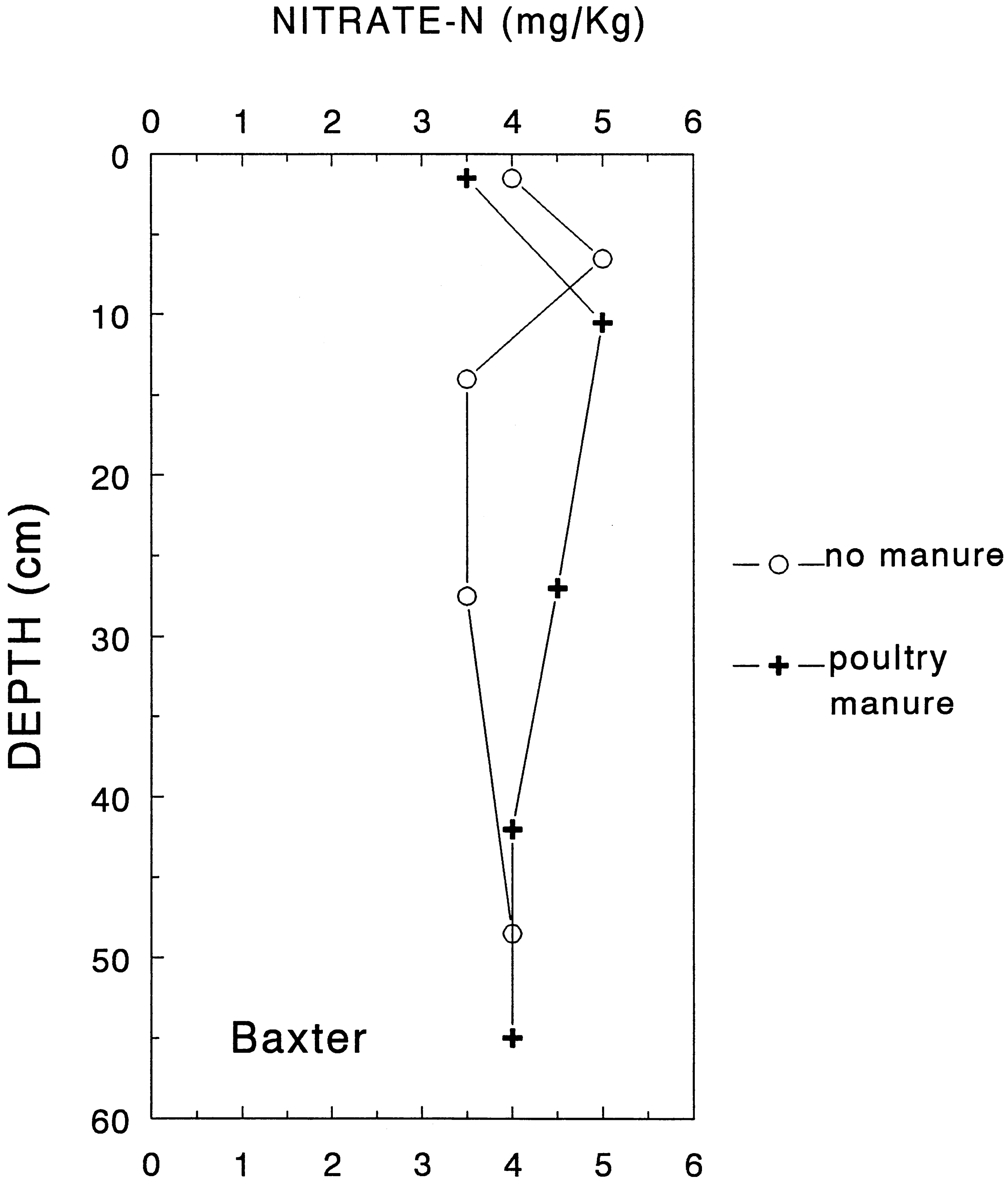
APPENDIXES

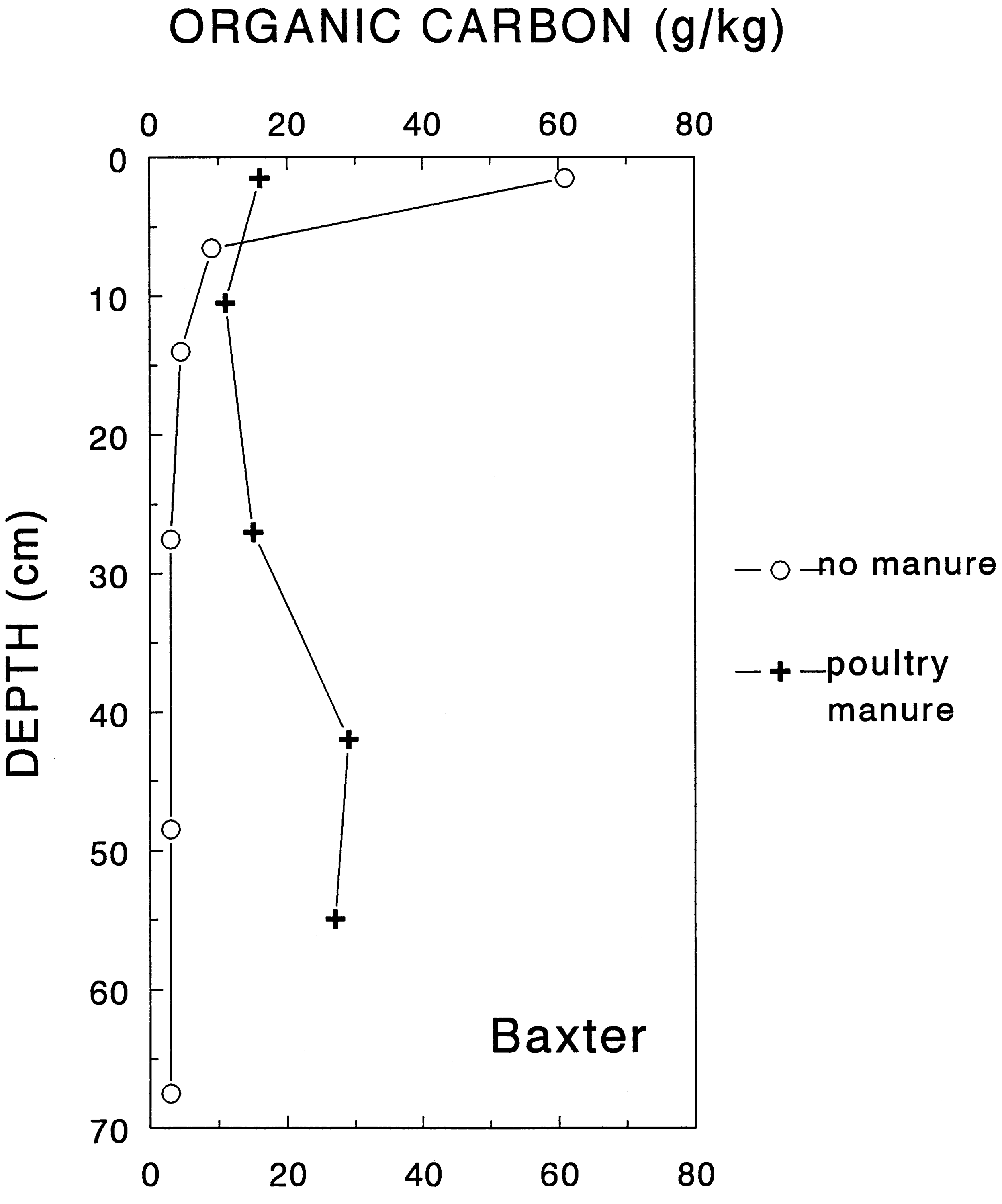
APPENDIX A

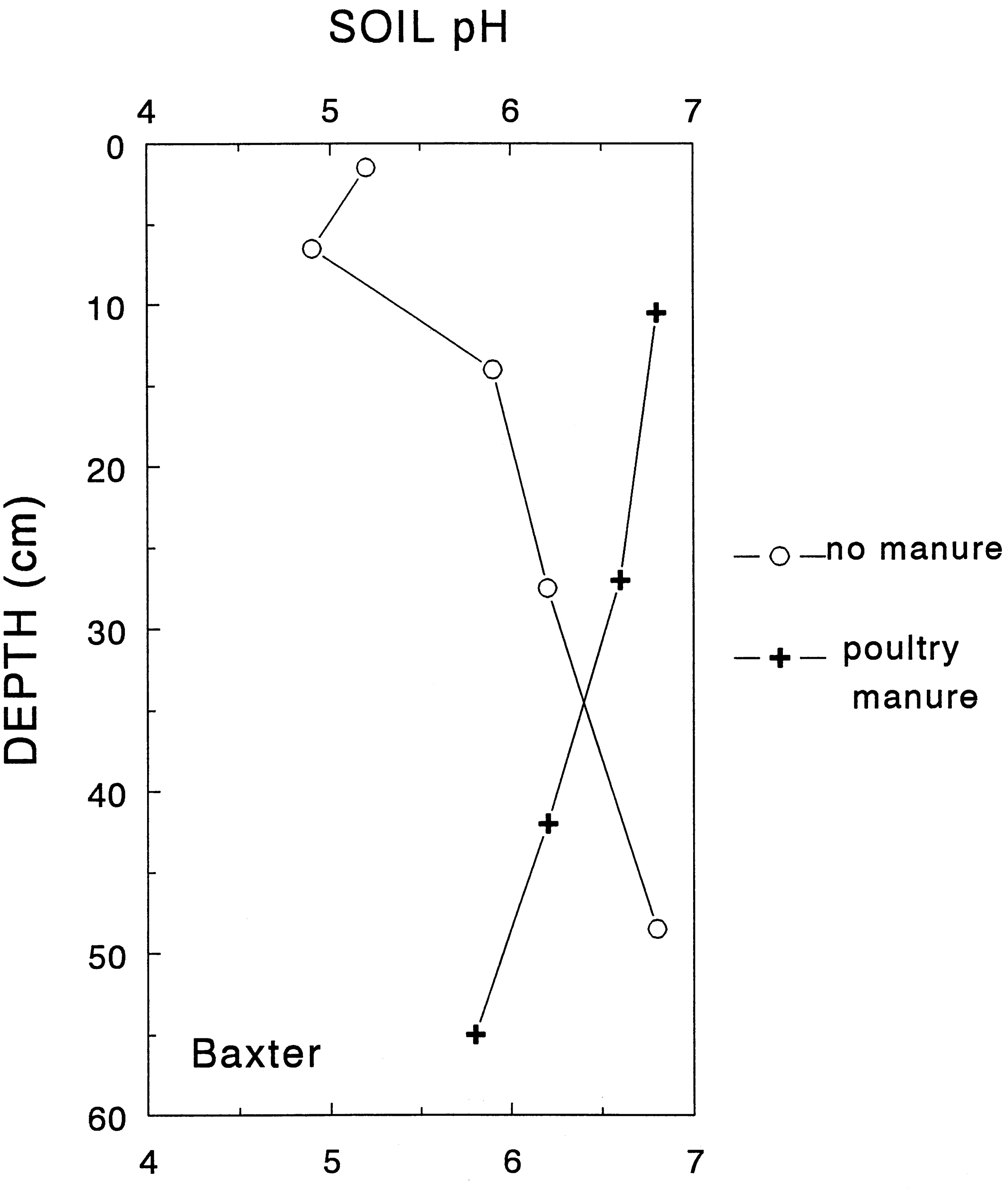
DISPOSITION GRAPHS OF CHEMICAL PROPERTIES FOR BAXTER AND STIGLER SOILS WITH AND WITHOUT POULTRY MANURE HISTORY

