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EVALUATION OF ORGANIC RESIDUE AMENDMENTS FOR THEIR EFFECT ON VEGETABLE PRODUCTION AND SOIL CHEMICAL PROPERTIES

By

Deliana Siregar

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ABSTRACT

THE EVALUATION OF ORGANIC RESIDUE AMENDMENTS FOR VEGETABLE PRODUCTION AND SOME SOIL CHEMICAL PROPERTIES

By

Deliana Siregar

Four sets of experiments, 1) preliminary greenhouse study, 2) laboratory study, 3) greenhouse study, and 4) field study, were conducted to evaluate the effects of organic residue amendment on vegetable production and soil chemical properties. Preliminary study determined the potential adverse effects from high poultry manure amendment rates and time after application on seed germination and growth of vegetable plants in two different soils. Planting immediately after application of >56 Mg ha^{-1} poultry manure caused injury to seed germination and growth. Injury was more serious in a McBride sandy loam (CEC= 4 cmol kg^{-1}) than in a Capac loam (CEC=8 cmol kg^{-1}). Delaying planting time 10 days after poultry manure application decreased injury to germination and plant growth. Applying poultry manure up to 56 Mg ha^{-1} increased the growth of carrots, snap bean and cabbage grown in both soils. Laboratory study determined the effect of poultry manure on NH_3 production, soil pH, soluble salts concentration , and the source of seedling injury. Soil pH, soil salinity and ammonia production in both soils increased with poultry manure rate. Change in soil pH, soil salinity and ammonia release was greater in McBride sandy loam than in Capac loam. Data from this study suggests that germination and seedling injury of the crops grown in McBride

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sandy loam was caused by a combination of ammonia toxicity and high salinity. In Capac loam the injury was caused by high salinity. Field studies determined the effects of poultry manure, leaf compost and method of application on the soil chemical properties and crop production. Incorporation of the organic materials increased nutrient availability and uptake by the plant compared to surface banding. Initially, soil receiving incorporated organic matter was more loose and drier than soil receiving banded materials. This condition reduced seed germination and significantly decreased crop yields per plot. Increasing poultry manure rate significantly increased soil pH, CEC, soil salinity, macro and micronutrient availability and uptake by the plants, but significantly reduced total number of carrot and snap bean plants per plot and had no effect on crop yields per plot. Combining leaf compost with poultry manure had no effect on germinating seed. Increasing leaf compost rates increased only CEC, Ca, Mg and Mn in the soil, and had no effect on crop growth and yields. Greenhouse study determined the effect of leaf compost and poultry manure on N, P and K availability in two different soils, and on the growth and N, P, K uptake by cabbage. The amount of N, P and K released from poultry manure increased with time and slowed down after 7 weeks. The N and P were released more slowly from poultry manure than from inorganic fertilizer, but K was released equally from two sources. There were no significant differences in N, P and K uptake (except P uptake in a low P soil) and total biomass production between the poultry manure and commercial fertilizer treatments. Leaf compost slowed the availability of N, P and K in soil solution, but increased plant nutrient uptake and growth. The effect on plant growth was only significant in the low P soil.

To my Late Father, Mother, Handoko, Rininta, and Rieza

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CHAPTER I

EVALUATION OF ORGANIC RESIDUE AMENDMENTS FOR THEIR EFFECT ON VEGETABLE PRODUCTION AND SOIL CHEMICAL PROPERTIES

1. INTRODUCTION

Using manures and composts to maintain and increase soil fertility has been a long standing practice. These organic residues (organic fertilizers) play a major role in chemical, physical and microbiological aspects of soil fertility. However, since the introduction of synthetic fertilizers (inorganic fertilizers), which are cheaper, easily handled and distributed, and can supply any nutrient element, the organic fertilizers have been somewhat neglected (Chen and Avnimelech, 1986). The use of inorganic fertilizers offsets the use of organic fertilizers as a sole source for nutrients and, in some cases, eliminates the use of manures to the point where these materials are accumulating and not being used (Avnimelech, 1986). In many places, organic residues are more of problem than an asset (Chen and Avnimelech, 1986; Havenstein, 1988), and the disposal of this waste is a major problem.

With the current emphasis on pollution control, the problem of manure disposal has provoked some thought and action on changing the emphasis to utilization (Abbott and Lingle, 1968; Olsen et al., 1970). For a century, the classical experiments at Rothamsted Experiment Station in England showed no difference in crop yields through farmyard manure or inorganic fertilizer use. Later, a long-term test on varieties with a high yield potential showed that farmyard and other organic manures can give higher yields than can be obtained with inorganic fertilizers only (Johnston and Mattingly, 1976). Research on residue disposal has provided new concepts related to the interaction between organic matter and soil, as well as ne

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as new handling technology for organic residues (Chen and Avnimelech, 1986; Simpson, 1986). Therefore, more farmers and scientists are showing renewed interest in the proper and effective use of organic residues, compost and other recycled organic additives. The role and function of organic amendments in modern agriculture have become topics of major interest in the scientific and agriculture communities (Havenstein, 1988; Naber, 1988; Olsen, 1986; Sweeten, 1988). The trend to use organic residues has led scientists to find ways of replacing conventional inorganic fertilizers with natural organic fertilizers. Additionally, more people in highly developed countries are willing to pay higher prices for food produced on soils where inorganic fertilizers and other agricultural chemicals have not been used (Chen and Avnimelech, 1986). Thus, the current interest in organic farming, where the use of synthetic chemicals is avoided or prohibited, leads the people to solve the disposal problem. Manure application, however, should be done carefully, because excessive application of manure may cause surface and groundwater pollution (Vitosh et al., 1986).

In terms of natural organic fertilizers, more research is needed to investigate soil-plant factors associated with high yields. This consideration leads to reviewing the literature that focuses on research related to the use of organic manures and compost as fertilizers.

Objectives

1) To quantify the effect of composted tree leaves and dried poultry manure on crop growth, yield, and soil chemical properties.
2) To evaluate the interactive effect of two organic amendments on crop growth, yields, and soil chemical properties.

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3) To determine the dynamics of N, P, and K concentration and availability, and their movement in the soil at different times after application of organic amendments.

Hypotheses

1) Leaf compost and dried poultry manure increase N, P, and K availability in the soil.
2) N, P and K are released more slowly from dried poultry manure and leaf compost than from commercial fertilizer.
3) Available N, P and K from leaf compost and poultry manure increase with time after application.
4) Leaf compost and dried poultry manure increase N, P and K content in plant tissue, as well as increase crop growth and yield.

2. LITERATURE REVIEW

2.1. Manures and Inorganic Fertilizers

The term 'manure' used in this paper refers to bulky organic materials, mainly plant residues and animal excreta, which are returned to the soil either directly or after some sort of processing (Simpson, 1986).

A major difference between organic and inorganic sources of nutrients is the rate of nutrient release. Most inorganic fertilizers are soluble with the nutrient elements being released upon application to the soil (Avnimelech, 1986; Simpson, 1986). This instantaneous release is often disadvantageous because a large portion of the applied P is fixed by the soil (Avnimelech, 1986) and ammonia is volatilized from surface-applied fertilizers (Freney and Simpson, 1983; Vitosh et al., 1986). Additionally, inorganic ammonium applied with fertil

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fertilizers is nitrified in the soil within a few weeks (Black, 1986), and a large accumulation of nitrate may occur in the soil profile. Nitrate is subject to leaching below the root zone and/or being lost through denitrification (Avnimelech, 1986).

In organic materials like manures, nutrients are slowly released through the microbially induced mineralization process (Chen and Avnimelech, 1986; Simpson, 1986). The release rates are controlled by the properties of organic material, microbial activity, and by soil environment. Mineralization is most rapid in moist soil with a moderate to high pH (5.5-7.5) immediately after incorporation of green manure or partially rotted farmyard manure (Simpson, 1986). A labile (fresh) organic material will decompose faster than a stabilized (composted) organic material (Avnimelech, 1986; Simpson, 1986). Fast decomposition leads to a high rate of nutrient release only when the organic substrate is rich in nutrients and has low C:N and C:P ratios (Avnimelech, 1986; Simpson, 1986). Nitrogen, P and S are released rapidly from easily decomposable organic matter (Simpson, 1986). Large accumulation of nitrate occurred in the soil profile after heavy manure applications (Vitosh et al., 1986). Yet, this does not necessarily mean that nutrient availability is better. The decomposition process often leads to an effective binding of nutrients by the developing and growing biomass (Avnimelech, 1986).

Different types of manures and different composting techniques, as well as different timing, levels and methods of application, affect the rate of nutrient release (Avnimelech, 1986; Simpson, 1986). Han and Wolf (1990) indicated that the lowest net N mineralization and net nitrification were in surface-amended soil held at 20 °C, whereas the highest ones were in the incorporated treatment incubated at 35 °C. A stabilized organic material will supp

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support a slow rate of nutrient supply while the addition of fresh organic material, rich in nutrients, will lead to a rapid supply of nutrients (Avnimelech, 1986). Much slower mineralization of more resistant organic matter reserves varies from season to season. Mineralization is greatest in a warm, moist summer, but the amount of nutrients to be released is very difficult to predict (Simpson, 1986).

Olsen (1986) has reviewed research works indicating that a stable supply of ammonium is essential for achievement of high yields. Manures are suggested in that work to be a stable source of ammonium. Abbott and Tucker (1973) concluded that the stable nature of manure, stimulation of microbial activity and association of P with organic components of the soil may account for the resistance of manure P to processes removing P from available forms. Therefore, the time and the rate at which the soil can supply available nutrients may become limiting factors to crop growth. This is why timing, rate and method of application of organic materials become important to ensure maximum nutrient availability at the time of maximum crop requirement.

2.2. Manures and Soil Organic Matter

By their nature, manures have two functions. First, they supply some organic matter to the soil, much of which is lost to the atmosphere after conversion to carbon dioxide. Some of the organic matter is changed to humus - black or dark brown organic substances, colloidal, and very complex organic compounds which persist in the soil and improves soil chemical and physical properties. Second, they supply a wide spectrum of nutrients derived from the decomposing organic residues (Brady, 1986; Simpson, 1986).

The organic matter in the soil can be characterized by its chemical composition and

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the amounts of various reactive groups. Organic matter can be divided into humic substances and non-humic substances (Barber, 1984). The non-humic substances are attacked readily by microorganisms and disappear rapidly. They consist of carbohydrates, proteins, amino acids, fats, waxes, alkanes, and low-molecular-weight organic acids (Schnitzer, 1978). The humic substances are the majority of organic matter and decompose slowly. They are chemically complex organic compounds with molecular-weight from a few hundred to several thousand (Barber, 1984).

The main functional groups in humic substances are carboxyl, carbonyls, alcoholic hydroxyl, and phenolic hydroxyl. The carboxyl and some of the phenolic hydroxyl groups provide cation exchange sites. The cation-exchange capacity, resulting from these sites, is strongly pH-dependent (Barber, 1984; Brady, 1986). Well decomposed humus has the highest cation-exchange capacity, two to three times more than montmorillonite (Simpson, 1986). Barber (1984) recorded the cation-exchange capacity of humus at pH 7.0 as ranging from 100 to 400 cmol(p^+)/kg with values of 150 cmol(p^+)/kg being common.

Through its higher ability to hold water and very high cation exchange capacity, humus helps reduce the leaching of nutrients (Simpson, 1986; Brady, 1986). In high-humus clays leaching is low, provided the soil is not allowed to become strongly acid. In soils with a very low cation exchange capacity, indigenous cations and cations from water-soluble fertilizer (NH_4^+, K^+) or water-soluble fractions of manure are easily leached (Simpson, 1986).

In addition to adsorption of cations in readily exchangeable forms, organic matter can also adsorb multivalent cations in a coordination complex. Cations in these complexes are not readily exchangeable with monovalent cations and do not dissociate readily in the soil.

Cations such as Mn, Zn, and Fe can be adsorbed in these complexes (Barber, 1984). Walker and Barber (1960) measured both complexed and exchangeable Mn on 12 Indiana soils and found almost as much Mn (12 mg kg^{-1} average) complexed as held in an exchangeable form (18 mg kg^{-1} average). Soluble organic compounds increase the cation concentration in solution (Barber, 1984). Hodgson et al. (1966) observed 20 Colorado soils with pH levels of 6.9 to 7.9 and found that about 75% of Zn and 98 to 99% of Cu in the soil solution were present as complexed soluble organic compounds.

Basically, organic matter in the soil is derived from plant residues, manures and dead or alive soil animals, including a vast population of microorganisms. Nutrients contained in soil organic matter are also available in varying degrees for plant uptake. Substantial amounts of nutrients contained in organic matter are in complex forms unavailable to the plant. Nitrogen, P and S are contained in persistent organic materials. Other organic matter, particularly from recent crop residues or manures, can be decomposed quickly by bacteria and thus mineralized. The carbon is released to the atmosphere as CO_2 and the nutrient elements become available to the plant as ammonium, nitrate, phosphate, sulphate and other ions (Simpson, 1986).

All manures make some contribution to long-term soil fertility and maintenance of humus in the soil. Young et al. (1960) conducted a long-term experiment using manure, crop residue, lime and fertilizer on a Fargo clay. As much as 15.7 to 22.4 Mg ha^{-1} of manure or all crop residues were applied as the treatments. Soil organic C and N declined 27% in check plots, but only declined 20% in manure or crop residue plots. Bishop et al. (1962) showed that applying 67.3 Mg ha^{-1} manure every 3 years over 21 years maintained initial levels of total N and soil organic matter, whereas both N and soil organic matter decreased significantly with lower rates of manure application. Cope et al. (1958) reported changes in soil N and C content after 30 years of manure applications. Annual application of 11.2 Mg ha^{-1} horse manure to soil for an 18-year period increased soil N content 62% and soil C content 33%, and decreased the C/N ratio from 21 to 17. Halstead and Sowden (1968) found similar results after 20 years of applying manure at 11.1 Mg ha^{-1} yr^{-1}. Total soil C and N content, and nitrification capacity of the soil were increased. Kubota et al. (1947), and Binford et al. (1993) also indicated annual manure application over 30 years was effective in maintaining N and organic matter in soil, and increased the nitrification capacity. In a 40 year study Young et al. (1960) indicated no treatment effect on C/N ratio. In a greenhouse study they showed manured plots were capable of releasing more available N than crop residue plots of the same total N content. With respect to oxidizable material and N content, Muhr et al. (1943) found that manure application increased both significantly.

Very large amounts of manure need to be applied to have a significant long-term effect on the organic matter content of the soil. The main reasons for this are the very high water content of many manures and the loss of much of the organic matter during decomposition in the soil. Simpson (1986) reported that bulky straw-based farmyard manures contain about 75% water and slurries contain 90% water. Hence, 1 Mg of each material will only add 250 or 100 kg organic matter to the soil, respectively, which is reduced to 60 kg after humification is complete. Thus, any attempt to increase soil organic matter simply by applying farmyard manure requires regular annual applications of 40 Mg ha^{-1} or more. Typically, in order to simply maintain the humus content of a sandy loam soil, annual applications of 15 to 25 Mg ha^{-1} c

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2.3. Manures and Macro-Nutrient Availability

Manures contain the full range of nutrients needed by the plant, but not necessarily in desirable proportion. The nutrient composition of manure varies greatly depending on the kind of livestock, feed ration, manure handling system and whether it has been diluted by water or bedding (Vitosh et al., 1986). The concentration of nutrients in manures is low compared with inorganic fertilizers, and not all nutrients contained in manures are immediately available to the crop. Appreciable amounts of the total nutrient content of manures occur in complex organic forms which have to be mineralized to release available nutrients. Manures, however, supply useful amounts of N, P, K, Ca, Mg, and S (Simpson, 1986). Simpson (1986) recorded the approximate amount of nutrients contained in 1 Mg dried poultry manure as 40 kg N, 30 kg P_2O_5 and 25 kg K_2O. Only 25 kg N, 15 kg P_2O_5, and 17 kg K_2O are available during the first year after application. The remaining N, P, and K become available for succeeding crops, although predicting precisely when or in what quantities this will occur is impossible.

Nitrogen is the nutrient of greatest concern because appreciable losses by NH_3 volatilization can occur within 24 hours after application. Approximately 20 to 30 percent of the N content of the farmyard manure and a greater proportion of P and particularly K are available for the first crop. The rest, 70 to 80 percent of N in farmyard manure and 50 to 70 percent of slurry N are in forms which become available more slowly. This part of the nutrient content will not be available for the first crop after application, but will increase the reserve of nutrients in the soil (Simpson, 1986).

Phosphorus availability can be increased by adding organic residues via several mechanisms. First, the slow release of inorganic P during the decomposition of the organic matter provides a continuous supply of P to the soil. Second, the presence of organic matter in the soil effectively decreases the P fixation by the polyvalent cations (Ca, Fe, Al) in the soil, through acidification and chelation processes. In these processes, the added organic matter and its decomposition products will reduce the activity of the polyvalent cations that form insoluble salts with P (Black, 1968). As a result, more soluble P will be available in the soil.

Manure effects on available P levels in soils appear dramatic and long lasting. Application of manure over a period of 117 years, at Rothamsted Experiment Station in England, showed a great increase of soluble P. Researchers also observed that inorganic superphosphate fertilizer was much less effective than manure in raising soluble P levels, when both were applied at approximately equivalent P levels (Olsen and Barber, 1977). Meek et al. (1979), reported that application of 392 kg P ha^{-1} as triple super phosphate (0-46-0) to a calcareous soil in each of two years increased $NaHCO_3$-extractable P by 11 ppm, whereas 334 kg P ha^{-1} from applied manure resulted in an increase of 100 ppm in bicarbonate-soluble P. The same result was observed by Abbott and Tucker (1973). Applying 22 Mg ha^{-1} (67 kg P ha^{-1}) manure at 2 or 3-year intervals appeared to assure adequate P availability while P availability from P fertilizer (37 kg P ha^{-1}) was negligible over the same period. In contrast, Young et al. (1960) indicated that extractable P remained low in manured plots, but increased in fertilizer P treated plots.

There have been many long-term studies using manure. In a thirty-year experiment, Brage et al. (1952), conducted research using barnyard manure applied every four years at

0, 11.2, 22.4, and 44.8 Mg ha^{-1}. They reported that the better yields of oats, barley, potatoes, rutabagas, and sunflower were obtained from the heavier manure application. The most profitable yield increases usually occur in crops such as potatoes, sugar beet, turnips and vegetables (Simpson, 1986; Wilson and Eltzroth, 1984; Percival, 1984; Bishop et al., 1962; Nonnecke, 1989). Many field experiments have been done on yield responses to farmyard manure applied at rates of 25 to 30 Mg ha^{-1}. Increases in sugar beet yield varied from 0.8 to 4 Mg ha^{-1}. Potatoes are even more responsive; yield increases from 7 to 13 Mg ha^{-1} have been found from farmyard manure application (Simpson, 1986). Pittman (1930) showed a high correlation between sugar beet yields and soluble P and NO_3-N derived from barnyard manure. Abbott and Tucker (1973) also indicated significant correlations between cotton yields and soil P measurements. Cope et al (1958) indicated that 30 years of annual manure application at 11.2 Mg ha^{-1} increased yields of corn and cotton for at least 8 years after the last application.

Halstead and Sowden (1968) summarized the results of a 20 year experiment on the application of different sources of organic matter to both sand and clay soils. They found that manure increased N and P uptake by the oats, and had the greatest effect on yield. Similarly, Correll et al. (1991) found the addition of poultry litter increased the P and K concentration in the rice tissue. Herron and Erhart (1965) conducted a four-year field trial using commercial cattle feedlot manure. They reported that one metric ton of cattle feedlot manure incorporated into the soil of a sorghum field was equivalent to 11 kg N as NH_4 and NO_3 per year. Pratt et al. (1976) also conducted a four-year field trial using animal manures on irrigated soils. Manure containing 1.6 to 2.2% N appeared to mineralize at the rate of 40 to 50% during the first year, 10 to 20% in the second year, and 5% in the third year following application.

Using both dairy manure and inorganic N fertilizer on a fine sandy loam, Jokela (1992) observed that 9 Mg ha^{-1} dairy manure were equivalent, in yield response, to 73 to 122 kg ha^{-1} fertilizer N in individual years, which represented 27 to 44% of the total manure N applied in that year. Yields and N uptake were increased by N fertilizer and by manure treatment. Application of manure resulted in similar or slightly lower soil profile NO_3 than equivalent rates of fertilizer N. The increase in soil NO_3 in the 1.5 m soil profile after harvest was related to the amount of manure and fertilizer N applied. Hedlin and Ridley (1964) showed that applying 18 tons ha^{-1} manure every six years in a 42 year wheat, flax, corn, oats, barley, and rye cropping sequence significantly increased crop yields. Both P and manure application increased the amount of $NaHCO_3$-extractable P, but manure alone resulted in higher levels of $NaHCO_3$-extractable P.

Some studies have been done to see the effect of manure on K, Ca, and Mg availability in the soil. Simpson (1986) reported that the amounts of K available for the first crop after manure application was 3.0 kg K_2O ton^{-1} of cattle farmyard manure, 17 kg K_2O ton^{-1} of dried poultry manure, 10 kg K_2O ton^{-1} of deep litter poultry manure, and 12 kg K_2O ton^{-1} of broiler litter poultry manure. Kubota et al. (1947) reported increases in exchangeable K in the soil by applying 269 and 404 Mg ha^{-1} manure over 30 years. Brage et al. (1952) showed that the level of exchangeable K, Mg, Na, and Ca in soil increased after 30 years of manure application. Similarly, Bishop et al. (1962) found the level of exchangeable K increased after application of up to 67 Mg ha^{-1} of manure for 21 years.

Therefore, due to low nutrient concentrations, large quantities of manure are needed to maintain soil fertility. Simpson (1986) recorded about 25 Mg ha^{-1} manure are needed to meet plant requirements. Similarly, about 25.0 Mg ha^{-1} of compost is recommended to achieve high crop yields (Rodale et al., 1973).