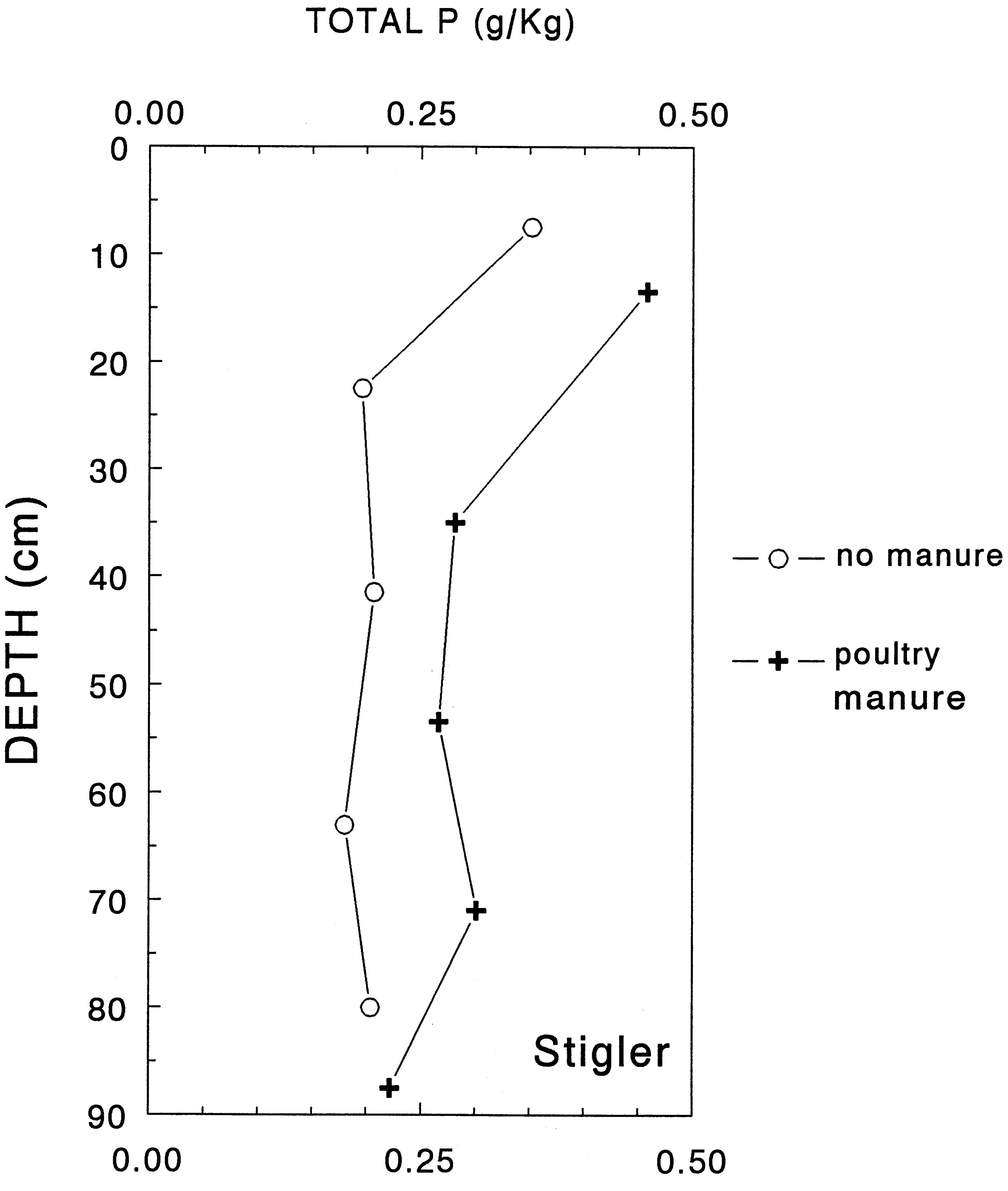

TOTAL P (g/Kg)
0.00
0.50
1.00
0
10
20
30
40
50
60
DEPTH (cm)
—○—no manure
—+— poultry manure
Baxter
0.00
0.50
1.00

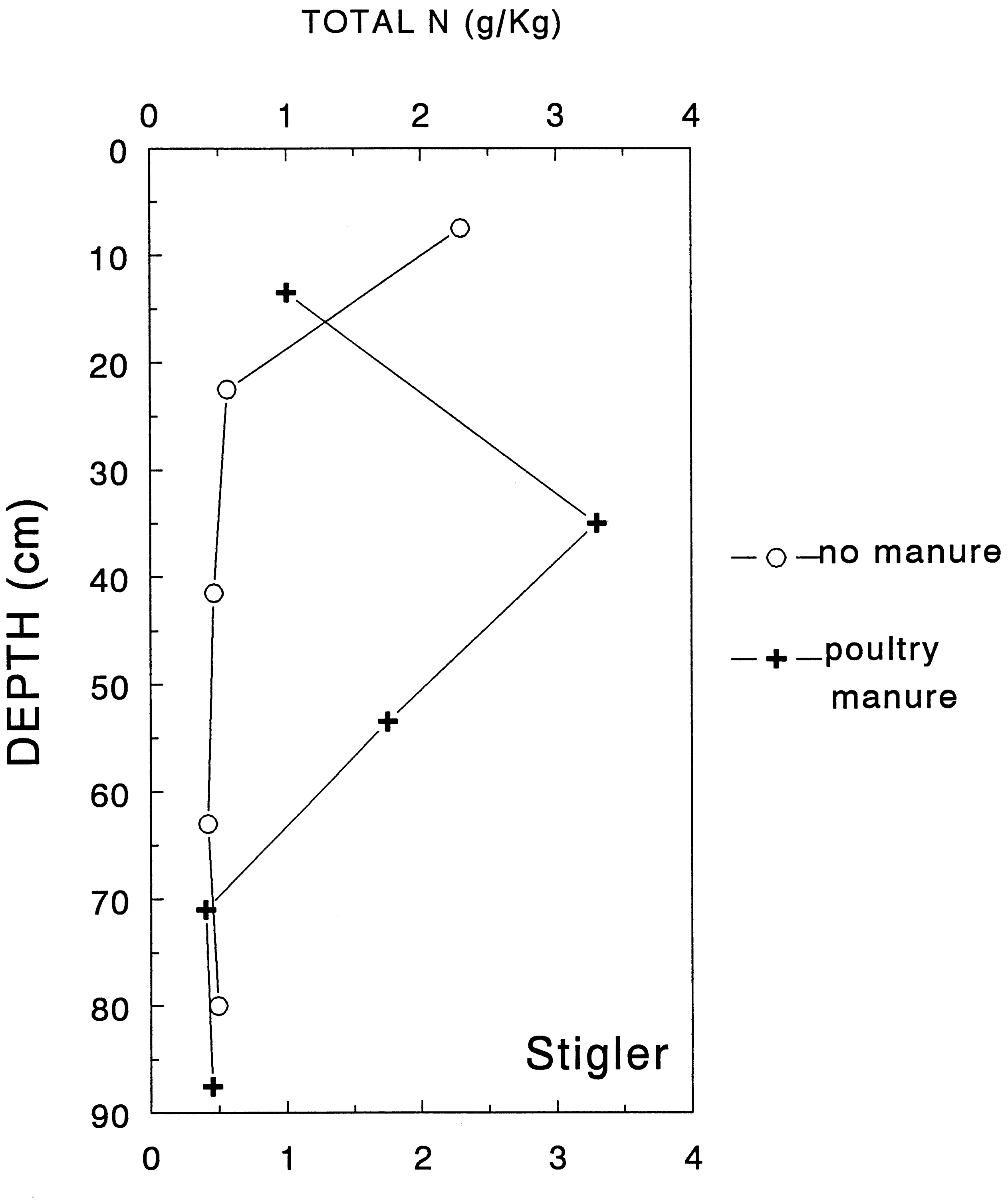

TOTAL N (g/Kg)
0.00
0.40
0.80
1.20
DEPTH (cm)
0
10
20
30
40
50
60
no manure
poultry manure
Baxter

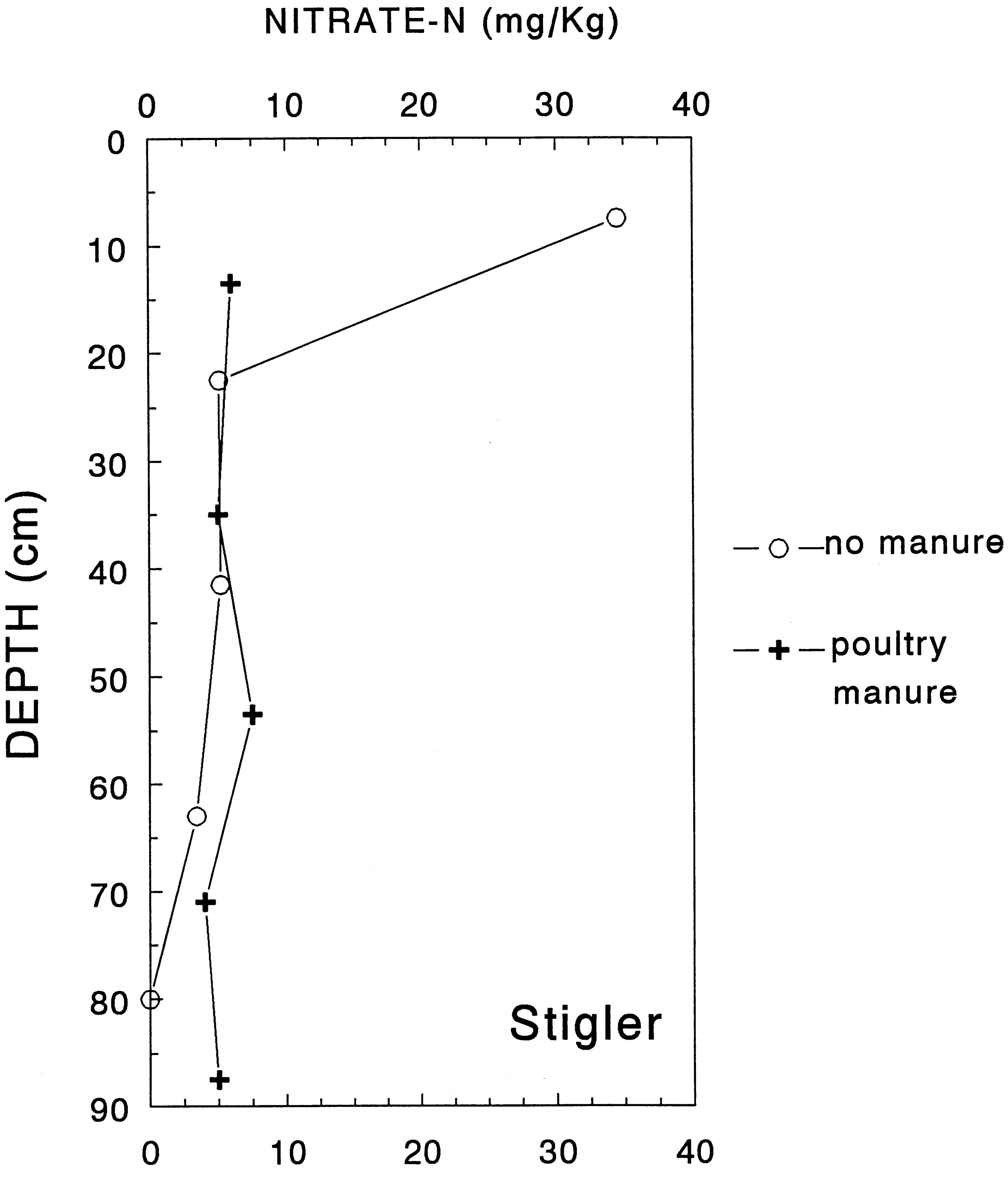

NITRATE-N (mg/Kg)
0
1
2
3
4
5
6
DEPTH (cm)
0
10
20
30
40
50
60
Baxter
no manure
poultry manure

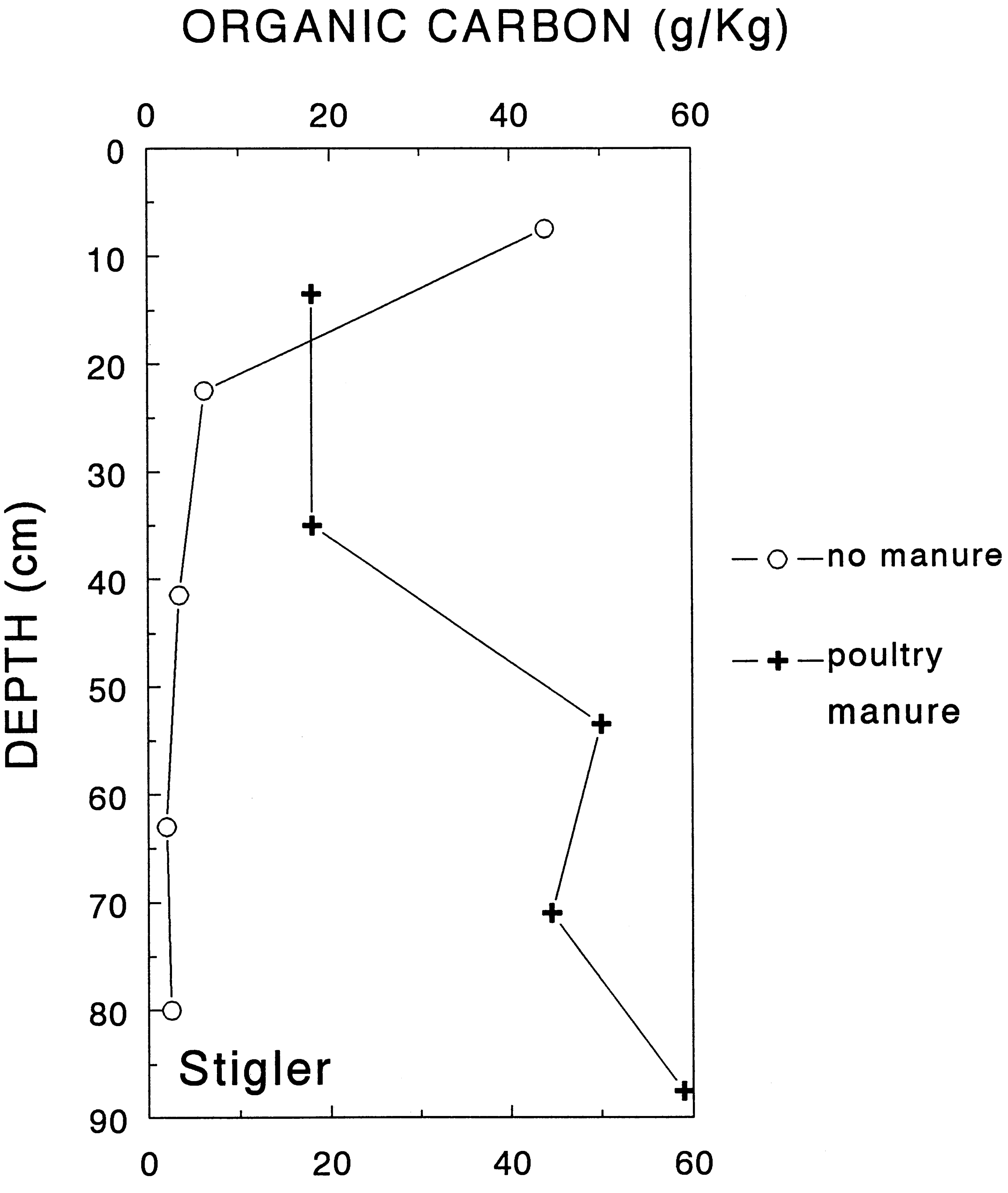

ORGANIC CARBON (g/kg)
0
20
40
60
80
DEPTH (cm)
0
10
20
30
40
50
60
70
Baxter
no manure
poultry manure