2.4. Manures and Trace Element Availability

Trace element availability can be increased by adding organic residues via several mechanisms. First, the slow release of trace elements during the decomposition of the organic matter provides a continuous nutrient supply to the soil (Simpson, 1986). Second, organic matter affects trace metal availability and solubility mainly through chelation (Chen and Stevenson, 1986).

In neutral soil, the solubility of most trace elements is often too low to support optimal plant growth, e.g., Fe solubility is 10^{-18} M L^{-1} (Lindsay, 1979). Raveh and Avnimelech (1979) observed that chelating agents supplied with organic additives can significantly raise the availability level of trace metals in soil. They reported the chelated Fe concentration in sanitary leachates to be in the order of 10^{-2} M L^{-1}. Miller and Ohlrogge (1958a&b) have shown the presence of water-soluble chelating agents in manure and other organic materials. From nutrient solution experiments they concluded those chelating agents held Fe and Zn in a form that was less available to the plant than in their ionic forms. The addition of manure and water extracts of manure decreased the availability of Zn and Cu but increased Mn availability (Miller and Ohlrogge, 1958a&b). Depending on the original pH of the soil, Parker et al. (1969) reported that the application of chicken manure in acid soil slightly decreased soil acidity and eliminated Mn toxicity in soybean. In a long-time exper

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Although manures supply useful amounts of trace elements (Simpson, 1986), the rate of decomposition and nutrient release are unfortunately rarely measured in many research studies dealing with the nutritive value of manures and composts (Avnimelech, 1986). Without this information, it is difficult to compare results and form any general conclusion.

2.5. Manures and Other Soil Properties

Some soil properties such as cation exchange capacity (CEC), bulk density, pH and water holding capacity of the soil may or may not change depending on the time, kind, rates and method of manure application. Research conducted by Metzger (1939) and Bishop et al. (1962) showed that manure application increased the CEC of the soil. Other studies using both manure and lime showed that manure significantly increased soil pH but not CEC (Muhr et al., 1943; Young et al. 1960). Brage et al. (1952), Halstead and Sowden (1968) showed that manure increased both CEC and soil pH. Hileman (1971) showed that manure increased soil pH only, whereas Bishop et al. (1962) indicated that the effect was negligible. Young et al. (1960) showed that manure and crop residue had no significant effect on soil aggregate diameter, but had some value in maintaining air space porosity (Young et al., 1960).

CHAPTER 2

AMMONIA VOLATILIZATION AND CHANGES IN SOIL CHEMICAL PROPERTIES AFTER POULTRY MANURE APPLICATION (1990)

1. INTRODUCTION

With the rapid growth of the poultry industry in the U.S.A. (National Agricultural Statistics Service, 1994), information is needed on the impact of land applying the associated litter on the nation's soil and water resources. Soluble salts and N have been major concerns of researchers investigating possible detrimental effects associated with animal manure application (Adriano et al., 1971, 1973; Shortall and Liebhardt, 1975; Jackson et al., 1977; Giddens and Rao, 1975; Weil et al., 1979; Wetterauer and Killorn, 1993).

Animal manure which produces NH_3 upon decay has been associated with inhibition of seed germination. Megie et al. (1967) observed that NH_3 above 10 ppm was phytotoxic to cotton. Ells et al. (1991) found that an ammonium hydroxide alfalfa hay extract, and chopped alfalfa produced free NH_3 upon decay and inhibited both cucumber germination and seedling growth. The rate of NH_3 loss from turkey manure was found to be highest immediately after application and gradually decreased with time (Nathan and Malzer, 1992). High NH_3 concentrations are toxic to plants (Vines and Wedding, 1960; Adriano et al., 1973; Weil et al., 1979; Ells et al., 1991) and *Nitrobacter* (Smith, 1964; Brady, 1986). As a result oxidation of nitrite to nitrate by *Nitrobacter* is inhibited to the extent that nitrite accumulates in sufficient quantity to adversely affect plant growth (Smith, 1964; Brady, 1986). The natural buffering capacity of the soil apparently mitigates the effect of NH_3. As the CEC of the soil increases, the toxicity effect on plant growth decreases (Ells et al., 1991).

The concentration of free NH_3 in the soil is influenced by soil pH (Cox and Seeley, 1984; Warren, 1962; Brady, 1986) and cation exchange capacity (Smith, 1964). At soil pH's above 7.0, NH_4OH in soil solution will dissociate to form NH_3. Hence, high NH_3 concentrations may be produced (Smith, 1964; Brady, 1986). Addition of material which produces free NH_3 in a sand with a low CEC increases the pH, while a greater CEC in soil may keep the pH relatively stable (Smith, 1964; Ells et al., 1991). The mechanism for increasing soil pH involves fewer exchange sites for NH_4^+ to be held in lower CEC soils and a resulting increase of NH_4^+ in soil solution to form NH_4OH and eventually increase soil pH (Smith, 1964).

A long-term land application of broiler litter increased soil pH by 0.5 unit at the depth 0 to 60 cm (Kingery et al., 1994). Application of 144 Mg ha^{-1} broiler litter increased the pH of an unlimed Wynnville sandy loam from 5.2 to 7.6. However, at 9 Mg ha^{-1} the limed soil pH decreased from 6.8 to 5.5 after 28 days of incubation (Lu et al., 1992). Hue (1992) demonstrated that chicken manure was effective in raising the pH of acid Hawaiian soils. Application of 20 Mg ha^{-1} chicken manure increased soil pH from 4.19 to 6.24 and then the pH decreased to 5.16 at harvest time. Jackson et al. (1975) showed that at the rate of 22.4 Mg ha^{-1}, soil pH of the 0 to 7.62 cm depth increased from 5.3 to 5.6 in the first year of application and decreased to 5.4 in the second year.

All soils contain some water soluble salts which include essential nutrients for plant growth. When the level of the water soluble salts exceeds a certain level, harmful effects on plant growth occur (Dahnke and Whitney, 1988). This may result from high rates of manure or sludge application. In a long term experiment Kingery et al. (1994) found that the average

EC (saturated paste) in soil profiles from 0 to 60 cm depth was 0.08 dSm^{-1} in soils treated with 6 to 22 Mg ha^{-1} yr^{-1} boiler litter application. Hue (1992) observed that application of 20 Mg ha^{-1} chicken manure increased soil salinity from 0.6 to 1.2 dSm^{-1}. These values are well below the threshold value of 4 dSm^{-1} found to be detrimental for many crops (U.S. Salinity Lab. Staff, 1954). Weil et al. (1979) observed that soil receiving poultry manure at the rate of >85 Mg ha^{-1} had a residual level of salt in excess of 4 dSm^{-1}, a concentration considered to be detrimental to corn germination and growth (Ayers and Hayward, 1948; Shortall and Liebhardt, 1975; Weil, et al. 1979). Wetterauer and Killorn (1993) observed that soil salinity increased after manure application but returned to initial levels before the next growing season.

The influence that a certain level of soluble salts will have on crop growth depends upon several factors that include climatic conditions, soil texture, salt distribution in the profile, salt composition and plant species. Soil, water, and environmental factors interact to influence the salt tolerance of a plant (Maas, 1986). High application rates of poultry manure (>56 Mg ha^{-1}) in field plots have reduced germination (Shortall and Liebhardt, 1975) and adversely affected growth and yield of corn due to excessive salinity (Ayers and Hayward, 1948; Ayers, 1952; Shortall and Liebhardt, 1975). Salinity affects plants at all stages of development, but sensitivity sometimes varies from one growth stage to the next. Soil salinity levels (saturated extract) reduce yields by 50% for snap beans, onion and cabbages are 4, 4, and 7 dSm^{-1}, respectively. The salt tolerance threshold values where yields start to decrease for carrots, snap beans, onions and cabbages are 1, 1, 1, and 2 dSm^{-1}, respectively (Maas, 1986).

Objectives

To further study the potential adverse effects from high poultry manure rates on seed germination and plant growth, a preliminary experiment was established in a greenhouse to address the following points:

1) Poultry manure rate at which germination is adversely affected.
2) Duration of adverse effects on germination and plant growth.
3) Role of soil texture on adverse effects of poultry manure.

Results of this preliminary experiment indicated that high rates of poultry manure can adversely affect seed germination and plant growth. However, the cause of the injury was not clear. Soil salinity, soil pH and NH_3 toxicity have been major concerns associated with the application of poultry manure for crop production. A laboratory experiment was designed to address the following points:

1) To determine the effects of poultry manure on soil pH, soluble salt concentrations and NH_3 production.
2) To determine whether the seedling injury in the preliminary study was due to NH_3 toxicity, high salinity and/or changing pH.

2. MATERIALS AND METHODS

2.1. Preliminary Greenhouse Study

Two soils, McBride sandy loam (coarse-loamy, mixed, Eutric Glossoboralf) and Capac loam (fine-loamy, mixed, mesic Udolic Ochraqualf), were used in this experiment. They were air dried and passed through a 2 mm sieve and analyzed for texture, pH (1:1

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soil:water ratio, Eckert, 1988) and salinity (1:1 soil:water ratio, Dahnke and Whitney, 1988). Total N concentration of poultry manure was determined by a Kjeldahl procedure (Bremner and Mulvaney, 1982), and NO_3-N and NH_4-N were extracted with 1M KCl (Keeney and Nelson, 1982). CEC was determined by saturation with NH_4^+ and displacement with Na (Warncke, 1994). Field capacity was determined by placing 2 kg of soil in three pots (a 1.6 L pot), saturating with water and then allowing drainage for 48 hours. Three soil cores of 12 cm depth were taken from each pot and oven dried at 105 °C for 24 hours. Moisture content was determined as the ratio of water: soil dry weight. The test results for the soils and the dried poultry manure are shown in Table 2.1. The rates of poultry manure and N to be applied are given in Table 2.2. The rates of poultry manure incorporated into the McBride sandy loam soil were 0, 20, 40, 60 g kg^{-1} soil (0, 56, 112 and 168 Mg ha^{-1}). The rates applied in the Capac loam soil were 0, 10.8, 21.6 and 32.4 g kg^{-1} soil (0, 30, 60 and 90 Mg ha^{-1}). The rates used in the Capac soil were reduced because of the injury observed at the higher rates in the McBride soil. No inorganic fertilizer was added to either soil.

Cabbage, carrot and snap beans were grown for 90, 90 and 60 days, respectively. Five seeds were grown in each 2 liter pot (1.6 kg soil) in 5 replications. Thinning to 1 plant was conducted after 2 weeks. Plant dry weight was measured at harvest time.

Table 2.1. Some properties of soils and poultry manure used in the greenhouse and laboratory experiments.

Chemical properties	McBride sandy loam	Capac loam	Poultry manure
Moist (%)	4.8	6.5	21.4
Field capacity (%)	19.2	20.0	-
pH	5.1	5.5	7.0
CEC cmol kg^{-1}	4.0	8.0	-
Total N (%)	-	-	4.0
Bulk Density	1.4	1.4	-
Organic matter (%)	1.2	1.5	-

Table 2.2. The total amount of poultry manure and N applied to soils for greenhouse and laboratory experiments.

Poultry manure applied		Total N applied
---- g kg^{-1} soil ----		--- g kg^{-1} soil ---
	McBride sandy loam	
0		0
20.0		0.80
40.0		1.60
60.0		2.40
	Capac loam	
0		0
10.8		0.43
21.6		0.86
32.4		1.29

2.2. Laboratory Study

The same two soils used in the preliminary study, a McBride sandy loam and a Capac Loam, were used in this experiment. One hundred grams of soil were placed in a 250 ml Erlenmeyer flask. Poultry manure was mixed thoroughly with the soil at the rate of 0, 2, 4 and 6 g per 100 g of soil (0, 56, 112 and 168 Mg ha^{-1}) for McBride sandy loam and at the rate of 0, 1.08, 2.16 and 3.24 g per 100 g of soil (0, 30, 60, and 90 Mg ha^{-1}) for Capac loam, and incubated at room temperature (20 °C) for 18 days.

To determine the amount of NH_3 volatilized, air was passed through each flask and then through boric acid containing methyl purple indicator to collect the NH_3. The inflowing air was cleaned from dust and other pollutants by passing it through 0.1N NaOH, 0.01N H_2SO_4 and water (Figure 2.1). The clean moist air flowed into a 5 cm PVC pipe (manifold) and from this pipe an air outlet was connected to each 250 ml Erlenmeyer flask containing 100 g soil. Using 0.5 cm (od) tygon tubing and glass tubing, air was directed through the Erlenmeyer flask containing soil and through 40 ml of 5% boric acid solution to trap NH_3 gas (Figure 2.2). The amount of NH_3 was determined by back titration with standardized H_2SO_4 (Bremner and Mulvaney, 1982). Moisture content of the soils was checked daily by weighing the Erlenmeyer flasks and adding water to maintain the soil moisture near field capacity. Soil salinity and pH were determined at the end of the study (after 18 days incubation) according to the procedures previously indicated.

Figure 2.1. The inflowing air was cleaned by passing it through 0.1N NaOH and 0.01N H_2SO_4.

Figure 2.2. The clean air was directed through the Erlenmeyer flask containing soil and through 40 ml of 5% boric acid solution to trap NH_3.

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3. RESULTS AND DISCUSSIONS

3.1. Preliminary Greenhouse Study

3.1.1. Seed Germination and Emergence

The effect of poultry manure on seed germination and emergence, seeded right after and 10 days after manure application is shown in Tables 2.3 and 2.4. Increasing poultry manure rates increased the time before seedling emergence and decreased the percent of seed germination (Table 2.3). Failure in germination and emergence may have been due to NH_3 toxicity released from the poultry manure and/or high soil salinity.

Table 2.3. Carrot, snap bean and cabbage seed germination in McBride sandy loam and Capac loam soil planted immediately after poultry manure addition.

Poultry manure applied	Seed Germination			Time before emergence		
	Carrot	S.beans	Cabbage	Carrot	S.beans	Cabbage
($g\ kg^{-1}$ soil)	(%)			(days)		
	McBride sandy loam					
0	100a*	100a	100a	4c	4b	3a
20.0	100a	100a	24b	6b	5b	3a
40.0	72b	48b	0c	8a	9a	**
60.0	24c	0c	0c	8a	**	**
	Capac loam					
0	100a	100a	100a	4c	4b	3b
10.8	100a	100a	100a	6b	5b	3b
21.6	100a	100a	72b	6b	5b	3b
32.4	88b	72b	48c	8a	8a	6a

* Mean separation by $LSD_{0.05}$. Numbers within a column followed by different letters are significantly different at $p<0.05$.

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Waiting 10 days after manure application before seeding significantly improved germination and seedling emergence in both soils, although at the higher poultry manure rates seedling emergence was still delayed (Table 2.4).

Table 2.4. Carrot, snap bean and cabbage seed germination in McBride sandy loam and Capac loam soil planted 10 days after poultry manure addition.

Poultry manure applied	Seed germination			Time before emergence		
	Carrot	S.beans	Cabbage	Carrot	S.beans	Cabbage
(g kg^{-1} soil)	---------------- (%) ----------------			------------- (days) -------------		
			McBride sandy loam			
0	100a*	100a	100a	4c	4c	3c
20.0	100a	100a	100a	7b	5b	5b
40.0	100a	100a	100a	7b	6a	5b
60.0	100a	80b	100a	8a	6a	6a
			Capac loam			
0	100a	100a	100a	7b	5b	5b
10.8	100a	100a	100a	7b	5b	5b
21.6	100a	100a	100a	7b	6a	5b
32.4	100a	80b	100a	8a	6a	6a

* Mean separation by $LSD_{0.05}$. Numbers within a column followed by different letters are significantly different at $p<0.05$.

3.1.2. Plant Dry Weight

The effect of poultry manure on plant dry weight is shown in Table 2.5. In McBride sandy loam, poultry manure applied at 20 and 40 g kg^{-1} soil increased significantly cabbage dry weight compared to the control. But, dry weight of cabbage at 40 g kg^{-1} soil was significantly less than that at 20 g kg^{-1} soil. At 60 g kg^{-1} soil, cabbage growth was reduced significant

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significantly compare to other poultry manure treated plants, and some bean plants died before harvest. There was no significant effect of poultry manure on carrot dry weight.

In Capac loam, poultry manure applied at 10.8 to 21.6 g kg^{-1} soil significantly increased growth and yield of carrot, snap bean and cabbage compared to control. However, their dry weight at 21.6 g kg^{-1} were not significantly different from those at 10.8 g kg^{-1} (Table 2.5).

Table 2.5. Plant dry weight of carrot, snap bean and cabbage grown 90, 60 and 90 days in McBride sandy loam and Capac loam planted 10 days after poultry manure addition.

Poultry manure applied	Dry weight		
	Carrot	S.beans	Cabbage
(g kg^{-1} soil)	---------------------------- (g) --------------------------		
		McBride sandy loam	
0	1.87**ab***	1.51**b**	3.51**c**
20.0	2.41**a**	2.52**a**	6.47**a**
40.0	1.98**ab**	1.50**b**	4.80**b**
60.0	1.65**b**	**	3.41**c**
		Capac loam	
0	1.78**b**	1.10**b**	3.45**c**
10.8	3.08**a**	2.41**a**	9.95**a**
21.6	3.62**a**	2.63**a**	8.70**ab**
32.4	3.31**a**	1.13**b**	7.76**b**

* Mean separation by $LSD_{0.05}$. Numbers within a column followed by different letters are significantly different at $p<0.05$.

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3.2. Laboratory Study

3.2.1. Soil pH

Table 2.6 presents soil pH values at the end of the volatilization study after the soil was air dried. Increasing manure rates increased soil pH in both soils. The increase was greatest in McBride soil. Hue (1992) observed chicken manure increased soil pH and inactivated Al. The production of OH^- associated with manure addition can be explained by the following process. Ligand exchange reaction might occur between organic anions (i.e., tartrate) and terminal hydroxyls of Fe and Al in the soil in return for release of OH^- into soil solution. Since increasing chicken manure rate increases the concentration of inactivated Al and Fe, as a result increasing chicken manure increases soil pH.

The soil pH during the first 18 days of incubation could be higher than the data show in Table 2.6. Increasing soil pH immediately after poultry manure application can be explained by the following processes. First, reduction of Mn and Fe oxide (mostly goethite) might occur under a localized, electron-rich environment created by rapid decomposition of manure to produce OH^- (Hue, 1992):

$$FeO(OH) + e^- + H_2O \text{ <----> } Fe^{2+} + 3\ OH^-$$

Second, a large quantity of NH_3 might be released soon after manure application. When the NH_3 reacts with the moist soil, the NH_4OH formed is in an equilibrium with NH_4^+ and OH^- in soil solution. Increasing OH^- concentration in the soil solution, increased soil pH (Smith, 1964).

After nitrification, the soil pH decreases because of H^+ released during the nitrification process (Brady, 1986). Hue (1992) observed that application of 40 Mg ha^{-1} chicken manure

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Table 2.6. Soil pH after poultry manure application and incubation (18 days).

Poultry manure applied	Soil pH (Soil : water 1:1)
(g kg $^{-1}$ soil)	McBride sandy loam
0	5.0d*
20.0	6.4c
40.0	6.9b
60.0	7.4a
	Capac loam
0	4.9d
10.8	5.7c
21.6	6.1b
32.4	6.5a

* Mean separation by $LSD_{0.05}$. Numbers within a column followed by different letters are significantly different at $p<0.05$.

increased soil pH from 4.19 to 7.30 at planting time, and then the pH decreased to 6.17 by harvest time. Adriano et al. (1973) found that soil pH rose sharply from 7.5 to 8.4 soon after addition of 112 to 224 Mg ha^{-1} fresh manure and then dropped back close to the initial value within a few weeks.

Soil pH was higher in the McBride sandy loam than in Capac loam when 20 g kg^{-1} and 21.6 g kg^{-1} poultry manure were applied, respectively. The greater change in pH in the McBride soil with comparable amounts of poultry manure applied was related to the lower CEC of this soil. It was found that a lower CEC in sandy soil permits the pH to increase more quickly, while a higher CEC in finer textured soil may keep the pH relatively stable (Smith, 1964; Brady, 1986; Ells et al., 1991).

3.2.2. Ammonia Volatilization

Figures 2.3 and 2.4 show the amount of NH_3-N loss from the McBride sandy loam and Capac loam soils, respectively, during the first 18 days after poultry manure application. Ammonia volatilization was highly rate dependent and was much higher in the McBride soil. At the beginning free NH_3-N loss was high but decreased with time. After 10 days the rate of NH_3-N loss was less than half the initial rate. Total NH_3-N losses for the 18 day incubation period from the McBride sandy loam soils receiving 0 , 20, 40 and 60 g poultry manure per kg of soil were 0, 58, 186, 378 mg N kg^{-1} soil, respectively. Total NH_3-N losses from the Capac loam soils receiving poultry manure at 0, 10.8, 21.6 and 32.4 g kg^{-1} of soil were 0, 7, 32 and 58 mg N kg^{-1} soil, respectively (Figure 2.5). The amounts of NH3-N released from the McBride sandy loam and Capac loam were similar at 20 g and 32.4 g poultry manure per kg of soil, respectively. At comparable poultry manure application rates (20 g kg^{-1} for McBride sandy loam and 21.6 g kg^{-1} for Capac loam), NH_3-N released from the McBride sandy loam soil (58 mg N kg^{-1} soil) was about 2 times higher than that from the Capac loam soil (32 mg N kg^{-1} soil). This suggests that soil with a lower CEC (McBride sandy loam) will have a more serious ammonia toxicity problem compared to a soil with a higher CEC (Capac loam).