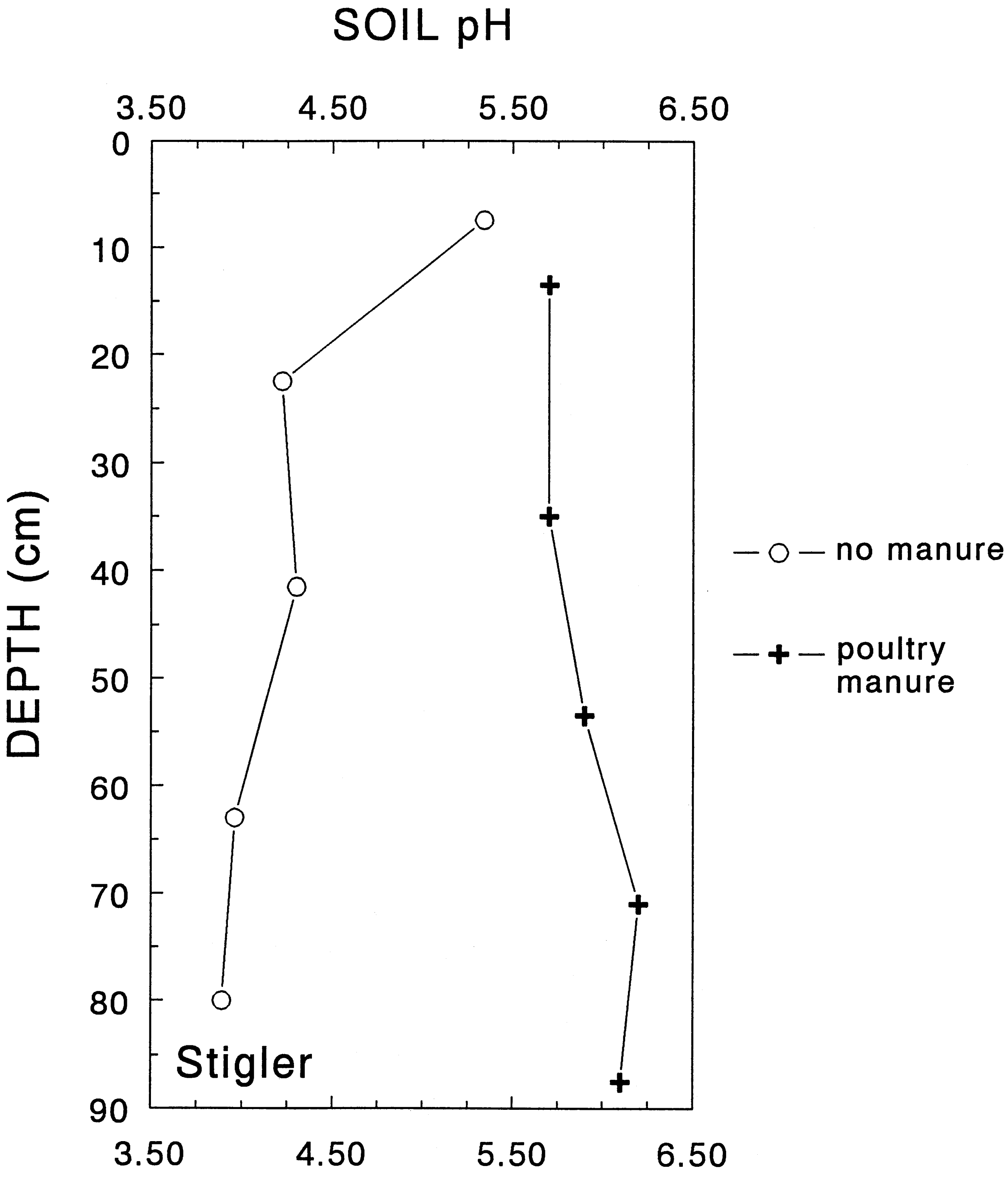

SOIL pH
4
5
6
7
0
10
20
30
40
50
60
DEPTH (cm)
Baxter
—○— no manure
—✚— poultry manure


TOTAL P (g/Kg)
0.00
0.25
0.50
0
10
20
30
40
50
60
70
80
90
DEPTH (cm)
— ○ — no manure
— ✚ — poultry manure
Stigler
0.00
0.25
0.50


TOTAL N (g/Kg)
0
1
2
3
4
DEPTH (cm)
0
10
20
30
40
50
60
70
80
90
no manure
poultry manure
Stigler


NITRATE-N (mg/Kg)
0
10
20
30
40
DEPTH (cm)
0
10
20
30
40
50
60
70
80
90
no manure
poultry manure
Stigler


ORGANIC CARBON (g/Kg)
0
20
40
60
DEPTH (cm)
0
10
20
30
40
50
60
70
80
90
Stigler
—○—no manure
—✚—poultry manure


SOIL pH
3.50
4.50
5.50
6.50
0
10
20
30
40
50
60
70
80
90
DEPTH (cm)
Stigler
—○— no manure
—✚— poultry manure

APPENDIX B

RECORD AND AVERAGE DAILY RAINFALL REPORTED, AND AMOUNTS OF APPLIED ARTIFICIAL RAINFALL AND COLLECTED PERCOLATES FOR LABORATORY SOIL COLUMNS

Appendix B. Recorded and average daily rainfall reported, and amounts of applied artificial rainfall and collected percolates for laboratory soil columns.$^{+}$

Application rate (MgHa^{-1})	rep no. + avg	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Reported rainfall															
		cm														
		10.3	1.2	1.1	1.2	2.0	1.4	1.1	1.1	1.0	1.9	1.2	1.4	1.2	1.1	1.7
		ml														
Baxter																
	Artificial rainfall															
		3334	387	362	305	642	445	370	354	321	617	395	461	387	362	560
	Percolate															
0	1		1302	269	294	272	560	382	343	302	278	554	345	423	328	306
	2		1303	190	296	272	581	382	338	298	279	562	345	416	327	298
	avg		1302.5	229.5	295	272	570.5	382	340.5	300	278.5	558	345	419.5	327.5	302
9	1		1448	232	320	266	586	395	337	310	282	565	352	415	344	314
	2		1317	216	298	270	582	388	340	302	278	554	355	425	330	307
	avg		1382.5	224	309	268	584	391.5	338.5	306	280	559.5	353.5	420	337	310.5
36	1		1476	329	255	272	576	390	349	309	293	575	362	422	357	328
	2		1283	227	236	258	544	364	340	289	270	549	340	402	319	298
	avg		1379.5	278	245.5	265	560	377	344.5	299	281.5	562	351	412	338	313

Appendix B. Recorded and average daily rainfall reported, and amounts of applied rainfall and collected percolates for laboratory soil columns.+ (Con't)

Application rate ($MgHa^{-1}$)	rep no. + avg	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Reported rainfall															
		-------------------------------							cm							-------------------------------
		11.1	1.3	1.6	1.1	1.9	0.9	0.4	0.9	1.3	2.2	1.5	1.2	0.8	1.0	1.1
		-------------------------------							ml							-------------------------------
Stigler																
	Artificial rainfall															
		3598	214	510	321	601	305	132	246	412	724	486	379	272	338	362
	Percolate															
0	1		1162	327	378	330	531	215	155	205	372	645	487	355	206	289
	2		1742	227	340	241	494	207	112	100	364	658	443	357	214	294
	avg		1452	277	359	285.5	512.5	211	133.5	152.5	368	651.5	465	356	210	291.5
9	1		1073	333	358	340	542	217	172	199	376	624	441	355	205	289
	2		1249	347	382	354	537	233	176	227	388	653	448	367	219	295
	avg		1161	340	370	347	539.5	225	174	213	382	638.5	444.5	361	212	292
36	1		959	349	304	334	514	204	176	200	368	645	434	338	210	279
	2		1538	300	292	250	479	185	131	215	344	640	445	347	227	2
	avg		1248.5	324.5	298	292	496.5	194.5	153.5	207.5	356	642.5	439.5	343	219	289

+ Length of time soil types had poultry litter applied; Baxter = 13 yrs and Stigler = 14 yrs.

APPENDIX C

PERCOLATE VOLUMES COLLECTED FOR SATURATED HYDRAULIC CONDUCTIVITY (K_{SAT}) DETERMINATION

Appendix C. Percolate volumes collected for saturated hydraulic conductivity K_{SAT} determination.

	Assigned litter application rates (Mgha^{-1})											
time (min)	C(rep1)	C(rep2)	9(rep1)	9(rep2)	36(rep1)	36(rep2)	C(rep1)	C(rep2)	9(rep1)	9(rep2)	36(rep1)	36(rep2)
						ml						
			Baxter						Stigler			
10.00	1867.00	2077.00	2241.00	2152.00	1983.00	2175.00	2480.00	2055.00	2128.00	1998.00	2270.00	2316.00
20.00	231.00	239.00	742.00	296.00	197.00	672.00	146.00	421.00	430.00	76.00	447.00	282.00
30.00	148.00	248.00	679.00	241.00	105.00	599.00	82.00	397.100	441.00	71.00	451.00	210.00
40.00	160.00	265.00	677.00	247.00	1380.00	621.00	83.00	347.00	442.00	92.00	453.00	220.00
50.00	169.00	277.00	679.00	153.00	152.00	641.00	83.00	303.00	448 .00	220.00	454.00	227.00
60.00	174.00	288.00	678.00	154.00	154.00	649.00	81.00	305.00	448.00	224.00	454.00	233.00
70.00	173.00	307.00	679.00	154.00	154.00	648.00	82.00	303.00	446.00	224.00	454.00	237.00
80.00	174.00	315.00	679.00	154.00	153.00	654.00	83.00	305.00	448.00	222.00	453.00	236.00
90.00	175.00	320.00	679.00	153.00	154.00	655.00	81.00	305.00	447.00	224.00	421.00	237.00
100.00	172.00	327.00	595.00	154.00	154.00	657.00	71.00	303.00	448.00	221.00	312.00	237.00
110.00	174.00	330.00	559.00	141.00	154.00	662.00	58.00	260.00	403.00	217.00	182.00	237.00
120.00	161.00	329.00	475.00	123.00	153.00	663.00	49.00	149.00	401.00	169.00	76.00	220.00
130.00	150.00	330.00	301.00	88.00	150.00	667.00	41.00	92.00	399.00	81.00	42.00	157.00
140.00	142.00	327.00	200.;00	60.00	140.00	672.00	37.00	53.00	398.00	64.00	32.00	97.00
150.00	135.00	330.00	151.00	37.00	119.00	675.00	27.00	41.00	395.00			67.00
160.00	131.00	275.00	131.00	26.00	102.00	676.00		33.00	393.00			45.00
170.00	128.00	106.00	89.00	18.00	95.00	677.00			383.00			
180.00	122.00	52.00	76.00	15.00	82.00	675.00			380.00			

Appendix C. Percolate volumes collected for saturated hydraulic conductivity K_{SAT} determination. (Con't)

time (min)	C(rep1)	C(rep2)	9(rep1)	9(rep2)	36(rep1)	36(rep2)	C(rep1)	C(rep2)	9(rep1)	9(rep2)	36(rep1)	36(rep2)
	Assigned litter application rates (Mgha^{-1})											
						ml						
			Baxter						Stigler			
190.00	120.00	32.00	62.00	12.00	75.00	677.00			362.00			
200.00		18.00	55.00	9.00		675.00			343.00			
210.00			48.00			675.00			330.00			
220.00			47.00			677.00			303.00			
230.00						654.00			221.00			
240.00						631.00			187.00			
250.00						272.00			164.00			
260.00						202.00			103.00			
270.00						143.00			88.00			
Constant vol. per 10 min.	173.67	329.20	676.00	153.80	153.71	678.57	82.40	304.20	446.50	222.50	453.75	236.80

APPENDIX D

SATURATED HYDRAULIC CONDUCTIVITY (K_{SAT}) DATA FOR PAIRING SEQUENCE USED IN SOIL SAMPLE REPLICATION

Appendix D. Saturated Hydraulic Conductivity (K_{sat})

Application rate (Mgha^{-1})*	rep no.	K_{sat} (cm hr^{-1})	Mean (cm hr^{-1})	standard cleviation	coefficient of variation**
			Baxter		
0	1	3.24			
	2	6.10	4.67	2.02	43.25
9	1	12.60			
	2	2.83	7.715	6.908	895.4
36	1	2.83			
	2	12.60	7.715	6.908	89.54
			Stigler		
0	1	1.52			
	2	5.63	3.575	2.906	81.29
9	1	8.28			
	2	4.32	6.30	2.80	44.44
36	1	8.28			
	2	4.32	6.30	2.80	44.44

* Application consisting of poultry litter.

** Coefficient of variation = (std.dev./means) x 100.

APPENDIX E

DAILY DIP AMOUNTS AND CONCENTRATIONS AND 14-DAY CUMULATIVE AMOUNTS IN SOIL PERCOLATES SAMPLED FROM LABORATORY COLUMNS

Appendix E. Daily DIP amounts and concentrations and 14-day cumulative amounts in soil percolates sampled from laboratory columns.

		Days after poultry litter treatment															
Application rate (Mgha^{-1})	rep no. + avg	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total amt.
		mg L^{-1}															
Baxter																	
0	1	0.48	0.41	0.14	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	-
	2	0.10	0.08	0.33	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	-
	avg	0.29	0.25	0.24	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	-
9	1	0.00	1.50	0.05	0.02	0.03	0.77	0.55	0.37	0.25	0.18	0.45	0.35	0.43	0.39	0.26	-
	2	0.00	1.79	0.55	0.00	0.00	0.00	0.00	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.00	-
	avg	0.00	1.65	0.30	0.01	0.02	0.39	0.38	0.20	0.14	0.10	0.23	0.18	0.22	0.20	0.13	-
36	1	0.01	32.8	8.87	0.56	0.01	0.57	0.19	0.11	0.74	0.22	0.89	1.17	1.98	2.75	2.63	-
	2	0.00	4.08	0.11	0.00	0.00	0.91	0.09	0.03	0.03	0.02	0.11	0.03	0.10	0.2	0.00	-
	avg	0.01	18.44	4.49	0.28	0.01	0.74	0.14	0.07	0.39	0.12	0.50	0.60	1.04	1.39	1.32	-
		ug															
0	1		0.53	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	.58
	2		0.10	0.06	0.00	0.00		0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	.17
	avg		0.32	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.005	0.005	0.00	0.00	0.00	0.00	0.38
9	1		2.17	0.01	0.01	0.01	0.45	0.22	0.12	0.08	0.05	0.26	0.12	0.18	0.13	0.08	3.89
	2		2.36	0.12	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	2.51
	avg		2.27	0.7	0.005	0.005	0.23	0.11	0.7	0.05	0.03	0.14	0.06	0.09	0.07	0.04	3.20
36	1		48.41	2.92	0.14	0.00	0.33	0.07	0.04	0.23	0.07	0.51	0.42	0.84	0.98	0.86	55.82
	2		5.23	0.03	0.00	0.00	0.50	0.03	0.01	0.01	0.00	0.06	0.01	0.04	0.01	0.00	5.93
	avg		26.82	1.475	0.07	0.00	0.415	0.05	0.025	0.12	0.035	0.285	.215	0.44	0.495	0.43	30.88