The ammonia equilibria of the soil can be partially represented by the following equations (Smith, 1964):

$$NH_4OH \Longleftrightarrow NH_3 + HOH \quad (1)$$

$$NH_4OH \Longleftrightarrow NH_4^+ + OH^- \quad (2)$$

$$NH_4OH + H\text{-Soil} \Longleftrightarrow NH_4\text{-Soil} + HOH \quad (3)$$

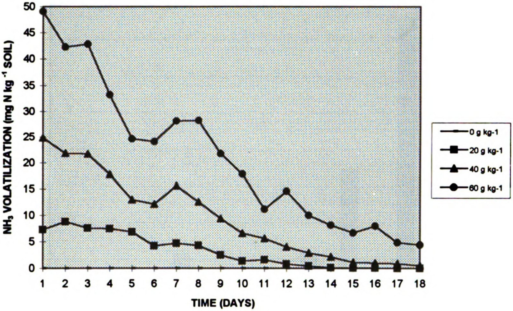

Figure 2. 3. Amounts of NH_3 release from McBride sandy loam.

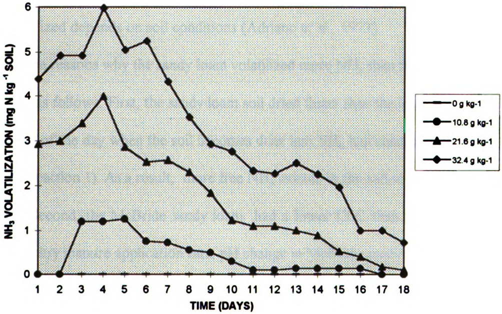

Figure 2. 4. Amounts of NH_3 release from Capac loam.

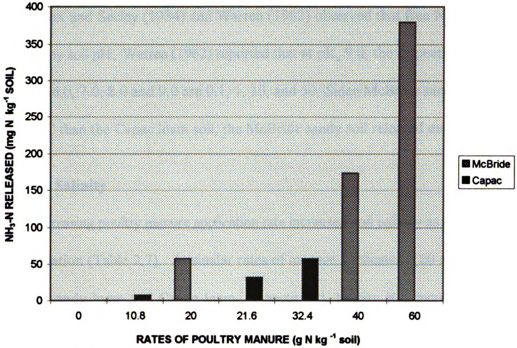

Figure 2.5. Total amount of NH_3-N released from soils.

Ammonia is adsorbed by the clay particles or volatilized and the proportion being adsorbed and volatilized depends on soil conditions (Adriano et al., 1973).

The reasons why the sandy loam volatilized more NH_3 than the Capac loam can be explained as follows. First, the sandy loam soil dried faster than the loam soil, consequently at the end of the day when the soil becomes drier less NH_3 had reacted with water to form NH_4OH (reaction 1). As a result, more free NH_3 existed in the soil to move from the soil to the air. Second, the McBride sandy loam had a lower CEC than the Capac loam. With similar poultry manure application rate, pH change in McBride sandy loam was higher than in the Capac loam (Table 2.6). The mechanism involves less exchange sites for NH_4^+ in the soil with a lower CEC. This results in a higher NH_4^+ concentration in the soil solution to form NH_4OH (reaction 2) which in turn increases a higher soil pH (Smith, 1964). Smith

(1964), Cox and Seeley (1984) and Warren (1962) observed that free NH_3 in the soil was influenced by soil pH. Warren (1962) reported that at pK_a 9.0, the respective percentages of NH_3 at pH 6.0, 7.0, 8.0 and 9.0 are 0.1, 1, 10, and 50. Since McBride sandy loam soil has a lower CEC than the Capac loam soil, the McBride sandy soil released more free NH_3.

3.2.3. Soil Salinity

Increasing poultry manure application rate increased soil salinity as measured after 18 days incubation (Table 2.7). At similar rates of manure application (20 and 21.6 g kg^{-1} for McBride sandy loam and Capac loam, respectively), salinity had increased more in the McBride sandy loam soil than in the Capac loam soil, by 1.7 and 1.3 dSm^{-1}, respectively. This was probably related to the lower CEC of the McBride soil compared to the Capac loam.

Table 2.7. Soil salinity after poultry manure application and incubation (18 days).

Poultry manure applied	Soil salinity
(g kg^{-1} soil)	(dSm^{1})
	McBride soil
0	0.7d*
20.0	2.4c
40.0	3.1b
60.0	3.5a
	Capac soil
0	1.4d
10.8	2.1c
21.6	2.7b
32.4	3.2a

* Mean separation by $LSD_{0.05}$. Numbers within a column followed by different letters are significantly different at $p<0.05$.

The mechanism involves less exchange sites for cations to be held at the lower CECs (Smith, 1964; Brady, 1986) including Na^+, Ca^{+2}, Mg^{+2} and K^+. This results in an increase in the concentration of cations in the soil solution producing a higher salt concentration.

4. SUMMARY AND CONCLUSIONS

General conclusions from this laboratory study are that increasing poultry manure rate increased NH_3 volatilization, soil salinity and soil pH. Changes in soil pH, soil salinity and NH_3 volatilization were greater in the lower CEC soil (McBride sandy loam) than in the higher CEC soil (Capac loam). Ammonia volatilization was greatest from McBride soil immediately after application and gradually decreased with time. Ammonia volatilization from Capac soil was greatest 4 days after application and gradually decreased with time.

Germination and seedling injury of plants grown in a McBride sandy loam soil was apparently caused by a combination of high salinity and NH_3 toxicity. In the Capac soil, the decrease of plant growth at higher rates of applied manure was most likely due to high salinity. Soil salinity of both soils for all poultry manure treatments was >2 dSm^{-1} which is sufficient to cause germination injury and reduce growth of carrots, cabbage and snap beans (Maas, 1986). Although inhibition of crop germination and reduction of seedling growth appeared to be primarily the result of high salinity and NH_3 accumulation during poultry manure decomposition, the possibility of organic toxins and some other nutrient toxicity may also have occurred. By delaying planting time, poultry manure applied up to 20 and 21.6 g kg^{-1} soil (56 to 60 Mg ha^{-1}) did not cause injury to cabbage, carrot and snap bean grown in both soils.

From these findings we conclude that relatively higher poultry manure rate may be applied to finer texture soil (higher CEC) without concern for NH_3 toxicity to germinating seed and plant growth compare to coarser texture soil (lower CEC soils). It is necessary to delay seeding/planting time after large amounts of poultry manure application to allow for

NH_3 release to the atmosphere and/or reaction with soil to minimize the risk of injury to germinating seed. Maintaining adequate soil moisture, through irrigation when necessary, enhances the formation of ammonium from NH_3 reducing the potential for NH_3 toxicity. Applying poultry manure well ahead of planting time allows for the dissipation of NH_3 and soluble salts by reaction and natural precipitation. To avoid soluble salt injury and/or NH_3 toxicity, poultry manure needs to be applied at rates less than 56 Mg ha^{-1}. Further field study is needed to evaluate the effect of high rate of poultry manure on seed germination and plant growth.

CHAPTER 3

EFFECTS OF POULTRY MANURE AND LEAF COMPOST APPLICATION ON PHOSPHORUS, NITROGEN AND POTASSIUM AVAILABILITY AND UPTAKE BY CABBAGE (1993)

1. INTRODUCTION

Poultry production is becoming increasingly important to the economic well-being of the United States. Between 1992 and 1993, total poultry production in United States increased 12% in value of production from $15 to 16.8 billion (National Agricultural Statistics Service, 1994). Along with an increase in poultry production comes an increase in litter production, which may cause environment problems if it is managed improperly. Therefore, utilization of manure that accumulates in poultry production areas is becoming a serious problem for the poultry industry.

With the current emphasis on pollution control, the problem of manure disposal has provoked some thought and action on changing the emphasis to utilization (Abbott and Lingle, 1968; Olsen et al., 1970). The manure can be used as a valuable resource of mineral N and P in maintaining or restoring soil fertility (Liebhardt, 1976b, Huhnke, 1982; Avnimelech, 1986; Brady, 1986; Simpson, 1986; Chen and Avnimelech, 1986 and Sims, 1987). However, the N and P contents of animal wastes typically are not balanced to meet plant needs. Applying manures to meet the needs of one nutrient can result in potential surface and/or groundwater contamination from the other nutrient. One solution may be manure application rates based on P content and the evaluation of crop N status to schedule supplemental N fertilizer application (Francis et al., 1993). Tyson et al. (1993) observed that

composting poultry litter into a product that releases N slowly may minimize nitrate groundwater contamination.

In making manure applications consideration should be given to crop N requirement due to concern for NO_3-N contamination of groundwater (Harris et al., 1991, Simmons and Baker, 1991, Grove, 1992, Wetterauer, and Killorn. 1993, Lauren et al. 1993, Malzer et al., 1993). Some research studies have shown that excessive application of poultry manure can have adverse effects on crops, soil, and water resources. Shortall and Liebhardt (1975) and Weil et al. (1979) found that high (>56 Mg ha^{-1}) amounts of poultry manure applied in the field reduced germination, and adversely affected the growth and yield of corn due to excessive soil salinity. With respect to corn yield, Liebhardt (1976a) observed that excessive salinity would be a problem only in the year of application. The salinity was reduced substantially before the next growing season (Liebhardt, 1976a, Wetterauer and Killorn, 1993). Continual poultry manure application to provide N at rates greater than crop requirement has caused N accumulation in soil (Jackson et al., 1977; Weil et al., 1979; Cooper et al., 1984). This accumulation increased NO_3-N movement through the soil into groundwater (Ritter and Chirnside, 1984; Bitzer and Sims, 1988, Wetterauer and Killorn, 1993). Liebhardt et al. (1979) applied poultry litter at rates of 0 to 179 Mg ha^{-1} (wet wt. basis) to loamy sand soils. He found the NO_3-N concentration in groundwater at 3 m depth increased with poultry manure rate. Application of 27 Mg ha^{-1} or more, significantly increased NO_3-N groundwater concentrations beyond the recommended 10 mg L^{-1} limit (U.S. Environmental Protection Agency, 1976). Similarly, Jackson et al. (1977) found that rates of 22.4 Mg ha^{-1} applied semi-annually were considered excessive from the stand point of potential loss of N for crop production. Adams et al. (1994) found that poultry litter application at the rate 10 Mg ha^{-1} produced NO_3-N as high as 13 mg L^{-1} in soil water. The recommended litter application rate in Arkansas is not more than 11.2 Mg ha^{-1}, split in two 5.6 Mg ha^{-1} applications. Sharpley et al. (1993) observed that 12 to 35 years of poultry liter application with an average of 6 Mg ha^{-1} yr^{-1} (dry wt basis) had the greatest effect on pH, N and P content in the surface 5 cm of the soil. Below 5 cm, P content decreased rapidly with only slight NO_3-N accumulation between 50 to 100 cm depth. Below 25 cm, litter had little effect on pH, NO_3 and P content, and there was no P movement below 30 cm. Similarly, Kingery et al. (1994) observed that 15 to 28 years of broiler litter application with rates of 6 to 22 Mg ha^{-1} yr^{-1} increased total N to depths of 15 and 30 cm, respectively; increased pH by 0.5 unit to a depth of 60 cm, and significantly increased the accumulation of NO_3-N in soil to near bedrock. They found that extractable P concentration in littered soil was more than 6 times greater than in non-littered soil to a depth of 60 cm. They also found elevated levels of extractable K, Ca and Mg to a depth greater than 60 cm.

Vitosh et al. (1973) observed that after 6 to 9 years of cattle manure application available P and exchangeable K increased with increasing rates of manure. The most favorable rate of manure application for growing corn in Metea sandy loam soil was found to be 22.4 Mg ha^{-1}. Larger applications caused a significant buildup of exchangeable K in the surface and subsurface horizons, and resulted in inefficient use of all nutrients. The K buildup was less in loam soil. Rao and Pan (1993) found that manure N was comparable to fertilizer N during a normal season, but was less efficient during a dry season. Similarly, Rylant et al. (1993) observed that as a source of N in turf grass, organic-based fertilizer (pelleted poultry

litter with conventional fertilizer to produce 12-4-6) performed as well as conventional fertilizers and provided a slower release of N. Provin and Tabatabai (1991) studied four types of animal manures (horse, cow, chicken and pig) as sources of N for corn production. They found that corn dry matter was the highest in the chicken manure-treated soil which was comparable to those of the UAN treatments. Regarding P availability, applications of organic materials to the soil may either increase or decrease the availability of soil P. Increased P availability is attributed to organic acids derived from organic matter decomposition that complex Fe and Al in the soil thereby reducing P adsorption sites (Singh and Jones, 1976). Decreased P availability is attributed to microbial assimilation (Singh and Jones, 1976). A decrease in P adsorption capacity of soil following litter application may increase the potential for P movement in runoff (Magette, 1988; Westerman et al., 1983). Large applications of animal manures (beef, poultry and swine) to the soil typically increased P availability and decreased P adsorption. It was found that P adsorption increased with depth (Reddy et al. 1980).

Incubation studies of several Coastal Plains soils showed that poultry litter increased available soil P (Field et al., 1985). Similarly, Sharpley and Smith (1989) incubated soil with crop residue to observe mineralization and leaching of phosphorus from soil. They found mineralization of P from crop residue and its movement within the soil was greater for surface-applied compared to incorporated residue. Greater amounts of inorganic P were leached from surface-applied compared to incorporated residues, but the opposite was true for organic P, with greater amounts leached from incorporated residues than from surface-applied residues. Francis et al. (1993) observed that corn grain yields showed a positive

response to manure application based on P content, but this strategy often resulted in temporary N deficiencies.

Fewer studies have been conducted based on manure P application to determine the fate of manure P in soil solution. With soils low in available P, root absorption of P and growth of plants increase as P concentration in soil solution increases up to a limit (Olsen and Sommers, 1982). As an index of P availability, P soluble in water is used to determine the P concentration level in the soil extract that limits growth of the plants (Olsen and Sommers, 1982). Thompson et al. (1960) found a high correlation between P uptake by sorghum and water-soluble P on 22 soils, most of which were acid. In contrast, Martin and Buchanan (1950); Martin and Mikkelsen (1960), showed that yields of crops grown in California soils with more than 0.13 mg L^{-1} of water soluble P failed to respond to P fertilization. Fried and Shapiro (1956) observed a poor relation between water-soluble P and P uptake in eight acids soils for the initial extract but observed a much better correlation for the 14th successive extract.

In soil testing practices, the water extract represents an attempt to approximate the soil solution P concentration (Adams, 1974). Phosphorus concentration in soil solution usually increases as the amount of soil increases per unit volume of water. A saturation extract more nearly approaches the P concentration expected to be in soil solution from which roots absorb P (Olsen and Sommers, 1982).

More information is needed on the fate of nutrients applied in organic matter to soil and their movement in the soil, in order to devise reliable disposal recommendations and management options. A greenhouse study was conducted to examine how poultry manure and leaf compost affect nutrient availability in the soil solution and crop growth. Soluble inorganic P, N and K have been of major importance for crop production. These effects were studied in two soils differing in available P level and pH.

Objectives

1) To quantify the effect of leaf compost and dried poultry manure on cabbage growth and on N, P, and K uptake by cabbage.
2) To determine the effect of poultry manure and leaf compost on the availability and movement of inorganic N, P and K in soil.

Hypotheses

1) Dried poultry manure increases N, P, and K availability in the soil, and the availability increases with time after application.
2) N, P and K release is slower from dried poultry manure than from commercial fertilizer.
3) Leaf compost will increase C/N ratio of the soil which slows nutrient release into the soil solution.
4) Leaf compost and dried poultry manure increase N, P and K uptake by plants, as well as increase crop growth compared to inorganic nutrient sources.

2. MATERIALS AND METHODS

Two Metea loamy sand soils, one low in P and one high in P (Arenic Hapludalfs, loamy, mixed, mesic) were used in this experiment. Each was air dried, passed through a 2 mm sieve, and analyzed for texture, pH (1:1) soil : water ratio (Eckert, 1988), soil NO_3-N and

NH_4-N (KCl extraction, Keeney and Nelson, 1982), extractable P (Bray and Kurtz P1, Knudsen and Beegle, 1988), and exchangeable K (1N NH_4OAc at pH 7.0, Brown and Warncke, 1988). Total nitrogen concentration of soil, leaf compost and poultry manure was determined by a Kjeldahl procedure (Bremner and Mulvaney. 1982). Organic C was determined by the Loss-On-Ignition procedure adapted from Storer, 1984 (Schulte. 1988). Micronutrients (Cu, Fe, Mn, and Zn) were determined in HCl extracts by atomic absorption (Whitney, 1988).

Leaf compost and dried poultry manure used in this experiment were passed through a 5 mm sieve, and analyzed for moisture content and pH. The total P, K, Ca, Mg, Cu, Fe, Mn, Zn, B, Mo, Al and Na contents were extracted by dry ashing at 500 °C followed by digestion with 3N HNO_3 containing 1000 ppm LiCl. Nutrient concentration was determined with a Direct Current Plasma Atomic Emission Spectrophotometer. Total N, NO_3-N and NH_4-N contents were analyzed by the same procedures used for soil. Total element contents of leaf compost and poultry manure are presented on a dry-weight basis. Analyses of the soil, leaf compost and partially composted poultry manure are given in Table 3.1.

The experimental design for this study was a 6x2 factorial, arranged as a Randomized Complete Block in 4 replications, plus 1 replication without plants which was not included in the statistical analyses. Factor A included 1 rate of fertilizer P (recommended) and 5 rates of manure. Factor B included 2 rates of leaf compost. Treatment differences for each variable observed were tested using the LSD, $P<0.05$. The treatments and the amount of nutrient applied are shown in Table 3.2. The soil to be placed in a 7.5 L pot was split into two parts; 4.7 kg of untreated soil was placed in the bottom of the pot, and 2.7 kg was mixed thoroughly with the treatment materials and placed in the top half of the pot. Supplemental fertilizer N (ammonium nitrate 34%N) and K (muriate potash 60%) were added to equalize their levels among the various treatments to meet crop requirement. Elements recommended for cabbage on the low-P soil were 123 kg N , 74 kg P and 127 kg K ha^{-1} (or 62 mg N, 37 mg P, and 64 mg K kg^{-1} soil, respectively), whereas for the high-P soil they were 109 kg N, 37 kg P and 132 kg K ha^{-1} (or 55 mg N, 19 mg K, and 66 mg K kg^{-1} soil, respectively).

Table 3.1. Some chemical properties of two Metea loamy sand soils, poultry manure and leaf compost used in experiment.

Chemical property	Low-P soil	High-P soil	Poultry manure	Leaf compost
Moist (%)	-	-	16.0	44.0
CEC (cmol/kg)	3.1	4.3	-	-
pH	8.1	6.4	-	-
C (%)	1.0	1.1	23.4	13.7
C/N	18.9	20.6	9.7	16.7
Organic matter(%)	1.8	2.0	40.4	23.6
Elements (g kg^{-1}):				
TKN (Kjeldahl)	0.54	0.55	24.3	8.20
	-- Extractable --		**----- Total -----**	
NO_3-N	0.016	0.022	0.77	0.09
NH_4-N	0.001	0.002	0.49	0.02
P	0.023	0.057	73.6	0.73
K	0.07	0.07	46.4	3.93
Ca	1.99	0.33	128.3	41.6
Mg	0.07	0.11	9.3	11.19
Cu	0.001	0.001	0.2	0.005
Fe	0.01	0.02	6.3	6.3
Mn	0.06	0.02	0.8	0.1
Zn	0.004	0.002	2.4	0.04
B	-	-	0.06	0.04
Mo	-	-	0.03	0.01
Na	0.02	0.014	10.9	0.80
Al	-	-	1.2	8.18

Table 3.2. Total estimated amounts of nutrients applied to soil from fertilizer P, poultry manure and leaf compost.

Treatment	Manure or compost Applied		Soil LP			Soil HP		
	Soil LP	Soil HP	N	P	K	N	P	K
	-- g kg^{-1} soil --		--------- mg kg^{-1} soil ---------					
P.manure/TSP								
m1 (manure)	0	0	0	0	0	0	0	0
m2 (TSP)*	0.04	0.02	0	38	0	0	19	0
m3 (manure)*	0.5	0.25	12	38	23	6	19	12
m4 (manure)	1.25	1.0	30	95	58	24	76	46
m5 (manure)	2.0	1.75	48	152	92	42	133	81
m6 (manure)	2.75	2.5	66	209	127	60	190	115
L.compost								
c1	0	0	0	0	0	0	0	0
c2	12.5	12.5	103	9	50	103	9	50
Fertilizer requirement	-	-	62	38	64	55	19	66

* Treatment m2 and m3 received the recommended amount of N, P and K.

Cabbage seedlings having 3 true leaves, cultivar Market Topper, were transplanted into each pot and grown for 10 weeks in a greenhouse. A single plant was harvested at 2, 4, and 10 weeks for determination of biomass and nutrient accumulation. Fully developed outer wrapper leaves were collected at 7 weeks after transplanting. At 10 weeks after transplanting plant tissue was separated into root, stem and shoot for analyses. Plant tissue was prepared for nutrient analysis by dry ashing at 500 °C and digesting the ash with 3N HNO_3 containing 1000 ppm LiCl. Nutrient concentration were determined with a Direct Current Plasma Atomic Emission Spectrophotometer (DCP-AES).

Soil solution was drawn from the top and bottom soil layers at 2, 4, 7 and 10 weeks after transplanting, 24 hours after watering, using Rhizon Soil Solution Samplers (Rhizon

SSS). The first Rhizon SSS was placed at the interface of the treated and untreated soil layers, 7 cm from the soil surface. The second Rhizon SSS was placed in the middle of the untreated bottom soil layer, 12 cm from the soil surface. Soil solution was analyzed for NO_3-N, NH_4-N, and P content using a Lachat rapid-injection flow system; whereas K was determined using a Varian atomic absorption unit.

Moisture content of the soils were checked daily by weighing the pots and adding water to ensure that the soil remained near field capacity. The moisture content of the low P and high P soils was maintained near 16% and 18%, respectively. Soil moisture content at the time of sampling were also measured using Time Domain Reflectometry (TDR). The TDR probes were placed parallel to the Rhizon SSS, at the depth of 5 and 12 cm from soil surface.