Appendix E. Daily DIP amounts and concentrations and 14-day cumulative amounts in soil percolates sampled from laboratory columns. (Con't)

Application rate (Mgha^{-1})	rep no. + avg	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total amt.
		Days after poultry litter treatment															
		mg L^{-1}															
Stigler																	
0	1	0.03	0.02	0.01	0.00	0.00	0.01	0.01	0.01	0.02	0.04	0.06	0.02	0.01	0.02	0.00	
	2	0.52	0.44	0.12	0.00	0.00	0.00	0.01	0.01	0.01	0.03	0.01	0.01	0.00	0.00	0.00	
	avg	0.28	0.23	0.07	0.00	0.00	0.01	0.01	0.01	0.02	0.04	0.04	0.02	0.01	0.01	0.00	
9	1	1.24	0.87	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.01	0.00	0.00	0.00	0.00	
	2	0.65	0.41	0.12	0.00	0.00	0.02	0.00	0.02	0.03	0.05	0.02	0.00	0.00	0.00	0.00	
	avg	0.95	0.64	0.06	0.00	0.00	0.01	0.00	0.02	0.03	0.04	0.02	0.00	0.00	0.00	0.00	
36	1	0.00	0.07	0.18	0.00	0.00	0.00	0.00	0.01	0.01	0.03	0.01	0.00	0.00	0.00	0.00	
	2	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.01	0.02	0.03	0.02	0.00	0.00	0.00	0.00	
	avg	0.00	0.05	0.09	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.02	0.00	0.00	0.00	0.00	
		ug															
0	1	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.03	
	2	0.77	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.81	
	avg	0.395	0.015	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.42	
9	1	0.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.93	
	2	0.51	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.55	
	avg	0.72	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.74	
36	1	0.07	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	
	2	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.04	
	avg	0.05	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.005	0.00	0.00	0.00	0.09	

APPENDIX F

DIP CONCENTRATION IN SOIL PERCOLATES SAMPLED FROM PAN (P) AND SUCTION (S) LYSIMETERS BEFORE POULTRY LITTER TREATMENT AND AFTER TWO MAJOR RAINFALLS

Appendix F. Dip concentration in soil percolates sampled from field pan (P) and suction (S) lysimeters before poultry litter treatment and after two major rainfalls.

Application rate (Mg ha^{-1})	Lysimeter	Plot no. + avg	Pre-treatment (day o)	1st rainfall (7.1cm) (day 5)	2nd rainfall (7.9cm) (day 13)
			mg L^{-1}		
Baxter					
0	P	1	1.55	0.17	0.04
		2	5.23	1.9	0.06
		avg	3.39	1.04	0.05
	S	1	+	0.74	0.44
		2	+	0.90	0.03
		avg	+	0.82	0.24
9	P	1	3.37	8.9	5.8
		2	2.67	11.2	6.35
		avg	3.02	10.05	6.08
	S	1	+	2.41	1.78
		2	+	2.62	1.19
		avg	+	2.52	1.49
18	P	1	0.23	0.36	0.2
		2	+	2.17	0.22
		avg	+	1.27	0.21
	S	1	+	3.76	+
		2	+	2.16	+
		avg	+	2.96	+
36	P	1	2.22	10.60	8.25
		2	2.16	37.40	32.2
		avg	2.19	24.00	20.23
	S	1	+	0.41	0.10
		2	+	5.84	1.18
		avg	+	3.13	0.64
Stigler					
0	P	1	0.00	0.48	0.10
		2	0.00	0.13	0.03
		avg	0.00	0.31	0.07
	S	1	0.02	0.03	0.00
		2	0.55	0.27	0.11
		avg	0.29	0.15	0.06

Appendix F. Dip Concentration in soil percolates sampled from field pan (P) and suction (S) lysimeters before poultry litter treatment and after two major rainfalls. (Con't)

Application rate (Mg ha^{-1})	Lysimeter	Plot no. + avg	Pre-treatment (day o)	1st rainfall (7.1cm) (day 5)	2nd rainfall (7.9cm) (day 13)
			mg L^{-1}		
9	P	1	0.00	0.15	0.22
		2	0.33	3.52	0.13
		avg	0.17	1.84	0.18
	S	1	0.05	0.14	0.07
		2	0.07	0.39	0.10
		avg	0.06	0.27	0.09
18	P	1	0.00	0.01	0.00
		2	0.27	6.14	0.39
		avg	0.14	3.08	0.20
	S	1	0.00	0.04	0.00
		2	0.02	0.01	0.00
		avg	0.01	0.03	0.00
36	P	1	+	8.00	0.72
		2	2.35	20.70	1.15
		avg		14.35	36.58
	S	1	0.05	2.79	0.61
		2	10.00	0.56	0.13
		avg	5.03	1.68	0.37

+ No water collected by lysimeter.

APPENDIX G

DAILY NO_3-N AMOUNT AND CONCENTRATION, AND 14-DAY CUMULATIVE AMOUNTS IN SOIL PERCOLATES SAMPLED FROM LABORATORY COLUMNS

Appendix G. Daily NO_3-N amounts and concentration and 14-day cumulative amounts in soil percolates sampled from laboratory columns.

Application rate (MgHa^{-1})	rep no. + avg	Days after poultry litter treatment 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total amt.
		mg L^{-1}															
Baxter																	
0	1	11.80	7.65	12.40	9.86	13.00	11.10	12.20	13.10	15.70	14.50	16.20	17.70	19.80	17.50	18.40	-
	2	15.40	9.80	21.70	18.60	20.40	16.6	17.70	18.80	18.00	18.90	18.60	18.70	19.30	19.3	19.60	-
	avg	13.60	8.73	17.05	14.23	16.70	13.85	14.95	15.95	16.85	16.70	17.40	18.20	19.55	18.40	19.00	-
9	1	0.00	0.57	8.66	5.39	9.91	10.10	11.40	13.60	18.40	16.50	19.50	18.4	20.50	22.00	23.20	-
	2	19.70	29.10	40.40	37.50	40.10	37.90	37.00	39.90	38.00	43.90	41.50	38.20	36.50	35.50	35.20	-
	avg	9.85	14.84	24.53	21.45	25.01	24.00	24.00	26.75	28.20	30.20	30.50	28.30	28.50	28.75	29.25	-
36	1	0.00	2.70	1.18	0.71	0.00	0.00	0.00	0.00	0.00	0.06	0.12	0.00	1.13	1.85	0.42	-
	2	0.00	0.75	11.20	12.40	16.00	13.80	13.60	16.30	18.50	17.00	18.30	19.40	19.50	17.30	17.30	-
	avg	0.00	1.73	6.19	6.56	8.00	6.90	6.80	8.15	9.25	8.53	9.21	9.70	10.32	9.58	8.86	-
		ug															
0	1		9.96	3.34	2.90	3.54	6.22	4.66	4.49	4.74	4.03	8.97	6.11	8.38	5.74	5.63	78.71
	2		12.77	4.12	5.51	55.45	9.64	6.76	6.35	5.36	5.27	64.2	6.45	8.03	6.31	5.84	94.38
	avg		11.365	3.73	42.05	4.55	7.93	5.71	5.42	5.05	4.65	7.695	6.28	8.205	6.025	5.74	86.55
9	1		0.83	2.01	1.72	2.64	5.92	4.50	4.58	5.70	4.65	11.02	6.48	8.51	7.57	7.32	73.45
	2		38.32	8.73	11.18	10.83	22.06	14.36	13.57	11.48	12.2	23.00	13.56	15.51	11.72	10.81	217.33
	avg		19.575	5.37	6.45	6.735	13.99	9.43	9.075	8.59	8.425	17.01	10.02	12.01	9.645	9.065	145.39
36	1		3.99	0.39	0.18	0.00	0.00	0.00	0.00	0.00	0.02	0.07	0.00	0.48	0.66	0.14	5.93
	2		0.96	2.54	2.93	4.13	7.51	4.95	5.54	5.35	4.59	10.05	6.60	7.84	5.52	5.16	73.67
	avg		2.475	1.465	1.555	2.065	3.755	2.475	2.77	2.675	2.305	5.06	3.30	4.16	3.09	2.65	39.80

Appendix G. Daily NO_3-N amounts and concentration and 14-day cumulative amounts in soil percolates sampled from laboratory columns. (Con't)

		Days after poultry litter treatment															
Application rate (MgHa^{-1})	rep no. + avg	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total amt.
Stigler																	
		mg L^{-1}															
0	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	avg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
9	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	
	2	0.00	0.00	0.00	0.00	0.00	0.43	0.21	0.50	0.85	0.20	0.40	0.22	0.04	0.00	0.00	
	avg	0.00	0.00	0.00	0.00	0.00	0.22	0.105	0.25	0.43	0.10	0.20	0.11	0.27	0.00	0.00	
36	1		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	
	2		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	avg		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	
		ug															
0	1		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	avg		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	1		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2		0.00	0.00	0.00	0.00	0.23	0.05	0.04	0.19	0.08	0.26	0.10	0.01	0.00	0.00	1.01
	avg		0.00	0.00	0.00	0.00	0.115	0.025	0.045	0.095	0.04	0.13	0.05	0.005	0.00	0.00	0.51
36	1		0.00	0.00	0.00	0.00	0.12	0.03	0.05	0.10	0.04	0.13	0.12	0.01	0.00	0.00	0.60
	2		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	avg		0.00	0.00	0.00	0.00	0.06	0.015	0.025	0.05	0.02	0.65	0.06	0.005	0.00	0.00	0.30

APPENDIX H

NO_3-N CONCENTRATION IN SOIL PERCOLATES SAMPLED FROM PAN (P) AND SUCTION (S) LYSIMETERS BEFORE POULTRY LITTER TREATMENT AND AFTER TWO MAJOR RAINFALLS

Appendix H. NO_3-N concentration in soil percolates sampled from pan (P) and suction (S) lysimeters before poultry litter treatment and after two major rainfalls.

Application rate (Mg ha^{-1})	Lysimeter	Plot no. + avg	Pre-treatment (day o)	1st rainfall (7.1cm) (day 5)	2nd rainfall (7.9cm) (day 13)
			-------------------	mg L^{-1}	-------------------
Baxter					
0	P	1	0.00	60.00	37.20
		2	24.50	27.00	38.30
		aug	12.0	43.50	37.75
	S	1	+	47.50	65.5
		2	+	41.80	54.6
		aug	+	44.65	60.05
9	P	1	5.40	0.20	6.20
		2	4.50	0.30	10.90
		aug	4.95	0.25	8.55
	S	1	+	13.00	8.80
		2	+	28.5	50.60
		aug	+	20.75	29.70
18	P	1	50.80	28.50	13.80
		2	+	1.20	14.00
		aug	+	14.85	13.40
	S	1	+	2.20	+
		2	+	10.0	+
		aug		6.00	+
36	P	1	3.80	0.10	0.00
		2	2.10	0.10	0.10
		aug	2.95	0.10	0.07
	S	1	+	7.90	8.3
		2	+	12.30	1.78
		aug	+	10.10	5.04
Stigler					
0	P	1	0.9	2.4	5.6
		2	0.5	2.8	5.5
		aug	0.7	2.6	5.55
	S	1	14.5	11.1	7.5
		2	19.2	17.6	11.4
		avg	16.85	14.35	9.45
9	P	1	0.7	0.3	8.6
		2	0.4	0.6	6.5
		avg	0.55	0.45	7.55
	S	1	13.4	14.6	10.3
		2	11.6	11.2	8.1
		avg	12.5	12.9	9.2

Appendix H. NO_3-N concentration in soil percolates sampled from pan (P) and suction (S) lysimeters before poultry litter treatment and after two major rainfalls. (Con't)

Application rate (Mg ha^{-1})	Lysimeter	Plot no. + avg	Pre-treatment (day o)	1st rainfall (7.1cm) (day 5)	2nd rainfall (7.9cm) (day 13)
			mg L^{-1}		
18	P	1	0.3	2.2	3.4
		2	0.5	6.7	0.1
		avg	0.4	4.45	1.75
	S	1	9.5	11.3	10.9
		2	8.8	7.2	8
		avg	9.15	9.25	9.45
36	P	1	+	0	0.1
		2	0	0	0
		avg	0	0	.05
	S	1	13.9	6.2	3.1
		2	9.8	5.9	2.8
		avg	11.85	12.1	5.9

+ No water sampled by lysimeter.

APPENDIX I

ANALYSIS OF VARIANCE PROCEDURE FOR POSTTREATMENT DAY 1 DIP CONCENTRATIONS IN BAXTER COLUMN PERCOLATES

Appendix I. Analysis of variance procedure for postreatment day 1 DIP concentrations in Baxter soil column percolates.

Dependent Variable: CONC

Source	DF	Sum of Sq.s	Mean Sq.s	F Value	Pr > F
Model	2	16.0	8.0	16.0	0.0251
Error	3	1.5	0.5		
Corrected Total	5	17.5			

APPENDIX J

ANALYSIS OF VARIANCE PROCEDURE FOR POSTTREATMENT DAY 1 DIP AMOUNTS IN BAXTER SOIL COLUMN PERCOLATES

Appendix J. Analysis of variance procedure for postreatment day 1 DIP amounts in Baxter soil column percolates.

Dependent Variable: UG

Source	DF	Sum of Sq.s	Mean Sq.s	F Value	Pr > F
Model	2	16.0	8.0	16.0	0.0251
Error	3	1.5	0.5		
Corrected Value	5	17.5			

APPENDIX K

ANALYSIS OF VARIANCE TEST FOR RATE OF INCREASE IN DAILY MEAN NO_3-N PERCOLATE CONCENTRATIONS OF THE VARIOUS SURFACE-APPLIED-LITTER BAXTER SOIL COLUMNS OVER FIRST FOUR SAMPLING DAYS

Appendix K. Analysis of variance test for daily mean NO_3-N percolate concentrations of the various surface-applied-litter baxter soil columns over first four sampling days.

```
          R-Square             C.V.          Root MSE             CONC Mean

          0.265773         91.18058         10.569349           11.59166667

Source          DF       Type I SS        Mean Square        F Value     Pr > F

TRT*DAY          1    599.44641026       599.44641026           5.37     0.0313

Source          DF     Type III SS        Mean Square        F Value     Pr > F
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VITA

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Master of Science

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