3. RESULTS AND DISCUSSION

3.1. LOW P SOIL

3.1.1. Soil pH

Soil pH in the top (treated) and bottom (untreated) layer soil solution were not affected by poultry litter application. Data in Table 3.3 show that after 10 weeks, the pH of soil solution in the top layer (ranging from 7.77 to 7.89) was consistently lower than in the bottom layer (ranging from 8.07 to 8.09). This was probably due to irrigation that leached salts and some cations from the top to the bottom soil layer.

Table 3.3. Soil pH in the top and bottom soil layer of a high pH, low-P Metea sandy loam treated with poultry manure and leaf compost.

Leaf compost incorporated	Manure or TSP incorporated ($g\ kg^{-1}$)						Mean
	0	TSP[a]	0.50	1.25	2.0	2.75	
$g\ kg^{-1}$soil	Top layer						
0	7.89	7.85	7.91	7.93	7.87	7.88	7.89a
12.5	7.86	7.84	7.87	7.79	7.84	7.65	7.81b
Mean	7.88a*	7.85a	7.89a	7.86a	7.85a	7.77a	
	Bottom layer						
0	8.06	8.07	8.07	8.07	8.11	8.08	8.08a
12.5	8.08	8.08	8.07	8.10	8.08	8.10	8.09a
Mean	8.07a	8.08a	8.07a	8.09a	8.09a	8.09a	

* Mean separation by LSD 0.05. Numbers within a row or a column followed by different letters are significantly different at $p < 0.05$.

[a] 0.04 g P kg^{-1} soil was incorporated.

Leaf compost applied at 12.5 g kg^{-1} soil significantly decreased the pH of top layer by 0.08 unit, and there was no effect on pH in the bottom soil layer (Table 3.3). Black (1968) attributed such a pH decrease to the presence of organic matter derived from leaf compost and its decomposition products which reduced the activity of polyvalent cations, especially Ca. Even though there was a possibility that some soluble organic compounds may have leached from the top to the bottom, the amounts were apparently not enough to reduce the pH in the bottom layer.

3.1.2. Biomass Accumulation

In the low-P soil, plant growth at 2 weeks in soil receiving no supplemental P was significantly lower than in the other treated soils. Overtime dry matter production in this treated soil (m1) caught up with the others (Fig.3.1). There was no significant difference in

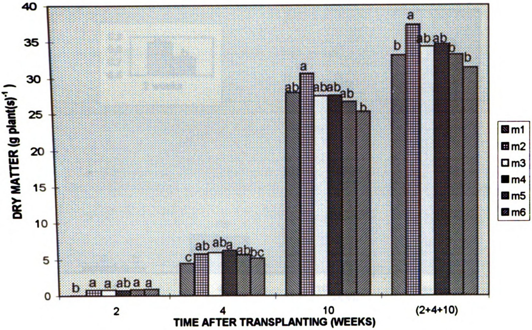

Figure 3.1. Poultry manure effect on dry matter production by cabbage grown in a low-P Metea sandy loam.

plant growth between the inorganic fertilizer P (m2) and poultry manure treated soils. At 10 weeks the plant receiving the highest manure rate produced significantly less dry matter than the soil treated with inorganic fertilizer. Also, at 10 weeks there was a significant interaction effect of poultry manure/fertilizer P and leaf compost on dry matter production. With 0.04 g P ha^{-1} from inorganic fertilizer (m2) adding leaf compost increased significantly dry matter production, but with 0.04 g P from poultry manure (m3) adding leaf compost did not increase dry matter production (Table 3.4).

At the beginning (2 weeks) adding leaf compost significantly decreased dry matter production. In the next 4 weeks leaf compost started to increased dry matter production and compensated for the initial decrease. After 10 weeks of growth significantly more dry matter had been produced in the soil receiving leaf compost (Fig.3.2). This likely happened because

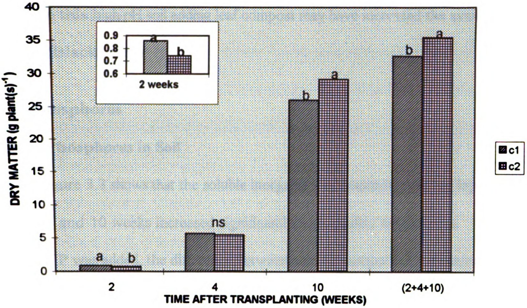

Figure 3.2. Leaf compost effect on dry matter production by cabbage grown in a low-P Metea sandy loam.

Table 3.4. Dry matter production of cabbage plant grown in the low-P soil for 10 weeks.

Leaf compost incorporated	Manure or TSP incorporated (g kg^{-1})					
	0	TSP^{a}	0.50	1.25	2.0	2.75
g kg^{-1} soil	g					
0	25.6**bcd***	25.3**bcd**	28.6**bcd**	24.4**cd**	28.6**bcd**	24.0**d**
12.5	30.4**bcd**	36.0**a**	26.4**bcd**	30.8**ab**	24.8**bcd**	26.6**bd**

* Mean separation by LSD 0.05. Numbers within a row or a column followed by different letters are significantly different at $p < 0.05$.

[a] 0.04 g P kg^{-1} soil was incorporated.

leaf compost decreased soluble N, P, and K concentration in soil which decreased early growth. At the same time, humic substances and growth-promoting substances may have been released (Stevenson, 1982) which later increased plant growth and dry matter production (Gaur and Bhardwaj, 1971) which compensated for reduced early cabbage growth. In this high pH soil adding leaf compost may have increased the availability of trace elements (Black, 1968).

3.1.3. Phosphorus

3.1.3.1. Phosphorus in Soil

Figure 3.3 shows that the soluble inorganic P concentration in top layer soil solution at 2, 4, 7 and 10 weeks increased significantly with poultry manure rate. When the same amount of P was added, the difference between soluble inorganic P concentration in poultry manure treatment ($m3=0.5$ g kg^{-1}) and fertilizer P (m2) was appreciable, but not significant, except during the first 2 weeks. Similarly, data in Table 3.5 show that during the first 4 weeks soluble inorganic P in soils without plants treated with m3 was much lower than soils treated with m2. These data indicate that P from poultry manure was released more slowly

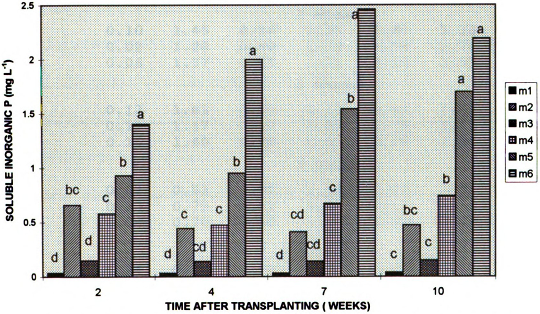

Figure 3.3. Poultry manure effect on soluble inorganic P concentration in the top layer of a low-P Metea sandy loam.

than from inorganic fertilizer P.

Data in Table 3.5 show that during 7 to 10 weeks the difference in soluble inorganic P concentration between soil treated with poultry manure (m3) and treated with inorganic fertilizer (m2) was very small. The amount of soluble P in soil treated with inorganic fertilizer P decreased with time while the soluble P concentration in soil treated with poultry manure was relatively constant. This decrease was probably due to precipitation of soluble P from fertilizer by Ca at pH 8.2. Brady (1986) attributed the decrease as follows. When an $H_2PO_4^-$-

Table 3.5. Inorganic P concentration in the top layer soil solution of a high pH, low-P Metea sandy loam treated with poultry manure and leaf compost (soils without plants)*.

Leaf compost incorporated	Manure or TSP incorporated (g kg^{-1})						Mean
	0	TSP[a]	0.5	1.25	2.0	2.75	
g kg^{-1} soil	mg P L^{-1}						
	2 Weeks						
0	0.10	1.45	0.46	1.35	2.41	3.28	1.50
12.5	0.02	1.28	0.49	1.30	1.92	2.78	1.30
Mean	0.06	1.37	0.48	1.32	2.16	3.03	
	4 Weeks						
0	0.12	1.62	0.70	1.41	3.43	3.40	1.78
12.5	0.19	1.17	0.67	1.28	2.75	3.20	1.54
Mean	0.16	1.40	0.68	1.35	3.09	3.30	
	7 Weeks						
0	0.02	0.62	0.69	1.60	2.93	3.02	1.48
12.5	0.13	0.79	0.52	1.19	2.41	2.54	1.26
Mean	0.08	0.70	0.60	1.39	2.67	2.78	
	10 Weeks						
0	0.24	0.63	0.75	1.69	2.93	3.24	1.58
12.5	0.22	0.81	0.59	1.35	2.51	2.30	1.30
Mean	0.23	0.72	0.67	1.52	2.72	2.77	

* data observed from 1 replication only

[a] 0.04 g P kg^{-1} soil was incorporated.

containing fertilizer such as concentrated superphosphate is added to an alkaline soil, the $H_2PO_4^-$ or $HPO4^{-2}$ ion quickly reacts with calcium to form less soluble compounds. In manure treatment (m3) soluble inorganic P concentrations after 2 weeks were slightly increased and relatively constant throughout 4 to 10 weeks. The possible mechanism is after 2 weeks, P from poultry manure was released slowly by decomposition. During that time organic substance from poultry manure decomposition may react with Ca in the soil (Black, 1968; Hue, 1992) and reduces the amounts of Ca that may precipitate soluble P from poultry manure. After 4 weeks P is continuously released by microbes activity, but at the same time the P released was continuously fixed or precipitated by Ca from the soil.

Figure 3.4 shows that increasing poultry manure rates increased significantly soluble inorganic P concentration in the bottom soil layer at 4 and 10 weeks. The concentration slightly increased with time and the trend was the same as the one in top layer solution, suggesting that soluble inorganic P continuously moved from the top to the bottom. Similarly, in soil without plants (Table 3.6) the soluble inorganic P concentration in treatment m1, m2 and m3 increased with time suggesting P movement from the top to the bottom. However, the soluble inorganic P concentration in treatment m4, m5 and m6 was mostly stable. These soils retained more water and dried out more slowly. Therefore, less water was applied to these soils resulting in less water and nutrient movement.

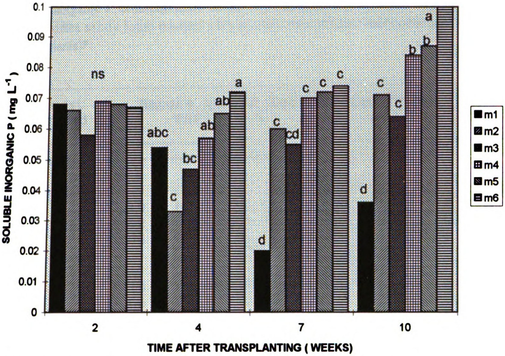

Figure 3.4. Poultry manure effect on soluble inorganic P concentration in the bottom layer of a low-P Metea sandy loam.

Table 3.6. Inorganic P concentration in the bottom layer soil solution of a high pH, low-P Metea sandy loam treated with poultry manure and leaf compost (soils without plants)*.

Leaf compost	Manure or TSP incorporated (g kg^{-1})						Mean
incorporated	0	TSP[a]	0.5	1.25	2.0	2.75	
g kg^{-1} soil	mg P L^{-1}						
				2 Weeks			
0	0.10	0.12	0.02	0.12	0.12	0.07	0.09
12.5	0.02	0.12	0.07	0.14	0.30	0.18	0.14
Mean	0.06	0.12	0.05	0.13	0.21	0.12	
				4 Weeks			
0	0.16	0.06	0.16	0.13	0.19	0.13	0.14
12.5	0.06	0.10	0.19	0.16	0.28	0.11	0.15
Mean	0.11	0.08	0.17	0.14	0.24	0.12	
				7 Weeks			
0	0.17	0.15	0.14	0.06	0.20	0.02	0.12
12.5	0.09	0.09	0.15	0.06	0.27	0.19	0.16
Mean	0.13	0.12	0.15	0.11	0.23	0.10	
				10 Weeks			
0	0.15	0.22	0.18	0.11	0.14	0.02	0.14
12.5	0.20	0.15	0.18	0.16	0.25	0.17	0.19
Mean	0.18	0.19	0.18	0.13	0.20	0.10	

* data observed from 1 replication only.

[a] 0.04 g P kg^{-1} soil was incorporated.

Figure 3.5 shows the effect of leaf compost on soluble inorganic P in the top and bottom layer of soils with plants. Adding leaf compost caused a significant decrease in soluble inorganic P in the top soil layer starting at 4 weeks after transplanting. Data in Table 3.5 show the same trend happened in the top layer of the soils without plants. This was probably due to microbial activity which bound soluble P into the organic pool (Brady, 1986). There was no significant effect of leaf compost on P concentration in the bottom soil layer. Soluble inorganic P concentration increased slightly in the leaf compost treatment. A similar

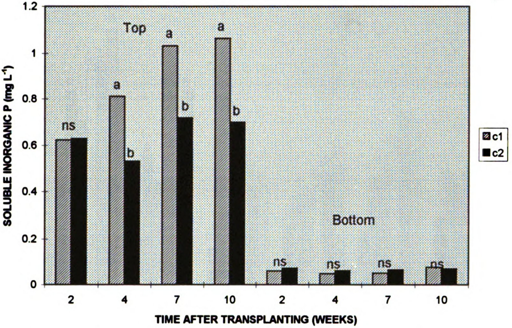

Figure 3.5. Leaf compost effect on soluble inorganic P concentration in the top and bottom layer of a low-P Metea sandy loam.

condition also occurred in the bottom layer of soils without plants (Table 3.6). This probably was due to some soluble organic substance derived from leaf compost which moved to the bottom and reacted with Ca (Black, 1968) to reduce the amounts of Ca which may precipitate P into an insoluble form (Brady, 1986).

3.1.3.2. Phosphorus in Plant

3.1.3.2.1. Phosphorus Concentration

Phosphorus concentration in the cabbage tissue increased significantly with poultry manure rates throughout the growth period (Fig.3.6). At 2 and 4 weeks after transplanting P concentration in the plants treated with inorganic fertilizer P (m2) was higher than those receiving comparable P amounts from poultry manure (m3). This suggests that P from poultry manure was released more slowly than from inorganic fertilizer. The P concentration

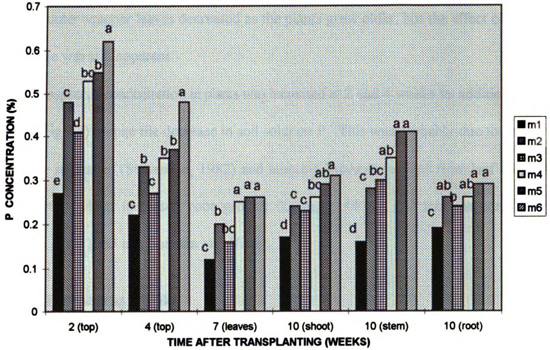

Figure 3.6. Poultry manure effect on P concentration in cabbage tissue grown in a low-P Metea sandy loam.

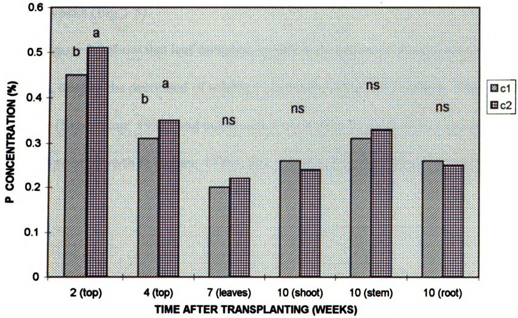

Figure 3.7. Leaf compost effect on P concentration in cabbage tissue grown in a low-P Metea sandy loam.

in top and outer wrapper leaves decreased as the plants grew older, but the effect of poultry manure rate was still apparent.

Phosphorus concentration in plants was increased at 2 and 4 weeks by addition of leaf compost (Fig.3.7) despite the decrease in soil solution P. This was probably due to growth-promoting substance (Stevenson, 1982) and humic substances derived from leaf compost (Chui, 1962) which increased root growth (Linehan, 1976), and increase ion uptake (Guminski et al. 1983 and Samson and Visser, 1989).

3.1.3.2.2. Phosphorus Uptake

Throughout the 10 week growth period adding higher manure amounts increased significantly P uptake by the cabbage plants. There were no significant differences between inorganic fertilizer P (m2) effect and poultry manure P effect (m3) on P uptake by the plant until 10 weeks (Fig.3.8).

Figure 3.9 show that leaf compost significantly increased P uptake by the cabbage at 10 weeks, despite the decreased of soluble P concentration in soil solution. Possibly a growth promotor (Stevenson, 1982) and humic substances derived from leaf compost (Chui, 1962) increased root growth (Linehan, 1976), and increase P uptake (Rochus, 1971).

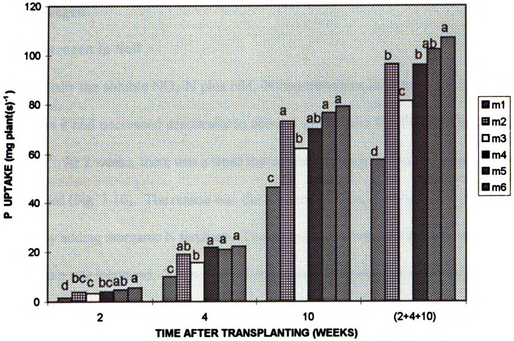

Figure 3.8. Poultry manure effect on P uptake by cabbage grown in a low-P Metea sandy loam.

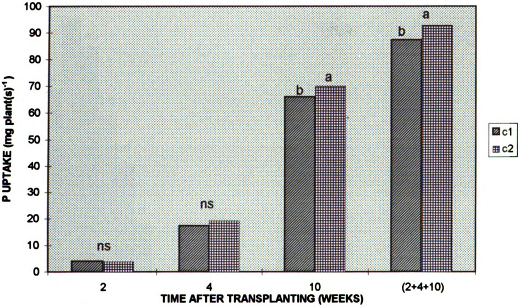

Figure 3.9. Leaf compost effect on P uptake by cabbage grown in a low-P Metea sandy loam.

3.1.4. Nitrogen

3.1.4.1. Nitrogen in Soil

Initially the soluble NO_3-N plus NH_4-N concentration in the top soil layer was high. By 4 weeks it had decreased drastically to about 1 mg L^{-1} and by 10 weeks had dropped to <0.1 mg L^{-1}. At 2 weeks, there was a trend that soluble N in soil decreased as poultry manure rate increased (Fig. 3.10). The reason was the amounts of N applied in every treatment were equalized by adding inorganic N fertilizer. The amount of inorganic fertilizer added decrease as the manure rate increased. The soluble N concentration tended to decrease as the amount of inorganic fertilizer added decreased. This shows that N from poultry manure was released more slowly than N from inorganic fertilizer.

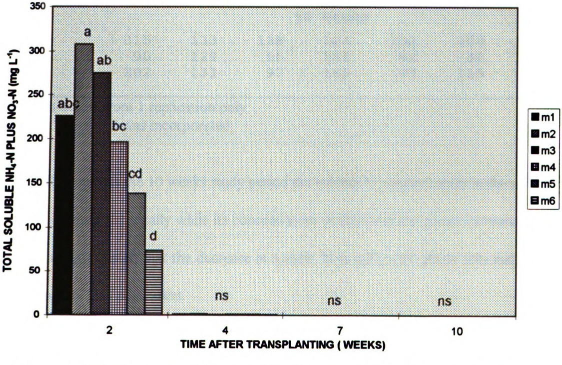

Figure 3.10. Poultry manure effect on total soluble N concentration in the top layer of a low-P Metea sandy loam.

Table 3.7. NO_3-N plus NH_4-N concentration in the top layer soil solution of a high pH, low-P Metea sandy loam treated with poultry manure and leaf compost (soils without plants)*.

Leaf compost incorporated	Manure or TSP incorporated (g kg^{-1})						Mean
	0	TSP[a]	0.5	1.25	2.0	2.75	
g kg^{-1} soil	mg NO_3+NH_4-N L^{-1}						
				2 Weeks			
0	158	76	126	91	81	70	100
12.5	40	46	30	44	50	42	42
Mean	99	61	78	67	65	56	
				4 Weeks			
0	195	106	168	83	138	97	131
12.5	47	81	69	48	91	40	63
Mean	121	93	118	65	114	68	
				7 Weeks			
0	224	169	337	170	341	145	231
12.5	220	125	73	118	63	57	109
Mean	222	147	205	144	202	101	
				10 Weeks			
0	315	133	128	164	102	150	165
12.5	90	129	66	161	92	80	103
Mean	202	131	97	162	97	115	

* data observed from 1 replication only

[a] 0.04 g P kg^{-1} soil was incorporated.

Throughout the 10 weeks study period the soluble N concentration in the soils with plants decreased drastically while its concentration in soils without plants increased (Table 3.7). This suggested that the decrease in soluble N in soils with plants was due to plant uptake, not N immobilization.

During the first 2 weeks, the N concentration in the bottom soil solution was significantly affected by poultry manure application (Fig.3.11). Changes in N concentration were almost similar with the change in the top soil layer, indicating that there was N movement from the top to the bottom soil layer. The soluble N concentration decreased with the time. At 2 weeks the concentration ranged from 9.6 to 12.8 mg L^{-1}. By the end of the study the concentration decreased drastically to less than 0.03 mg L^{-1}. However, data in Table 3.8 show that the soluble N concentrations in bottom soil layer of the soils without plants increased with the time. This suggests that the decrease of N concentration in bottom layer of the soil with plants was predominantly due to plant uptake.

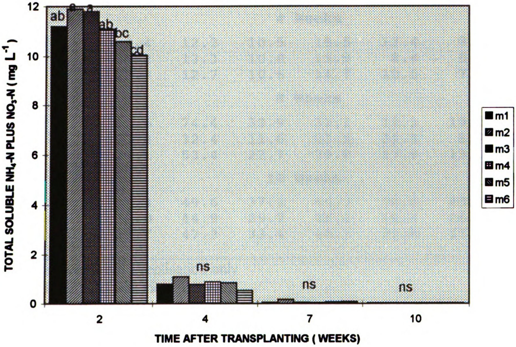

Figure 3.11. Poultry manure effect on total soluble N concentration in the bottom layer of a low-P Metea sandy loam.

Table 3.8. NO_3-N plus NH_4-N concentration in the bottom layer soil solution of a high pH, low-P Metea sandy loam treated with poultry manure and leaf compost (soils without plants)*.

Leaf compost incorporated	Manure or TSP incorporated (g kg^{-1})						Mean
	0	TSP[a]	0.5	1.25	2.0	2.75	
g kg^{-1} soil	mg NO_3+NH_4-N L^{-1}						
			2 Weeks				
0	31.4	21.7	14.8	19.7	21.0	10.5	19.9
12.5	5.7	14.3	10.8	16.7	15.4	2.6	10.9
Mean	18.6	18.0	12.8	18.2	18.2	6.6	
			4 Weeks				
0	29.4	12.2	10.5	15.5	12.4	9.2	14.9
12.5	5.2	13.3	10.8	13.9	8.6	5.5	9.5
Mean	17.3	12.7	10.6	14.7	10.5	7.4	
			8 Weeks				
0	34.5	74.4	33.9	32.1	14.1	19.1	34.7
12.5	23.8	32.4	11.6	27.6	21.8	8.4	20.9
Mean	29.1	53.4	22.7	29.8	17.9	13.7	
			10 Weeks				
0	57.4	49.6	37.1	44.3	36.6	48.4	45.6
12.5	22.0	44.9	29.7	45.1	26.6	26.0	32.4
Mean	39.7	47.3	33.4	44.7	31.6	37.2	

* data observed from 1 replication only

[a] 0.04 g P kg^{-1} soil was incorporated.

Figure 3.12 shows the effect of leaf compost on NO_3-N plus NH_4-N concentration in the soil solution of the top and bottom soil layers. At 2 weeks the soluble NO_3-N plus NH_4-N concentration in soil solution of the top was significantly lower when leaf compost was incorporated. The same pattern occurred in the bottom soil layer indicating that there was N movement from the top to the bottom soil layer. Similarly, in soils without plants the NO_3-N plus NH_4-N concentration in soil solution from soils treated with leaf compost was always lower than from untreated soils. But, the soluble N concentration increased with time (Table

3.7 and 3.8). The decrease in N concentration may have been due to N being immobilized by microbes. After 4 weeks N was released to the soil solution as the microbes died and decomposed. Another mechanism may have occurred. Leaf compost contains humus which is negatively charged. This charge is pH dependent and is high at a high pH (Brady, 1986). As a result, in soil with a higher pH (pH 8.2) leaf compost has more negative charge. More NH_4^+ adsorption can occur in this soil which in turn reduces the amount of NH_4-N in soil solution.

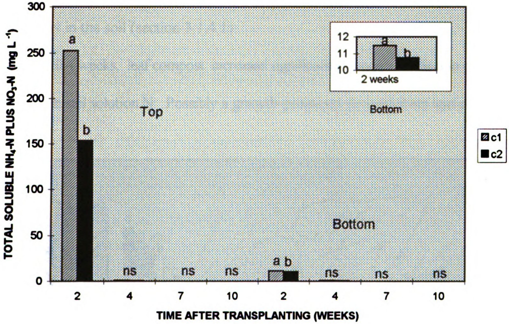

Figure 3.12. Leaf compost effect on total soluble N concentration in the top and bottom layer of a low-P Metea sandy loam.

3.1.4.2. Nitrogen in Plant

3.1.4.2.1. Nitrogen Concentration

At 2 weeks after transplanting there was no poultry manure effect on N concentration in plant tissue. At 4 weeks the N concentration in the cabbage treated with comparable amount of N manure (m6 = 2.75 g kg^{-1}) was significantly lower from that treated with inorganic fertilizer N (m2). This suggests that N from poultry manure was not as readily available to the plant as fertilizer N. After 10 weeks the N concentration in the cabbage was similar for all treatments (Fig.3.13). The change in plant N concentration reflects the change in soluble N in the soil (section 3.1.4.1).

Until 4 weeks, leaf compost increased significantly N concentration in plants, despite a decrease in soil solution N. Possibly a growth-promotor derived from leaf compost (Chui,

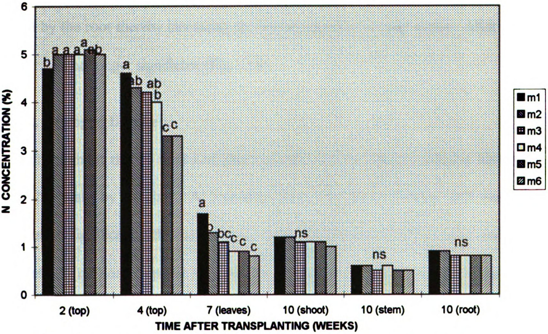

Figure 3.13. Poultry manure effect on N concentration in cabbage tissue grown in a low-P Metea sandy loam.

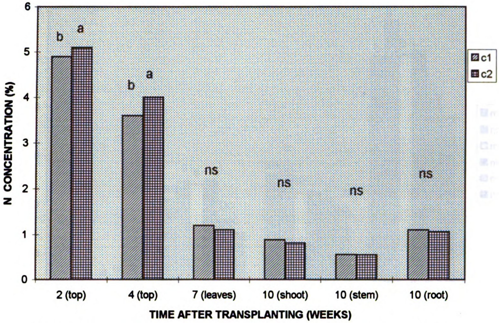

Figure 3.14. Leaf compost effect on N concentration in cabbage tissue grown in a low-P Metea sandy loam.

1962 and Stevenson, 1982) increased root growth (Linehan, 1976). As a result, more N was absorbed by the root thereby increasing the N concentration in plant tissue. After 4 weeks the effect was no longer significant (Fig.3.14).

3.1.4.2.2. Nitrogen Uptake

Throughout the 10 weeks of plant growth, poultry manure addition significantly affected N uptake by the plant. At 2 weeks when a comparable amount of N was added, there was no significant difference between inorganic fertilizer N effect (m2) and poultry manure effect (m6) on N uptake by the plant. Starting at 4 weeks, N uptake significantly decreased in poultry manure treatment (Fig.3.15). This result indicated that at 2 weeks cabbage plant needed only a small amount of N. At this time N in soil solution was enough for plant need. After 4 weeks the plants N requirement increased, but N was released more

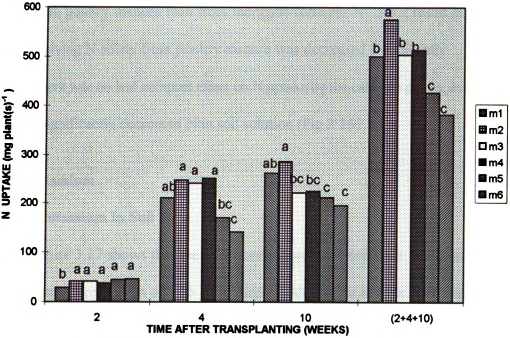

Figure 3.15. Poultry manure effect on N uptake by cabbage grown in a low-P Metea sandy loam.

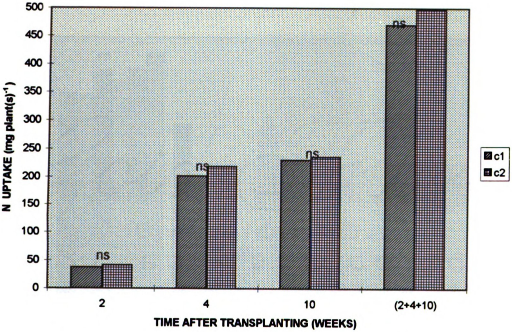

Figure 3.16. Leaf compost effect on N uptake by cabbage grown in a low-P Metea sandy loam.

slowly from poultry manure than from inorganic fertilizer N. As a result N uptake by the plants receiving N solely from poultry manure was decreased significantly.

There was no leaf compost effect on N uptake by the cabbage plants, even though leaf compost significantly decreased N in soil solution (Fig.3.16)

3.1.5. Potassium

3.1.5.1. Potassium in Soil

Figure 3.17 shows that the K concentration in the top layer soil solution decreased with the time. Application of 2.75 g kg^{-1} (m6) produced the highest K concentration in soil solution. At 4 weeks with comparable amounts of K added, soluble K concentrations in soil treated with 1.25 and 2.0 g kg^{-1} (m4 and m5) were significantly lower than those treated with inorganic fertilizer only (m2). However, in soil without plant, these K concentrations were

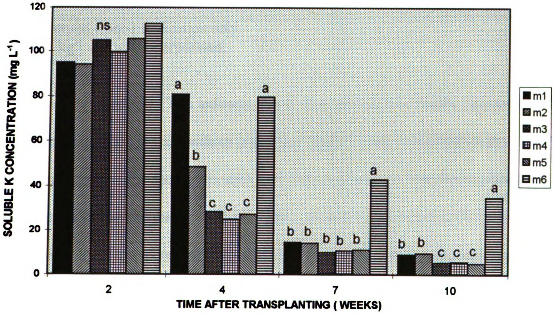

Figure 3.17. Poultry manure effect on soluble K concentration in the top layer of a low-P Metea sandy loam.

Table 3.9. K concentration in the top layer soil solution of a high pH, low-P Metea sandy loam treated with poultry manure and leaf compost (soils without plants)*.

Leaf compost incorporated	Manure or TSP incorporated (g kg^{-1})						Mean
	0	TSP[a]	0.5	1.25	2.0	2.75	
g kg^{-1} soil				mg K L^{-1}			
				2 Weeks			
0	100	38	70	68	59	85	70
12.5	24	36	21	47	135	100	61
Mean	62	37	45	57	97	92	
				4 Weeks			
0	120	62	128	56	100	82	91
12.5	25	42	38	37	91	60	49
Mean	73	52	83	47	96	71	
				7 Weeks			
0	135	72	187	69	159	93	119
12.5	81	56	33	60	53	47	55
Mean	108	64	110	65	106	70	
				10 Weeks			
0	171	70	102	70	73	84	95
12.5	49	66	73	65	64	50	61
Mean	110	68	87	68	68	67	

* data observed from 1 replication only

[a] 0.04 g P kg^{-1} soil was incorporated.

almost similar (Table 3.9). This indicates that K from manure was readily released. At 10 weeks, K concentration in soils without plants was higher than K concentration in soils with plants, suggesting that the decrease in soils with plants might have been due to plant uptake.

Figure 3.18 shows that at 7 and 10 weeks the soluble K concentration in the bottom layer of soils with plants increased as the amount of poultry manure applied increased. This indicated that more K released into the soil solution as amount of K from poultry manure increased, and there was K movement from the top to the bottom soil layer. However, this situation did not occur in soils without plants (Table 3.10). No K movement occurred because less water was given daily to each pot, especially at the higher rates of manure application. These soils retained more water and dried out more slowly. After 4 weeks the K concentration in soils with plants decreased with time. In soils without plants K concentration was almost similar for all treatments and was higher than that in soils with plants. This show that in soils with plants the decrease of K concentration with time was due to plant uptake.

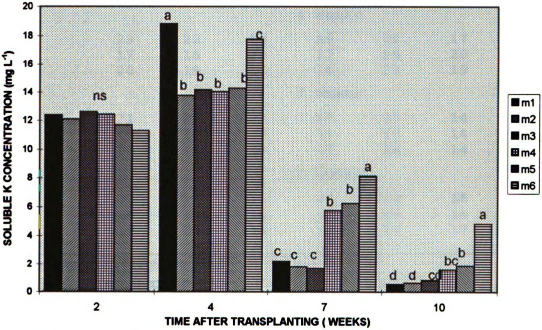

Figure 3.18. Poultry manure effect on soluble K concentration in the bottom layer of a low-P Metea sandy loam.

Table 3.10. K concentration in the bottom layer soil solution of a high pH, low-P Metea sandy loam treated with poultry manure and leaf compost (soils without plants)*.

Leaf compost incorporated	Manure or TSP incorporated (g kg^{-1})						Mean
	0	TSP[a]	0.5	1.25	2.0	2.75	
g kg^{-1} soil	mg K L^{-1}						
	2 Weeks						
0	15	15	15	13	16	14	15
12.5	15	14	14	15	18	15	15
Mean	15	14	15	14	17	14	
	4 Weeks						
0	23	22	22	16	21	17	20
12.5	17	16	24	17	26	20	20
Mean	20	19	23	16	23	19	
	7 Weeks						
0	21	25	23	15	17	14	19
12.5	15	14	15	14	19	14	15
Mean	18	19	19	15	18	14	
	10 Weeks						
0	22	27	21	14	19	18	20
12.5	16	19	18	18	19	16	18
Mean	19	23	19	16	19	17	

* data observed from 1 replication only

[a] 0.04 g P kg^{-1} soil was incorporated.

Figure 3.19 shows the effect of leaf compost on soluble K in top and bottom soil layers. Adding leaf compost caused a significant decrease in soluble K in the top layer at 2 weeks only. This was probably due to microbial activity which initially bound K into the organic pool. There may also have been K adsorption in humus substances (Brady, 1986) derived from the leaf compost (Stevenson, 1982).

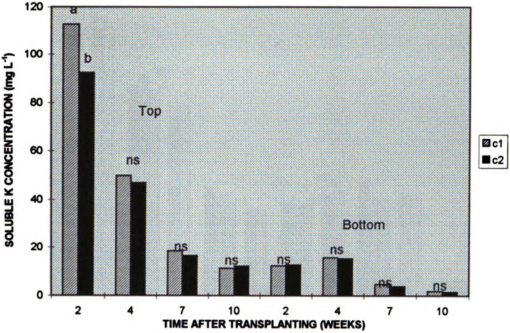

Figure 3.19. Leaf compost effect on soluble K concentration in the top and bottom layer of a low-P Metea sandy loam.

3.1.5.2. Potassium in Plant

3.1.5.2.1. Potassium Concentration

Throughout the growth period, the K concentration in the cabbage treated with manure at the comparable amount of K (m4, m5) was not significantly different from that treated with inorganic fertilizer K (m2). Only at 10 weeks was K concentration significantly higher in shoots when higher poultry manure amount (m6) was applied (Fig.3.20).

At 2 weeks, K concentration in plant tissue with P addition (m2, m3, m4, m5 and m6) was significantly higher than without P (m1). Phosphorus is needed in root development, particularly for lateral and fibrous rootlets (Brady, 1986). Cabbage with P addition will have better root development and this may increase K absorption.

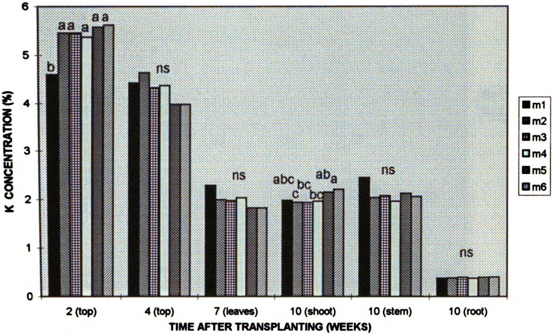

Figure 3.20. Poultry manure effect on K concentration in cabbage tissue grown in a low-P Metea sandy loam.

The K concentration in the cabbage grown in the low-P soil was increased significantly by leaf compost application (Fig.3.21), although at 2 weeks the K concentration in soil solution was decreased significantly (section 3.1.5.1). The leaf compost may have provided humus which contains a growth-promoting substance (Stevenson, 1982) to enhance root growth (Linehan, 1976) and nutrient uptake (Guminski et al., 1983).

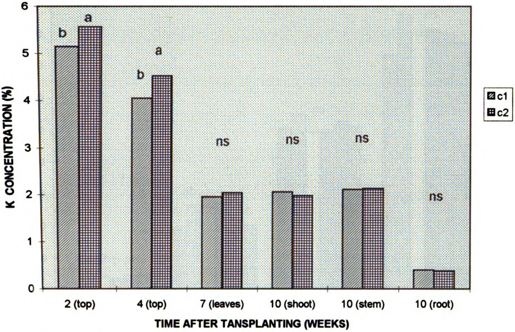

Figure 3.21. Leaf compost effect on K concentration in cabbage tissue grown in a low-P Metea sandy loam.

3.1.5.2.2. Potassium Uptake

At 2 weeks K uptake by plants without P addition (m1) was significantly lower than that of all other treatments. From week 2 to 10, K uptake by cabbage treated with manure at the comparable amount of K (m4) was not significantly different from that for those treated with inorganic fertilizer K (Fig.3.22).

Leaf compost addition increased slightly K uptake by the plant, but the increase was not significant throughout the growth period. However, it was significant for total uptake from the pot (Fig.3.23), despite a decreased of K in soil solution. This suggested that increase in K uptake may have been due to a humus substance derived from leaf compost (Stevenson, 1982) which improved root growth (Rochus, 1967; Linehan, 1976, and Mylonas and McCants, 1980), and as a result compensated K uptake from the soil.

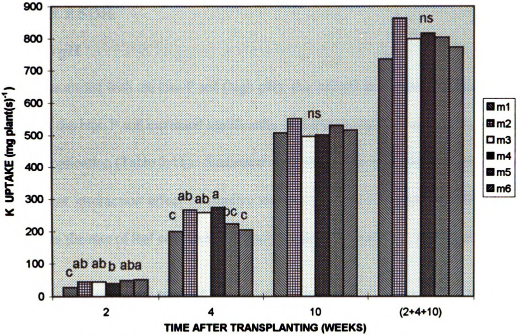

Figure 3.22. Poultry manure effect on K uptake by cabbage grown in a low-P Metea sandy loam.

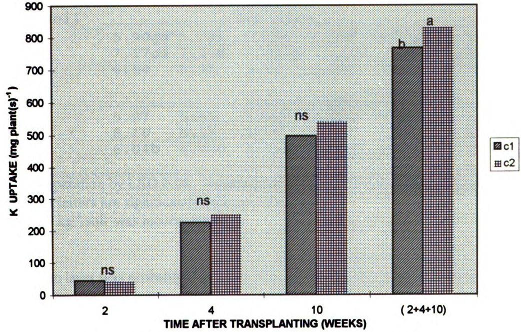

Figure 3.23. Leaf compost effect on K uptake by cabbage grown in a low-P Metea sandy loam.

3.2. HIGH P SOIL

3.2.1. Soil pH

In contrast with the low-P soil (high pH), the soil pH in the top and bottom layer soil solution of the high P soil increased significantly with increasing rates of poultry litter and leaf compost application (Table 3.11). Statistical analysis of data in Table 3.11 shows there was a significant interaction effect of poultry manure and leaf compost on soil pH. Soil pH increased as the rate of leaf compost and poultry manure increased. Increased pH in the top and bottom layer was probably due to the presence of organic matter derived from leaf compost and poultry manure and its decomposition products which reduced the activity of polyvalent cations, especially Al and Fe (Black, 1968, and Hue, 1992). In addition, leaf compost and poultry manure also added Ca into the soil which may have increased the soil

Table 3.11. Soil pH in the top and bottom soil layer of a low pH, high-P Metea sandy loam treated with poultry manure and leaf compost.

Leaf compost incorporated	Manure or TSP incorporated (g kg^{-1})						Mean
	0	TSP[a]	0.25	1.0	1.75	2.5	
g kg^{-1} soil	Top layer						
0	5.90gh*	5.79h	6.02g	6.57f	6.87e	7.16d	6.38
12.5	7.17cd	7.17d	7.23cd	7.33bc	7.42ab	7.52a	7.31
Mean	6.54	6.48	6.63	6.95	7.15	7.34	
	Bottom layer						
0	5.97	5.93	5.96	6.00	6.04	6.12	6.00a
12.5	6.10	6.11	6.08	6.07	6.10	6.15	6.10b
Mean	6.04b	6.02b	6.02b	6.04b	6.07b	6.14a	

* Mean separation by LSD 0.05. Numbers within a row or a column followed by different letters are significantly different at $p < 0.05$.

[a] 0.02 g P kg^{-1} soil was incorporated.

pH. The amounts of calcium contributed by 12.5 g leaf compost kg^{-1} soil was 520 mg Ca, and by 0.25, 1.0, 1.75 and 2.5 g poultry manure kg^{-1} soil were 32, 128, 225 and 320 mg Ca, respectively (Table 3.1). Since some organic matter, its decomposition products and Ca are soluble in water (Brady, 1986), they likely moved into the bottom soil layer by water movement. As a result, pH in the bottom soil layer was increased slightly by poultry manure and leaf compost application. The pH change in the bottom soil layer was only significant for the highest manure rate.

3.2.2. Biomass Accumulation

In the high-P soil, poultry manure applied at 1.0 g kg^{-1} soil (m4) increased dry matter production significantly at 2 weeks of growth (Fig. 3.24). Dry matter produced in soil treated with inorganic fertilizer P (m2) was not significantly different from soil treated with the comparable amount of poultry manure P (m3). By week 10 dry matter production in soil receiving the highest manure rate (2.5 g kg^{-1} soil) was significantly less than with the other manure or inorganic P treatments. This was due to less N available in soil solution as the rates of poultry manure increased. Adding leaf compost had no effect on dry matter production (Fig.3.25).

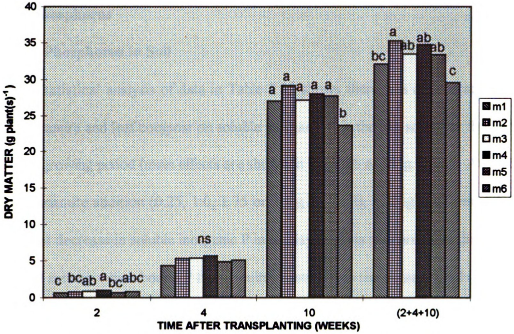

Figure 3.24. Poultry manure effect on dry matter production by cabbage grown in a high-P Metea sandy loam.

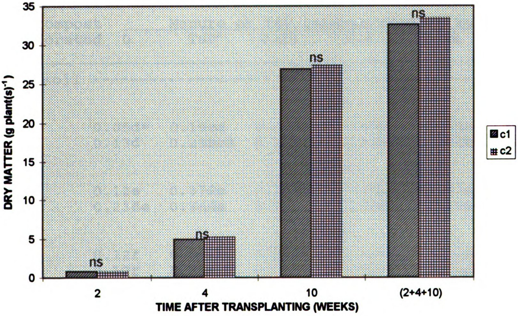

Figure 3.25. Leaf compost effect on dry matter production by cabbage grown in a high-P Metea sandy loam.

3.2.3. Phosphorus

3.2.3.1. Phosphorus in Soil

Statistical analysis of data in Table 3.12 shows there was an interaction effect of poultry manure and leaf compost on soluble inorganic P in the top soil layer throughout the 10 week growing period (main effects are shown in Fig.3.26 and Fig. 3.28). At each rate of poultry manure addition (0.25, 1.0, 1.75 or 2.5 g kg^{-1} soil), adding leaf compost caused a significant decrease in soluble inorganic P in top layer. This was probably due to increased microbial activity which bound P from poultry manure into the organic pool (Brady, 1986).

Table 3.12. Inorganic P concentration in the top layer soil solution of a low pH, high-P Metea sandy loam treated with poultry manure and leaf compost (soils with plants).

Leaf compost incorporated	Manure or TSP incorporated (g kg^{-1})					
	0	TSP[a]	0.25	1.0	1.75	2.5
g kg^{-1} soil			mg P L^{-1}			
			2 Weeks			
0	0.05**d*****	0.10**cd**	0.09**cd**	0.50**b**	0.96**a**	1.28**a**
12.5	0.13**d**	0.29**bcd**	0.06**cd**	0.20**bcd**	0.44**bc**	0.55**b**
			4 Weeks			
0	0.12**e**	0.37**de**	0.26**de**	0.98**bc**	3.03**a**	3.27**a**
12.5	0.23**de**	0.36**de**	0.08**e**	0.40**de**	0.79**cd**	1.54**b**
			7 Weeks			
0	0.12**f**	0.50**ef**	0.29**f**	1.70**cd**	5.11**b**	6.66**a**
12.5	0.12**f**	0.31**f**	0.10**f**	0.48**ef**	1.19**de**	2.29
			10 Weeks			
0	0.09**d**	0.44**d**	0.24**d**	1.78**c**	5.16**b**	6.09**a**
12.5	0.12**d**	0.24**d**	0.13**d**	0.45**d**	1.59**c**	2.27**c**

* Mean separation by LSD 0.05. Numbers within a row or a column followed by different letters are significantly different at $p<0.05$.

[a] 0.02 g P kg^{-1} soil was incorporated.

In this process leaf compost provides humus substance and a lots of fiber (carbonaceous) material while poultry manure supplies nutrients as a sources of food for microorganisms that eventually increased microorganism activity (Brady, 1986). In contrast, with or without leaf compost addition increasing poultry manure rate increased soluble inorganic P concentration in soil. Between weeks 2 and 4 soluble inorganic P in all treatments increased. This shows that initially P from manure, P in the soil or P from fertilizer was slow to be released. Probably at the beginning P was tied up in the microorganisms (Brady, 1986), due to increased microbial activity as water added to the soil which was initially very dry. Throughout the growth period there was no significant difference between soluble P in soil treated with fertilizer P and poultry manure. Increasing poultry manure rates to 1.75 and 2.5 g kg^{-1} soil increased soluble P concentration significantly. This indicates more P was released

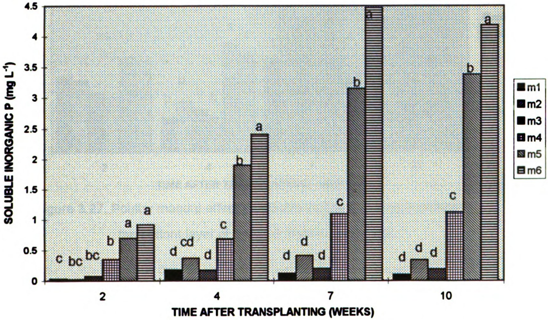

Figure 3.26. Poultry manure effect on soluble inorganic P concentration in the top layer of a high-P Metea sandy loam.

as the amount of P from poultry manure increases.

Figure 3.27 shows that poultry manure rates applied at 1.75 and 2.5 g kg^{-1} soil significantly increased soluble inorganic P concentration in the bottom soil layer starting at 4 weeks. The soluble P concentration increased with time and the trend was similar to the P concentration in the top layer. This suggests that P moved continuously from the top to the bottom soil layer. However, this situation did not occur in soils without plants (Table 3.13). Less P movement occurred because less water was given daily to each pot.

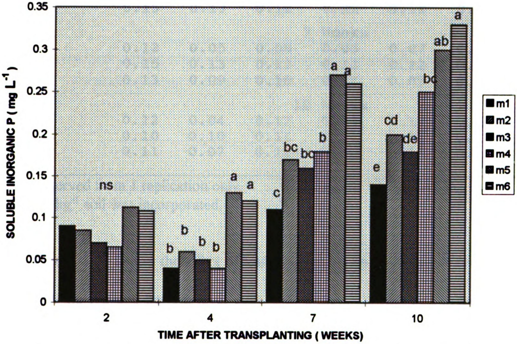

Figure 3.27. Poultry manure effect on soluble inorganic P concentration in the bottom layer of a high-P Metea sandy loam.

Table 3.13. Inorganic P concentration in the bottom layer soil solution of a low pH, high-P Metea sandy loam treated with poultry manure and leaf compost (without plants)*.

Leaf compost incorporated	Manure or TSP incorporated (g kg^{-1})						Mean
	0	TSP[a]	0.25	1.0	1.75	2.5	
g kg^{-1} soil	mg P L^{-1}						
				2 Weeks			
0	0.17	0.09	0.03	0.02	0.14	0.14	0.10
12.5	0.02	0.12	0.20	0.22	0.19	0.15	0.15
Mean	0.09	0.11	0.11	0.12	0.16	0.14	
				4 Weeks			
0	0.17	0.13	0.06	0.25	0.19	0.21	0.17
12.5	0.14	0.13	0.17	0.20	0.16	0.14	0.16
Mean	0.15	0.13	0.12	0.22	0.18	0.18	
				7 Weeks			
0	0.12	0.05	0.08	0.03	0.07	0.17	0.09
12.5	0.15	0.13	0.13	0.12	0.12	0.13	0.13
Mean	0.13	0.09	0.10	0.07	0.09	0.15	
				10 Weeks			
0	0.12	0.04	0.12	0.10	0.10	0.11	0.10
12.5	0.10	0.10	0.11	0.11	0.11	0.12	0.11
Mean	0.11	0.07	0.11	0.10	0.11	0.12	

* data observed from 1 replication only.

[a] 0.02 g P kg^{-1} soil was incorporated.

Figure 3.28 shows the effect of leaf compost on the inorganic P concentration in solution in the top and bottom layer soils with plants. Adding leaf compost caused a significant decrease in soluble inorganic P in the top soil layer starting 2 weeks after transplanting. The same trend occurred in the top layer soils without plants (Table 3.14). This was probably due to microbial activity which bound soluble P into the organic pool. In the bottom soil layer, leaf compost addition did not caused a significant decreased in inorganic P concentration in soil solution (Fig.3.28). A similar situation occurred in soils without plants (Table 3.13).

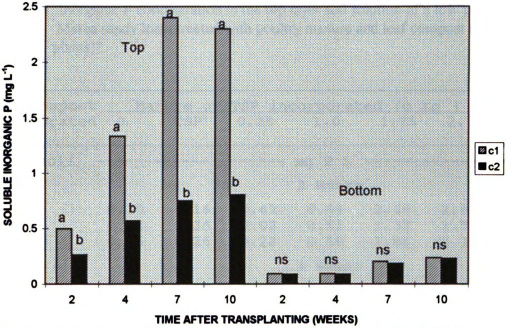

Figure 3.28. Leaf compost effect on soluble inorganic P concentration in the top and bottom layer of a high-P Metea sandy loam.

Table 3.14. Inorganic P concentration in the top layer soil solution of a low pH, high-P Metea sandy loam treated with poultry manure and leaf compost (soils without plants)*.

Leaf compost incorporated	Manure or TSP incorporated (g kg^{-1})						Mean
	0	TSP[a]	0.25	1.0	1.75	2.5	
g kg^{-1} soil	mg P L^{-1}						
				2 Weeks			
0	0.10	0.16	0.42	0.64	2.40	2.66	1.06
12.5	0.01	0.36	0.02	0.51	1.32	1.58	0.63
Mean	0.06	0.26	0.22	0.58	1.86	2.12	
				4 Weeks			
0	0.11	0.15	0.39	0.63	2.71	3.41	1.23
12.5	0.11	0.36	0.17	0.41	1.68	2.12	0.81
Mean	0.11	0.25	0.28	0.52	2.20	2.77	
				7 Weeks			
0	0.07	0.16	0.24	0.33	2.02	3.07	0.98
12.5	0.12	0.08	0.25	0.42	1.10	1.77	0.62
Mean	0.09	0.12	0.24	0.38	1.56	2.42	
				10 Weeks			
0	0.08	0.15	0.26	0.53	2.28	3.04	1.06
12.5	0.15	0.28	0.26	0.36	0.87	1.55	0.58
Mean	0.11	0.22	0.26	0.44	1.57	2.29	

* data observed from 1 replication only.

[a] 0.02 g P kg^{-1} soil was incorporated.

3.2.3.2. Phosphorus in Plant

3.2.3.2.1. Phosphorus Concentration

In the high-P soil, P concentration in the cabbage tissue increased significantly with poultry manure rate throughout the growth period (Fig.3.29). At 2 and 4 weeks after transplanting, P concentration in the plants treated with inorganic fertilizer P (m2) was higher than in plants treated with a comparable P amount from poultry manure (m3). The P

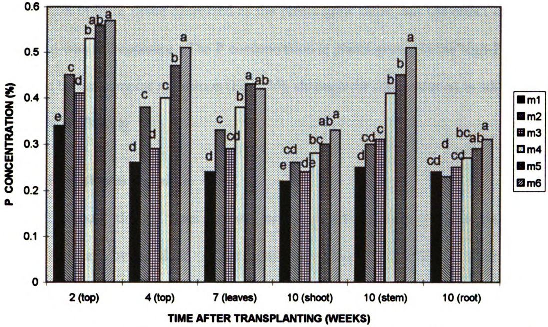

Figure 3.29. Poultry manure effect on P concentration in cabbage tissue grown in a high-P Metea sandy loam.

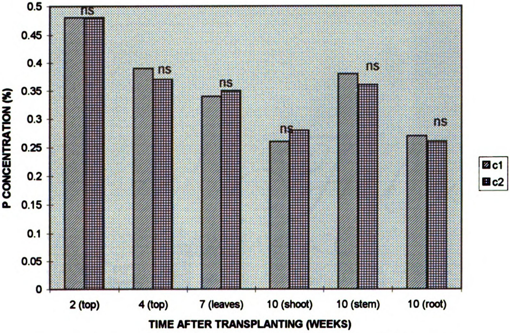

Figure 3.30. Leaf compost effect on P concentration in cabbage tissue grown in a high-P Metea sandy loam.

concentration in plant tissue decreased as the plants grew older, but the effect of poultry manure rate was still apparent. The P concentration in plants grown in the high-P soil was not affected by leaf compost application (Fig.3.30), although the concentration in soil solution decreased significantly.

3.2.3.2.2. Phosphorus Uptake

Throughout the 10 week growth period poultry manure addition significantly increased P uptake by the plant. At the comparable amount of P addition, there were no significant difference between inorganic fertilizer P and poultry manure effect on P uptake by the plant, except at 4 weeks (Fig.3.31). Leaf compost did not decrease P uptake by the plant although soluble P concentration in the soil decreased with compost application (Fig.3.32).

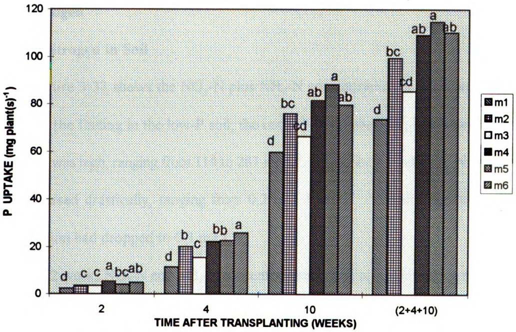

Figure 3.31. Poultry manure effect on P uptake by cabbage grown in a high-P Metea sandy loam.

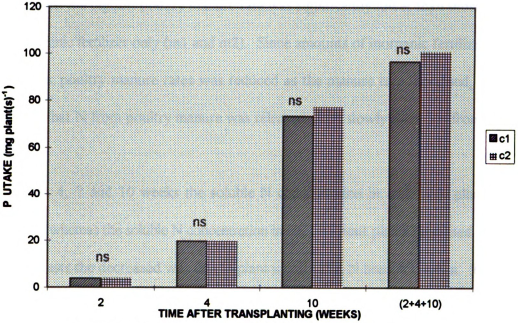

Figure 3.32. Leaf compost effect on P uptake by cabbage grown in a high-P Metea sandy loam.

3.2.4. Nitrogen

3.2.4.1. Nitrogen in Soil

Figure 3.33 shows the NO_3-N plus NH_4-N concentration in top layer soil solution. Similar to the finding in the low-P soil, the initial NO_3-N plus NH_4-N concentration in the high-P soil was high, ranging from 114 to 281 mg L^{-1}. Then, by 4 weeks the N concentration had decreased drastically, ranging from 0.2 to 1.1 mg L^{-1}. Finally, by 10 weeks the N concentration had dropped to 0.1 mg L^{-1}.

At 2 weeks NO_3-N and NH_4-N concentrations in soil solution in the top layer treated with fertilizer P, 0.25, 1.0 and 1.75 Mg ha^{-1} poultry manure (m2, m3, m4 and m5) were not significantly different from control (m1). However, the N concentration in the soil solution was reduced steadily as the manure rate increased. Total soluble N concentration in soil treated with the highest poultry manure rate was significantly lower than those treated only with inorganic fertilizer only (m1 and m2). Since amounts of inorganic fertilizer N added to the higher poultry manure rates was reduced as the manure rate increased, this decrease indicates that N from poultry manure was released more slowly than that from inorganic N fertilizer.

At 4, 7 and 10 weeks the soluble N concentration in soils with plants decreased markedly, whereas the soluble N concentration in soils without plants increased (Table 3.15). This suggests the decreased was due to plant uptake, not N immobilization. The soluble N concentration in the soils without plants at 10 weeks was higher than at 7 weeks, suggesting the rate of N mineralization was still high. In contrast in the low-P (high pH soil), N mineralization slowed greatly after 7 weeks.

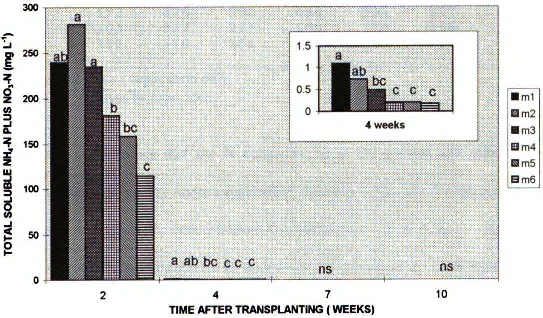

Figure 3.33. Poultry manure effect on total soluble N concentration in the top layer of a high-P Metea sandy loam.

Table 3.15. NO_3-N plus NH_4-N concentration in the top layer soil solution of a low pH, high-P Metea sandy loam treated with poultry manure and leaf compost (soils without plants)*.

Leaf compost incorporated	Manure or TSP incorporated (g kg^{-1})						Mean
	0	TSP[a]	0.25	1.0	1.75	2.5	
g kg^{-1} soil	mg NO_3+NH_4-N L^{-1}						
				2 Weeks			
0	122	127	160	43	68	70	98
12.5	68	60	58	31	61	114	65
Mean	95	93	109	37	64	92	
				4 Weeks			
0	271	191	139	120	92	91	151
12.5	179	302	80	52	56	85	126
Mean	225	246	109	86	74	88	
				7 Weeks			
0	243	251	98	318	323	69	304
25	259	114	43	102	42	89	108
Mean	251	183	70	210	183	79	
				10 Weeks			
0	472	426	280	444	214	127	327
12.5	303	327	221	160	170	136	220
Mean	388	376	251	302	192	131	

* data observed from 1 replication only.

[a] 0.02 g P kg^{-1} soil was incorporated.

Figure 3.34 shows that the N concentration in the bottom soil solution was significantly affected by poultry manure application, during only the first 4 week period after transplanting. At 2 weeks the concentrations ranged from 22.7 to 54.3 mg L^{-1}. By the end of the experiment the concentration for all treatments had decreased to < 0.08 mg L^{-1}. Data in Table 3.16 show that soluble N concentrations in the bottom layer of soils without plants increased with time. This indicates that the decrease in N concentration in soil with plants was due to plant uptake. Changes in soluble N concentration in the bottom layer (Fig.3.34)

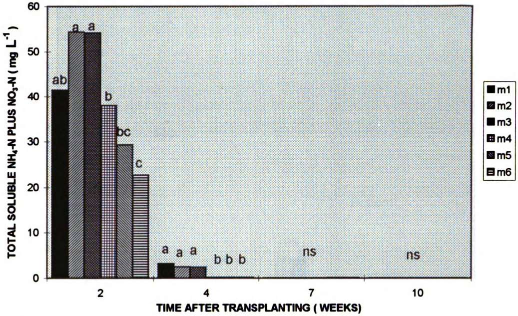

Figure 3.34. Poultry manure effect on total soluble N concentration in the bottom layer of a high-P Metea sandy loam.

were similar to those observed in top layer solution (Fig.3.33), showing that there was N movement from the top to the bottom soil layer.

Data in Figure 3.35 and Tables 3.15 and 3.16 show the effect of leaf compost on NO_3-N plus NH_4-N concentration in the soil solution of the top and bottom soil layers. Although the soluble N concentration in the soil treated with leaf compost was slightly lower than that of untreated soil, the difference was not significant. This is in contrast to the low-P (high pH) where the addition of leaf compost reduced the soluble N concentration significantly. This difference may have been related to the difference in soil pH which affected ammonia adsorption and fixation by organic matter (leaf compost). First, leaf compost contains humus which is negatively charged. This charge is pH dependent and is less at a lower pH (Brady, 1986). As a result, leaf compost in soil with a lower pH (pH 6.2, high-P

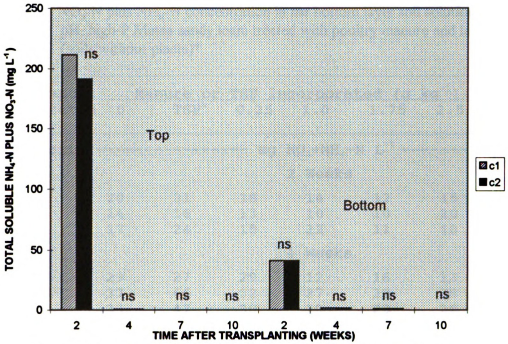

Figure 3.35. Leaf compost effect on total soluble N concentration in the top and bottom layer of a high-P Metea sandy loam.

soil) provides less buffering capacity than in higher pH soil (pH 8.2, low-P soil). Less NH_4^+ adsorption may occur in these colloids which in turn does not significantly decrease amounts of NH_4-N in soil solution. Second, there was a possibility that fertilizer contain free ammonia or that form it (poultry manure) when added to the soil can react with soil organic matter to form compounds that resist decomposition. The reaction takes place most readily in the presence of oxygen and high pH (Brady, 1986). Since the high-P soil has a lower pH, it seems that less ammonia fixation occurred in the high-P soil than in the low-P soil.

Table 3.16. NO_3-N plus NH_4-N concentration in the bottom layer soil solution of a low pH, high-P Metea sandy loam treated with poultry manure and leaf compost (soils without plants)*.

Leaf compost incorporated	Manure or TSP incorporated (g kg^{-1})						Mean
	0	TSP[a]	0.25	1.0	1.75	2.5	
g kg^{-1} soil	mg NO_3+NH_4-N L^{-1}						
				2 Weeks			
0	20	31	18	14	12	15	18
12.5	14	16	13	10	10	20	14
Mean	17	24	15	12	11	18	
				4 Weeks			
0	29	27	29	12	16	13	21
12.5	37	66	32	27	29	39	38
Mean	33	47	30	19	23	26	
				7 Weeks			
0	57	42	59	45	60	37	50
12.5	38	37	22	41	41	58	39
Mean	47	40	40	43	50	47	
				10 Weeks			
0	70	74	92	100	153	88	96
12.5	137	101	66	99	98	93	99
Mean	103	88	79	99	126	90	

* data observed from 1 replication only.

[a] 0.02 g P kg^{-1} soil was incorporated.

3.2.4.2. Nitrogen in Plant

3.2.4.2.1. Nitrogen Concentration

Similar to the results in low-P soil, there was no significant effect of poultry manure on N concentration in cabbage plants 2 weeks after transplanting (Fig 3.36). There was an interaction effect of poultry manure and leaf compost on N concentration in shoots at 4 weeks ($p<0.05$). At similar rate of leaf compost addition, N concentration in plant tissue decreased with poultry manure rate. This was because N concentration in the soil solution

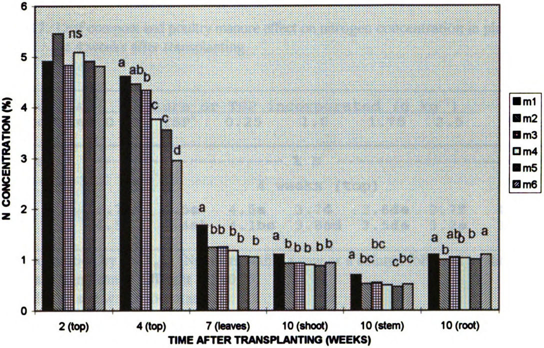

Figure 3.36. Poultry manure effect on N concentration in cabbage tissue grown in a high-P Metea sandy loam.

decreased as poultry manure rate increased. At the highest rate of manure application (m6), N concentration in shoots increased significantly with leaf compost addition (Table 3.17). This data shows that leaf compost increased N uptake by the plant as the source of N comes only from poultry manure.

There was no significant difference between the N concentration in plants treated with inorganic fertilizer N (m2) and the one treated with a comparable N amount from poultry manure (m6), except in the shoots at 4 weeks and in the root 10 weeks after transplanting (Fig. 3.36). The N concentration in plant tissue decreased as the plants grew older. Figure 3.37 shows that the N concentration in plants grown in the high-P soil was not affected by leaf compost application (Fig. 3.37).

Table 3.17. Leaf compost and poultry manure effect on nitrogen concentration in plant tissue at 4 weeks after transplanting.

Leaf compost incorporated	Manure or TSP incorporated (g kg^{-1})						
	0	TSP[a]	0.25	1.0	1.75	2.5	Mean
g kg^{-1} soil				% N			
				4 weeks (top)			
0	4.7**a***	4.5**a**	4.6**a**	3.7**d**	3.6**de**	2.7**f**	4.0**a**
12.5	4.5**a**	4.4**ab**	4.1**bc**	3.8**cd**	3.5**de**	3.2**e**	3.9**a**

* Mean separation by LSD $_{0.05}$. Numbers within a row or a column followed by different letters are significantly different at $p<0.05$.

[a] 0.02 g P kg^{-1} soil was incorporated.

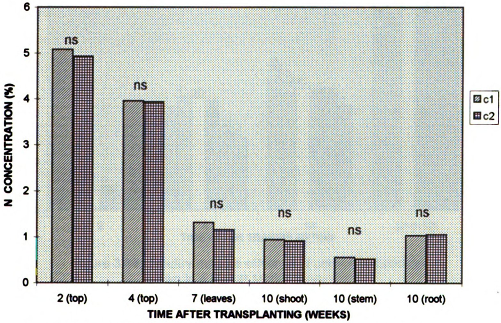

Figure 3.37. Leaf compost effect on N concentration in cabbage tissue grown in a high-P Metea sandy loam.

3.2.4.2.2. Nitrogen Uptake

At 4 weeks after transplanting poultry manure decreased N uptake by the plant. The decrease was significant at the highest rate of manure application (Fig.3.38). This was related to lower N concentrations in the soil solution as the manure rate increased. The N uptake by plants grown in the high-P soil was not affected by leaf compost application (Fig.3.39), despite a slight decrease in the N concentration in soil solution.

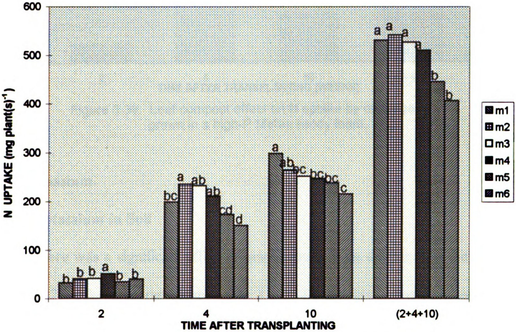

Figure 3.38. Poultry manure effect on N uptake by cabbage grown in a high-P Metea sandy loam.

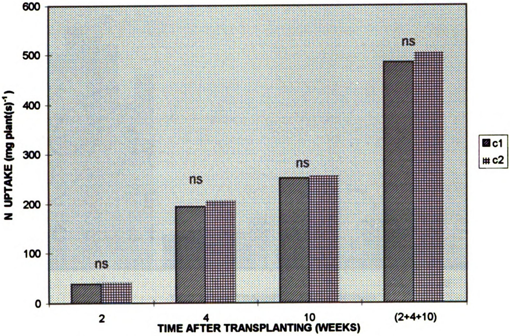

Figure 3.39. Leaf compost effect on N uptake by cabbage grown in a high-P Metea sandy loam.

3.2.5. Potassium

3.2.5.1. Potassium in Soil

There was a significant effect of poultry manure on soluble K in the top soil layer starting at 7 weeks after transplanting (Fig.3.40). Similar to the finding in low-P soil, only the highest manure rate caused a significant increase in the soluble K concentration. There was no significant difference in the effect of inorganic fertilizer K (m2) and poultry manure (m3, m4, and m5) on the soluble K concentration in the top soil layer, where the K level was equalized. This indicates that K from poultry manure was released as fast as from inorganic fertilizer. From 4 to 7 weeks, the K concentration in soils with plants was always lower than K concentration in soils without plants (Table 3.18), and its concentration decreased with the time. This suggests that the decrease in K concentration was due to plant uptake.

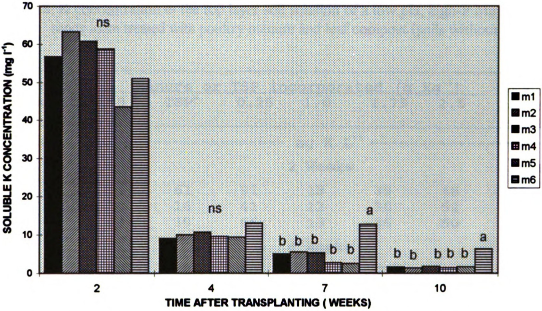

Figure 3.40. Poultry manure effect on soluble K concentration in the top layer of a high-P Metea sandy loam.

Table 3.18. K concentration in the top layer soil solution of a low pH, high-P Metea sandy loam treated with poultry manure and leaf compost (soils without plants)*.

Leaf compost incorporated	Manure or TSP incorporated ($g\ kg^{-1}$)						Mean
	0	TSP[a]	0.25	1.0	1.75	2.5	
$g\ kg^{-1}$ soil	-------------------		$mg\ K\ L^{-1}$			-------------------	
			2 Weeks				
0	61	61	91	18	39	48	53
12.5	24	16	41	12	30	52	29
Mean	43	39	66	15	35	50	
			4 Weeks				
0	100	78	80	18	43	48	61
12.5	71	63	43	27	23	40	44
Mean	85	70	62	23	33	44	
			7 Weeks				
0	288	158	44	96	105	34	121
12.5	58	35	20	26	16	31	31
Mean	173	96	32	61	61	32	
			10 Weeks				
0	191	175	96	173	84	43	127
12.5	104	87	67	33	43	42	63
Mean	148	131	81	103	64	43	

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* data observed from 1 replication only.

[a] 0.02 $g\ P\ kg^{-1}$ soil was incorporated.

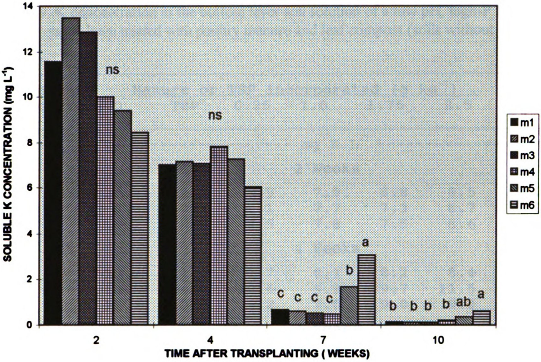

Figure 3.41. Poultry manure effect on soluble K concentration in the bottom layer of a high-P Metea sandy loam.

The soluble K concentration in the bottom soil layer decreased with time paralleling the trend found in the top soil layer (Fig.3.41), indicating that K in soils with plants continuously moved from the top to the bottom soil layer. Starting at 4 weeks, the K concentration in soils with plants was lower than that in soils without plants (Table 3.19), suggesting that the decrease in K concentration was due to plant uptake.

Table 3.19. K concentration in the bottom layer soil solution of a low pH, high-P Metea sandy loam treated with poultry manure and leaf compost (soils without plants)*.

Leaf compost incorporated	Manure or TSP incorporated (g kg^{-1})						
	0	TSP[a]	0.25	1.0	1.75	2.5	Mean
g kg^{-1} soil	mg K L^{-1}						
	2 Weeks						
0	10.4	11.4	8.9	7.9	8.8	8.5	9.2
12.5	8.0	8.1	8.1	7.7	7.3	8.7	7.9
Mean	9.2	9.8	8.5	7.8	7.5	8.6	
	4 Weeks						
0	13.2	11.3	11.7	8.1	8.2	8.4	10.2
12.5	12.5	14.2	10.6	9.9	9.7	11.5	11.2
Mean	12.3	12.8	11.2	9.0	9.0	9.9	
	7 Weeks						
0	17.5	15.5	15.1	11.4	13.5	10.7	14.0
12.5	12.9	12.2	8.3	12.2	9.8	15.0	11.6
Mean	14.7	13.8	11.7	11.8	11.6	12.8	
	10 Weeks						
0	19.8	27.3	21.4	22.7	24.6	16.9	22.1
12.5	24.6	19.7	14.1	19.7	20.2	21.8	19.9
Mean	22.2	23.0	17.8	21.2	22.4	19.4	

* data observed from 1 replication only.

[a] 0.02 g P kg^{-1} soil was incorporated.

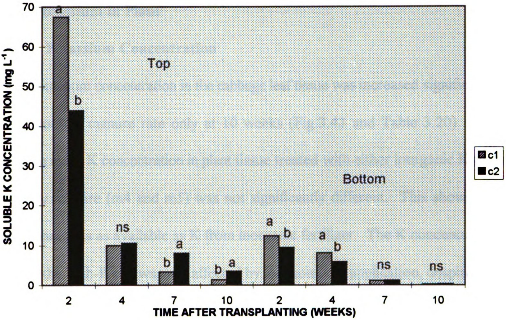

Figure 3.42. Leaf compost effect on soluble K concentration in the top and bottom layer of a high-P Metea sandy loam.

Figure 3.42 shows the effect of leaf compost on soluble K concentration in the top and bottom layers of soils with plants. Adding leaf compost caused a significant decrease in soluble K in the top at 2 weeks and in bottom soil layers at 2 and 4 weeks. Starting at 7 weeks K concentration in top soil solution was greater with leaf compost applied than without. Throughout the 10 weeks K concentration in top layer soil without plants decreased when leaf compost was applied (Table 3.18). It is concluded that leaf compost application decreased the K concentration in soil solution. The decrease in K concentration in soil without plants may have been due to increased microorganism growth immobilizing K (Brady, 1986). This conclusion suggests that the difference in soluble K concentration in top layer of soils with plants at 7 and 10 weeks was not the direct effect of K solubility in leaf compost, but was due to a difference in plant uptake.

3.2.5.2. Potassium in Plant

3.2.5.2.1. Potassium Concentration

Potassium concentration in the cabbage leaf tissue was increased significantly with the highest poultry manure rate only at 10 weeks (Fig.3.43 and Table 3.20). At similar K application rates, K concentration in plant tissue treated with either inorganic K (m1 and m2) or poultry manure (m4 and m5) was not significantly different. This shows that K from poultry manure is as available as K from inorganic fertilizer. The K concentration in plants grown in the high-P soil was not affected by leaf compost application, despite the decrease K concentration in soil solution (Table 3.18 and 3.19).

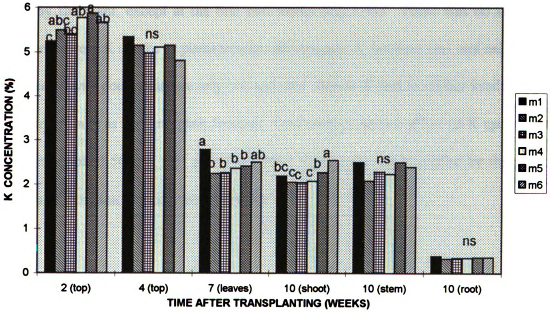

Figure 3. 43. Poultry manure effect on K concentration in cabbage tissue grown in a high-P Metea sandy loam.

Table 3.20. Potassium concentration in head and leaves at 10 weeks after transplanting.

Leaf compost incorporated	Manure or TSP incorporated (g kg^{-1})					
	0	TSP[a]	0.25	1.0	1.75	2.5
g kg^{-1} soil	mg K L^{-1}					
0	2.4**ab***[*]	1.9**d**	2.1**cd**	2.1**cd**	2.2**cd**	2.6**a**
12.5	2.0**cd**	2.2**bc**	2.0**cd**	2.1**cd**	2.4**ab**	2.5**a**

[*] Mean separation by LSD $_{0.05}$. Numbers within a row or a column followed by different letters are significantly different at $p<0.05$.

[a] 0.02 g P kg^{-1} soil was incorporated.

3.2.5.2.2. Potassium Uptake

Throughout the 10 week growth period poultry manure addition did not affect the K uptake by the plant, except at the first two weeks (Fig.3.44). There was no significant difference between K uptake by plants treated with inorganic K fertilizer (m1 and m2) and the plants treated with poultry manure only (m5 and m6). Hence, K was as readily available from the poultry manure as from inorganic fertilizer. Leaf compost had no effect on K uptake even though it supplied 50 g K kg^{-1} soil (Fig.3.45). Apparently the K applied by the poultry manure and inorganic fertilizer was adequate.

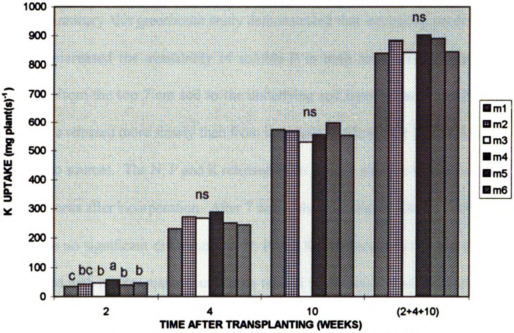

Figure 3.44. Poultry manure effect on K uptake by cabbage grown in a high-P Metea sandy loam.

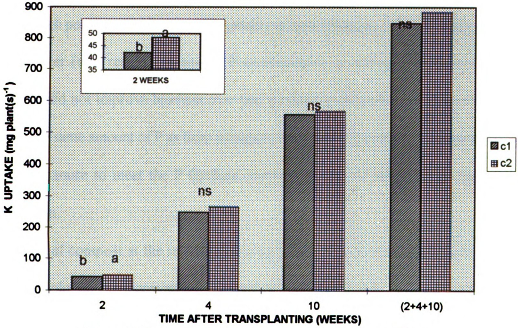

Figure 3.45. Leaf compost effect on K uptake by cabbage grown in a high-P Metea sandy loam.

4. SUMMARY AND CONCLUSIONS

In summary this greenhouse study demonstrated that increasing poultry manure rate gradually increased the availability of soluble P in both soils. There was N, P and K movement from the top 7 cm soil to the underlying soil layer. The N and P from poultry manure were released more slowly than from inorganic fertilizer, but K was released equally from the two sources. The N, P and K released from poultry manure increased with time for the first 7 weeks after incorporation. After 7 weeks the N, P and K release in the soil slowed. There were no significant differences in N, P and K concentration in plant tissue between plants treated with poultry manure and those treated with commercial fertilizer. In addition, there were no significant differences in P (except in the low P soil) and K uptake by cabbage, and total biomass production between the poultry manure and commercial fertilizer treatments. N uptake by cabbage treated with N fertilizer was significantly higher than those treated with poultry manure. Applying poultry manure to supply 2.5 to 4 times the P supplied by fertilizer (m4) resulted in similar P accumulation in cabbage. However, these higher amounts did not improve biomass over that produced when poultry manure was applied to supply the same amount of P as from inorganic fertilizer. Therefore, it appears that applying poultry manure to meet the P fertilizer recommendation is adequate for optimizing crop production.

Leaf compost at the rate of 12.5 g kg^{-1} soil reduced the concentration of N, P, and K in soil solution, but increased plant growth and nutrient uptake. The effect of leaf compost on increasing plant growth and nutrient uptake was only significant in the low P soil (high pH= 8.2). A decrease in nutrient concentration in soil solution following leaf compost application may reduce the potential for N, P and K leaching to ground water. Therefore, although leaf compost does not contribute much nutritional, its application has the potential for improving plant growth and groundwater quality.

CHAPTER 4

THE EFFECT OF LEAF COMPOST AND POULTRY MANURE ON SOIL CHEMICAL PROPERTIES, GROWTH AND YIELDS OF SOME SELECTED VEGETABLE CROPS (1991)

1. INTRODUCTION

Land application of organic residue from leaf compost and poultry manure is an important management practice to recycle nutrients and to improve soil fertility. The litter from poultry manure is a rich source of nutrients for crop production and a low-cost alternative to mineral fertilizer for many farmers (Huhnke, 1982). However, use of organic residue for optimum crop yields often conflicts with potential groundwater contamination. This situation is particularly important in the area where the number of poultry operations have dramatically increased and has created public concern over potential groundwater pollution regarding the use and disposal of the associated manure.

Organic waste application rates are often based on estimated crop yields and estimated available N from manure during the growing season. Excessive amounts of N may be applied by farmers to assure high yields. Kingery et al. (1994) observed that 15 to 28 years of applying 6 to 22 Mg broiler litter ha^{-1} yr^{-1} increased organic C and total N to depths of 15 and 30 cm, respectively, increased soil pH by 0.5 units to a depth of 60 cm, and significantly increased the accumulation of soil NO_3-N to or near bedrock. Extractable P concentration in litter-amended soil was more than 6 times greater to a depth of 60 cm than in soil not receiving broiler litter. Elevated levels of extractable K, Ca and Mg to a depth greater than 60 cm and accumulation of extractable Cu and Zn to a depth of 45 cm were also found. From analyses of field soils, Van der Watt et al. (1994) found that the build-up of possible toxic levels of Cu, Mn, and Zn occurred only in one soil which had received 6 Mg ha^{-1} yr^{-1} poultry litter for 16 years.

Some researchers found that high rates of manure application caused high levels of total soluble salt (Ayers and Haywards, 1948; Shortall and Liebhardt, 1975; Weil et al., 1979), nitrites (Bingham et al., 1954; Court et al., 1962; Oke, 1966; Lamaire, 1969; Weil et al, 1979) and NH_3 (Aleem and Alexander; 1960; Giddens and Rao, 1975; Siegel et al., 1975; Weil et al.,1979) at levels that were toxic to both crops and microorganisms.

Hue (1992) found that application of 20 Mg ha^{-1} chicken manure in acid soil, increased soil pH from 4.19 to 6.24, increased soil salinity and concentrations of P, K, Ca, and Mg in soil solution and plant tissue, and increased total plant (*Desmodium intortion*) dry matter.

Application of ammonium-containing fertilizer, which quickly hydrolyses to NH_3, can result in significant losses of ammonia gas, especially on sandy soils and alkaline or calcareous soil. Both the organic and inorganic soil fractions have the ability to bind or "fix" ammonia in forms relatively unavailable to higher plants or microorganisms. Anhydrous ammonia or other fertilizers that contain free ammonia or that form it when added to the soil can react with soil organic matter to form organic compounds that resist decomposition. In this sense the ammonia can be said to be "fixed" by organic matter. The reaction takes place most readily in the presence of oxygen and at high pHs. In organic soils with high fixing capacity it could be serious and would dictate the use of fertilizer other than those which supply free ammonia (Brady, 1986).

Research conducted by Brage et al. (1952), Halstead and Sowden (1968) showed that manure increased both CEC and soil pH. Metzger (1939), and Bishop et al. (1962) showed that manure application increased CEC of the soil. Hileman (1971) showed that manure increased soil pH only, whereas Bishop et al. (1962) indicated that the effect was negligible.

Greenhouse study conducted in 1990 (Chapter 2), showed that high rates of poultry manure application reduced seed germination. The adverse effect on seed germination was lower in Capac loam (higher CEC) than in McBride sandy loam (lower CEC). Following lab study in 1990, showed increasing poultry manure rate increased soil salinity and ammonia release from McBride sandy loam and Capac loam. Soil with a higher CEC (Capac loam) had a lower NH_3 release and soluble salt concentration changing than soil with the lower CEC (McBride sandy loam). The decrease in seed germination may have been related to the increase of NH_3 release and/ or increase of salinity in both soils. Since adding leaf compost will increase organic matter and the CEC of a soil, leaf compost may alleviate NH_3 toxicity and reduce soluble salt concentration. Therefore, we were interested in determining whether this effect would occur in the field. In this study high application rates of leaf compost and poultry manure were used where the rates of poultry manure was considered potentially toxicity for seed germination. The effect of leaf compost and poultry manure application on the N, P, K, Ca, Mg and some trace elements Cu, Fe, Mn and Zn in soil and plant were investigated.

Objectives

1) To evaluate the effect of high amounts of leaf compost and poultry manure application on germination, growth, yields, and some soil chemical properties.
2) To evaluate the interaction effect of leaf compost and poultry manure on germination, growth, yields, and some soil chemical properties.
3) To evaluate the effect of methods of application on germination, growth, yields, and some soil chemical properties.

Hypotheses

1) Dried poultry manure will increase N, P, K , Ca, Mg, and trace element concentrations and availability in the soil.
2) Leaf compost will increase nutrient availability to the plant.
3) Combining leaf compost and dried poultry manure will reduce NH_3 toxicity to germinating seed and seedling.
4) Band application will supply fewer nutrients to the plant than incorporated poultry manure and/or leaf compost.

2. MATERIALS AND METHODS

Two soils, a Houghton muck and a Capac loam, were used in these field studies. Samples of the two soils were air dried and passed through a 2 mm sieve, and analyzed for pH (1:1 soil : 0.01M $CaCl_2$ solution ratio) (Eckert, 1988), total N concentration by a Kjeldahl procedure (Bremner and Mulvaney. 1982), NO_3-N and NH_4-N (KCl extraction, Keeney and

Nelson, 1982), extractable P (Bray and Kurtz P1, Knudsen and Beegle, 1988), and exchangeable K (1M NH_4OAc at pH 7.0, Brown and Warncke, 1988). The soils were also analyzed for Cu (1N HCl), Fe (0.1 N HCl), Mn (0.1 N HCl), and Zn (0.1 N HCl) (Whitney, 1988). Ten soil cores of 20 cm depth were taken from every plot in the Capac loam after snap bean harvest. Each sample was analyzed for pH, P, K, Ca, Mg, Cu, Fe, Mn, and Zn with the same procedures used for the soil samples before planting.

Leaf compost and dried poultry manure used in this experiment were passed through a 2 mm sieve prior to elemental analysis. Moisture content and pH were determined on the bulk sample. Organic C was determined by the Loss-On-Ignition procedure adapted from Storer, 1984 (Schulte, 1988). The total P, K, Ca, Mg, Cu, Fe, Mn, Zn, B, Mo, Al and Na contents were determined by dry ashing at 500 °C followed by dissolution with 3N HNO_3 containing 1000 ppm LiCl. Element concentrations were determined with a Direct Current Plasma Atomic Emission Spectrophotometer (DCP-AES). Total N, NO_3-N and NH_4-N contents were analyzed by the same procedures used for soil. Total element contents of leaf compost and poultry manure are presented on a dry-weight basis. The complete data set of soils analysis, and element content of leaf compost and poultry manure are shown in Table 4.1.

Table 4.1. Some chemical properties of a Houghton Muck, Capac loam, poultry manure and leaf compost used in this study.

Chemical properties	Muck soil (Houghton)	Mineral soil (Capac)	Poultry manure	Leaf compost
Moist (%)	-	-	16.0	54.0
pH	6.4	6.5	6.9	7.4
Organic C (%)	47.3	1.6	25.5	17.4
Elements (g kg^{-1})**:**				
Total N	28.5	2.9	32.7	9.7
	-- Extractable --		**----- Total -----**	
P	0.19	0.08	27.2	0.9
K	0.44	0.16	40.5	4.3
Ca	14.22	1.68	66.6	40.1
Mg	1.90	0.31	7.3	7.2
Cu	0.03	0.01	0.3	0.01
Fe	0.02	0.04	1.3	6.9
Mn	0.04	0.05	1.1	0.11
Zn	0.01	0.01	0.5	0.06
B	-	-	0.2	0.06
Mo	-	-	0.1	0.01
Na	-	-	4.6	0.71
Al	-	-	2.5	11.9

Cabbage (cultivar Market Topper), carrot (cultivar Paramount), and onion (cultivar Sweet Sandwich) were grown in a Houghton muck at the MSU Research Farm. Snap bean (cultivar Bush Blue Lake) was grown in a Capac loam at the MSU Horticulture Research Center. Cabbage, carrots and onions were seeded during mid-May in three row beds with 46 cm between rows. The cabbage was thinned to one plant every 35 cm. The snap beans were seeded in early June. Ten carrot plants were harvested from each plot at 3 and 6 weeks after planting to observe biomass accumulation. Fully developed outer wrapper leaves for cabbage were counted at 7 weeks after planting to measure the vegetative growth. Whole plant samples of snap beans were collected at harvest (9 weeks) and analyzed for nutrient content. Plant tissue samples were dry ashed at 500 °C and the ash was digested with 3N HNO_3 containing 1000 ppm LiCl. Element concentrations were determined by DCP-AES. Carrot, onion, snap bean and cabbage were harvest at 16, 21, 9 and 12 weeks, respectively from 5 m of one center row. Plant dry weight was measured after oven drying for 3 days at 65 °C.

The experimental design was a 2x3x3 factorial, arranged as a Randomized Complete Block in 3 replications. Factor A included 2 methods of applications: banded and incorporated. Factor B included 3 rates of poultry manure: 0, 12.5 and 25 Mg ha^{-1}. Factor C included 3 rates of leaf compost: 0, 12.5 and 25 Mg ha^{-1}. The soil was plowed and treatments were applied one day prior to sowing time. In band application, poultry manure and leaf compost was placed in a band on the soil surface between the rows, 5 cm from the plant row. When poultry manure and leaf compost were applied together, leaf compost was placed on top of poultry manure. For the incorporated treatments the poultry manure and leaf compost were rototilled into the soil. Treatment differences for each variable observed were tested using the LSD, $P<0.05$. The amount of nutrients applied are shown in Table 4.2.

Table 4.2. Total estimated amounts of nutrients applied to the soils from poultry manure and leaf compost.

Treatment	N	P	K	Ca	Mg	Cu	Fe	Mn	Zn
	-------------------			kg ha^{-1}					-------------------
P. Manure: (Mg ha^{-1})									
0	0	0	0	0	0	0	0	0	0
12.5	410	340	505	835	95	3.6	16	14	6
25	820	680	1,010	1,670	190	7.2	32	28	12
L. Compost: (Mg ha^{-1})									
0	0	0	0	0	0	0	0	0	0
12.5	120	12	55	500	90	0.1	87	1.4	0.8
25	240	24	110	1,000	180	0.2	174	2.8	1.6

3. RESULTS AND DISCUSSION

3.1. Soil Chemical Properties - Snap Bean Study

3.1.1. Soil pH, CEC, Salinity, Extractable P, Exchangeable K, Ca, and Mg in the Soil

Application method had no significant effect on pH, CEC, salinity, extractable P, and exchangeable K, Ca and Mg in the Capac loam. Although the value for each measurement in the incorporated treatments was higher than in banded treatments (except for K), the difference was not significant (Table 4.3). By harvest time the poultry manure had decayed and only a small portion of the leaf compost was recognizable on the soil surface. Some of the roots grew near the soil surface, especially when residues were band applied. For these reasons only the undecayed part of leaf compost on the very top of soil sample (1 cm) was discarded when soil samples were collected. Hence, there was no significant effect of application method on measured soil parameters.

No interaction effect of poultry manure, leaf compost and application method on the measured soil parameter (except for extractable P concentration) was observed. Application of 12.5 Mg ha^{-1} poultry manure significantly increased soil salinity, extractable P and K. Increasing the rate to 25 Mg ha^{-1} poultry manure significantly increased soil pH, CEC, salinity, extractable P, and exchangeable K, Ca and Mg compared to the control (Table 4.3). The possible mechanism to explain how these elements became more available is phosphate along with other nutrients were released from poultry manure during decomposition (Hue, 1992). Adding 12.5 Mg ha^{-1} leaf compost had no effect on soil pH, CEC, salinity, P, K, Ca and Mg in the Capac loam. Increasing the rate to 25 Mg ha^{-1} leaf compost significantly increased the

Table 4.3. Effect of poultry manure, leaf compost and application method on pH, CEC, salinity, P, K, Ca, and Mg concentration in a Capac loam where snap beans were grown (main effect).

Treatment	pH	CEC	Salinity	P	K	Ca	Mg
		cmol kg^{-1}	dSm^{-1}	-------- mg kg^{-1} --------			
A. method:							
Incorporated	6.6a*	9.6a	0.38a	155a	191a	1,209a	290a
Banded	6.5a	9.3a	0.35a	148a	194a	1,153a	272a
P. manure: (Mg ha^{-1})							
0	6.4b	9.1b	0.22c	82c	146c	1,099b	268b
12.5	6.5ab	9.2b	0.36b	152b	184b	1,121b	266b
25	6.7a	10.1a	0.52a	221a	248a	1,325a	309a
L. compost: (Mg ha^{-1})							
0	6.5a	8.6b	0.35a	148a	188a	1,099b	267b
12.5	6.5a	9.1b	0.38a	156a	191a	1,117b	265b
25	6.6a	10.7a	0.37a	151a	199a	1,328a	311a

* Mean separation by LSD 0.05. Numbers within a column followed by different letters are significantly different at $p<0.05$.

CEC, exchangeable Ca and Mg only. Leaf compost had no significant effect on P and K concentration in the soil, because additions of P and K from leaf compost applications were very low compared to those in poultry manure (Table 4.2).

There was an interaction effect of application method and poultry manure on extractable P concentration in the Capac loam (Table 4.4). In both application methods, P concentration in the soil increased significantly with poultry manure rate. At 0 and 12.5 Mg ha^{-1} poultry manure, P concentration in both application methods was not significantly different. At 25 Mg ha^{-1} poultry manure, P concentration in the top 20 cm soil was significantly lower when poultry manure was applied on the soil surface as compared to being incorporated. This indicates that the decomposition process was more effective when poultry manure was mixed thoroughly with the soil.

Table 4.4. Effect of poultry manure rate and application method on P concentration in a Capac loam where snap beans were grown (interaction effect).

Manure applied	Methods of application	
	Incorporated	Banded
-- Mg ha^{-1} --	------ mg kg^{-1} P ------	
0	81d*	82d
12.5	145c	159c
25.0	240a	202b

* Mean separation by LSD 0.05. Numbers within a row or column followed by different letters are significantly different at $p<0.05$.

3.1.2. Extractable Cu, Fe, Mn and Zn Concentration in the Soil

No significant effect of application method on extractable Cu, Fe, Mn and Zn concentration in the top 20 cm of the Capac loam was found (Table 4.5). At harvest, poultry manure and/or leaf compost applied on the soil surface had decayed, so only a small part of the residue could be recognized. Only the undecayed part of leaf compost on the very top of the soil sample (1 cm) was discarded. Hence, even though the nutrients were concentrated near the soil surface they were included in the soil sample. For this reason there was no significant effect of application method on the extractable levels of these micronutrients.

Table 4.5. Effect of poultry manure, leaf compost and application method on extractable Cu, Fe, Mn, and Zn concentration in the soil where snap beans were grown (main effect).

Treatment	Cu	Fe	Mn	Zn
	----------------	mg kg^{-1}	----------------	
A. method:				
Incorporated	4.1**a*****	46.8**a**	52.4**a**	7.0**a**
Banded	4.0**a**	48.8**a**	51.8**a**	9.6**a**
P. manure: (Mg ha^{-1})				
0	3.7**b**	51.9**a**	44.9**b**	5.9**b**
12.5	3.9**b**	50.1**a**	45.9**b**	6.7**b**
25.0	4.6**a**	41.5**b**	65.5**a**	12.0**a**
L. compost: (Mg ha^{-1})				
0	4.1**a**	49.5**a**	45.3**b**	7.2**a**
12.5	4.0**a**	48.9**a**	48.2**b**	8.6**a**
25	4.2**a**	45.2**a**	62.8**a**	9.1**a**

* Mean separation by LSD 0.05. Numbers within a column followed by different letters are significantly different at $p<0.05$.

Application of 12.5 Mg ha^{-1} poultry manure did not significantly affect the Cu, Fe, Mn and Zn concentrations in the soil, but 25.0 Mg ha^{-1} significantly increased Cu, Mn and Zn concentrations in the soil and significantly decreased the Fe concentration. Singhania et al. (1983) also observed that manure increased the water- soluble Zn. Possible mechanisms to explain how these nutrients became more available are: 1) Copper, Mn and Zn were released from manure itself during decomposition (Hue, 1992); 2) Increasing amounts of organic matter created reducing conditions and decreased the oxide fraction making the Cu, Mn, and Zn more bioavailable (Mandal and Mandal, 1987a,b; Shuman, 1988); 3) Copper, Fe, Mn and Zn form soluble organic complexes through a chelation process (Chen and Stevenson, 1986; Hodgson et al 1966; Barber, 1984). The decrease in extractable Fe concentration may have been related to the increase in soil pH from 6.4 to 6.7. Iron uptake by the snap bean plants increased despite a significant decrease in extractable levels in the soil (Table 4.9). This indicates that less Fe was present in the soluble inorganic form, but more was present in the organic form that was available to the plant.

Leaf compost application at the rate of 12.5 Mg ha^{-1} had no effect on Cu, Fe, Mn and Zn concentrations in the soil. This occurred because leaf compost supplied only a small amount of Cu, Mn and Zn compare to poultry manure (Table 4.2). Increasing the rate to 25 Mg ha^{-1} leaf compost significantly increased the extractable Mn concentrations. Since leaf compost contained only a small amount of Mn, the possible mechanisms to explain how Mn became more available are: 1) Increasing amounts of organic matter created reducing conditions and decreased the oxide fraction (Mandal and Mandal, 1987 a, b; Shuman, 1988) making Mn originally present in the soil became more soluble (Table 4.1); 2) Soil Mn formed soluble organic complexes through chelation process (Chen and Stevenson, 1986; Hodgson et al 1966; Barber, 1984).

3.2. Nutrient Concentrations in Plant Tissue

3.2.1. Macro-Nutrient Concentrations in Snap Bean Tissue

Data in Table 4.6 show that P, K, Ca, and Mg concentrations in snap bean shoot (stems and leaves) for all treatments were in the range sufficient for normal growth (Jones, et al. 1991). The N concentration was considered low (Jones, et al. 1991), probably because of N translocation to the pods. However, N, Ca and Mg concentrations in the shoots (Table 4.6), and N and K concentration in pods (Table 4.7) were significantly higher when poultry manure and/or leaf compost were incorporated than when they were applied on the soil surface (band application). This indicates that those elements were more available to the plant when the poultry manure and leaf compost were incorporated than when banded on the soil surface, inspite of no difference in concentration in the top 20 cm of soil (Table 4.3). This occurred because when the residues were incorporated the nutrients were distributed in the soil. Whether they reached the root by mass flow and/or root interception (Brady, 1986) the process was more effective when all nutrients were uniformly distributed in the soil than when they were concentrated near the soil surface.

There was no significant difference in P and K concentration in the shoots for the two methods of application (Table 4.6). These elements move to the root surface mostly by diffusion (Barber, 1974; Brady, 1986) suggesting that P and K continuously moved from the higher concentration zone near the soil surface to the soil below where the roots were

Table 4.6. Effect of poultry manure, leaf compost and application method on N, P, K, Ca, and Mg concentration in snap bean shoots (main effect).

Treatment	N	P	K	Ca	Mg
	----------------		%		----------------
A. method:					
Incorporated	3.0a*	0.32a	3.6a	2.8a	0.55a
Banded	2.7b	0.31a	3.6a	2.0b	0.41b
P. manure: (Mg ha^{-1})					
0	2.6b	0.28c	3.0c	1.9c	0.43b
12.5	2.9a	0.32b	3.6b	2.5b	0.50a
25.0	3.0a	0.35a	4.2a	2.8a	0.52a
L. compost: (Mg ha^{-1})					
0	2.8a	0.32a	3.5a	2.3a	0.47a
12.5	2.9a	0.31a	3.6a	2.4a	0.49a
25.0	2.9a	0.32a	3.7a	2.4a	0.49a

* Mean separation by LSD 0.05. Numbers within a column followed by different letters are significantly different at $p<0.05$.

growing. Also, with residue on the soil surface more roots may have developed near the soil surface than when residues were incorporated.

The N, P, K, concentration in the snap bean shoots and pods (Table 4.6 and 4.7), and Ca and Mg concentration in the snap bean shoots (Table 4.6) increased with poultry manure rate. Applying 12.5 Mg ha^{-1} poultry manure or more significantly increased N, P, K, Ca and Mg concentrations in snap bean tissues. Leaf compost had no significant effect on N, P, K and Ca concentrations in plant tissue (Table 4.6 and 4.7), because the amounts of N, P, K, and Ca supplied by the leaf compost were much lower than from poultry manure (Table 4.2).

Table 4.7. Effect of poultry manure, leaf compost and application method on N, P, K, Ca, and Mg concentration in snap bean pods (main effect).

Treatment	N	P	K	Ca	Mg
	----------------		%	----------------	
A. method:					
Incorporated	3.9a*	0.60a	3.6a	0.55a	0.30a
Banded	3.7b	0.58a	3.4b	0.55a	0.29a
P. manure: (Mg ha^{-1})					
0	3.5c	0.56b	3.0c	0.53a	0.29a
12.5	3.8b	0.58b	3.5b	0.56a	0.30a
25.0	4.1a	0.64a	3.9a	0.56a	0.29a
L. compost: (Mg ha^{-1})					
0	3.7a	0.57a	3.4a	0.55a	0.29a
12.5	3.8a	0.59a	3.4a	0.54a	0.29a
25.0	3.9a	0.62a	3.6a	0.56a	0.29a

* Mean separation by LSD 0.05. Numbers within a column followed by different letters are significantly different at $p<0.05$.

Statistical analysis shows an interaction effect of application method and poultry manure rate on K concentration in pods. In both band and incorporation methods, K concentration in pods increased as the amount of poultry manure added increased. Potassium concentration in pods was lower when poultry manure was banded on the soil surface (Table 4.8).

Table 4.8. Effect of poultry manure rate and application method on K concentration in the snap bean pods (interaction effect).

Manure applied	Method of application	
	Incorporated	Banded
-- Mg ha^{-1} --	------- %K	-------
0	3.0**d***	3.1**d**
12.5	3.6**b**	3.3**c**
25.0	4.1**a**	3.7**b**

* Mean separation by LSD 0.05. Numbers within a row or column followed by different letters are significantly different at $p<0.05$.

3.2.2. Trace Element Concentration in Snap Bean Tissue

The concentrations of Fe and Mn in snap bean shoots and pods were significantly lower when poultry manure and/or leaf compost were applied on the soil surface (band application); but there was no significant effect of application methods on Cu, Zn and B concentrations in snap bean tissues (Table 4.9 and 4.10). Since the concentrations of the extractable Cu, Fe, Mn and Zn in soil were not affected by method of application, apparently Fe and Mn which were concentrated near the soil surface were not available to the plant.

The concentration of Fe, Mn, and B in snap bean shoot (Table 4.9) and Zn in snap bean pods (Table 4.10) increased significantly as poultry manure applied increased. Leaf compost had no effect on the concentration of these elements in snap bean shoot and pods (Table 4.9 and 4.10). This occurred because leaf compost supplied only small amounts of Cu, Mn and Zn compared to poultry manure (Table 4.2), and apparently Fe from leaf compost remained in the organic pool.

Table 4.9. Effect of poultry manure, leaf compost and application method on Cu, Fe, Mn, Zn and B concentration in snap bean shoots (main effect).

Treatment	Cu	Fe	Mn	Zn	B
	----------------		mg kg^{-1}	----------------	
A. method:					
Incorporated	7.8a*	330a	36.0a	20.3a	26.2a
Banded	8.4a	158b	29.9b	21.2a	25.1a
P. manure: (Mg ha^{-1})					
0	7.3a	164b	24.9b	21.3a	24.2b
12.5	8.6a	269a	35.9a	19.6a	25.7ab
25.0	8.4a	299a	37.9a	21.4a	27.0a
L. compost: (Mg ha^{-1})					
0	8.5a	216a	30.9a	23.9a	25.4a
12.5	7.7a	268a	34.5a	19.3a	25.7a
25.0	7.9a	247a	33.4a	19.0a	25.8a

* Mean separation by LSD 0.05. Numbers within a column followed by different letters are significantly different at $p<0.05$.

Table 4.10. Effect of poultry manure, leaf compost and application method on Cu, Fe, Mn, Zn and B concentration in snap bean pods (main effect).

Treatment	Cu	Fe	Mn	Zn	B
	---------------	---------------	mg kg^{-1}	---------------	---------------
A. method:					
Incorporated	6.7a*	85.1a	29.1a	26.3a	26.6a
Banded	7.2a	72.0b	20.3b	25.9a	25.6a
P. manure: (Mg ha^{-1})					
0	5.5a	78.8a	24.2a	25.1b	26.9a
12.5	7.9a	78.0a	24.4a	26.2ab	26.6a
25.0	7.4a	70.0a	25.6a	27.1a	26.4a
L. compost: (Mg ha^{-1})					
0	6.1a	79.5a	25.2a	26.3a	26.8a
12.5	7.8a	79.6a	25.1a	25.9a	26.3a
25.0	7.0a	76.7a	23.9a	26.1a	26.8a

* Mean separation by LSD 0.05. Numbers within a column followed by different letters are significantly different at $p<0.05$.

3.3. Growth and Yields

3.3.1. Growth and Yield of Snap Beans

Increasing poultry manure rates had no significant effect on the growth and yield of snap bean plants after establishment (Table 4.11). However, increasing poultry manure rate significantly decreased total number of plants per plot. The initial adverse effect on the germinating seed may have been due to release of NH_3 or increased salinity.

Leaf compost did not affect plant growth and yield; nutrients in the soil were adequate for plant growth and the amount of nutrients supplied were low compared to those supplied from poultry manure (Table 4.11).

Method of application had a significant effect on growth and yield of snap bean. Incorporation of the poultry manure and leaf compost significantly reduced growth and yield of snap beans per plot but the effect on individual plant growth and yield after plant establishment were not significant (Table 4.11). No signs of toxicity were seen in mature plants, and the nutrient concentrations in plant tissue were in the sufficient range for normal growth (Table 4.6 and 4.9). The decrease in stand due to incorporation was related to adverse effects of the poultry manure (Table 4.12). This may have been compounded by the soil being rototilled for incorporation while for band application the soil was not rototilled. The soil of the incorporated treatments was more loose and drier than the soil for band

Table 4.11. Effect of poultry manure, leaf compost and application method on the growth and yields of snap beans (main effect).

Growth and yields	Applic. method		Poultry manure	Leaf compost
	Incorp.	Banded		
Shoot fw. (kg/plot)	4.72b*	5.85a	ns	ns
Shoot dw. (kg/plot)	0.31b	0.38a	ns	ns
Total plant fw. (kg/plot)	7.77b	9.86a	ns	ns
Total plant dw. (kg/plot)	0.51b	0.65a	ns	ns
Total number of plant/plot	39.85b	49.96a	**	ns
Total pods fw. (kg/plot)	3.09b	4.01a	ns	ns
Total pods dw. (kg/plot)	0.20b	0.27a	ns	ns
Marketable pods (kg/plot)	2.48b	3.19a	ns	ns
Oversized pods (kg/plot)	0.14b	0.23a	ns	ns
Small size pods (kg/plot)	0.29b	0.40a	ns	ns
Pod length (cm)	14.6 b	14.9 a	ns	ns
Pods fw. (g/plant)	78.3 a	79.4 a	ns	ns
Pods dw. (g/plant)	5.2 a	5.4 a	ns	ns
Plant dw. (g/plant)	13.2 a	13.1 a	ns	ns

* Mean separation by LSD 0.05. Numbers within a row followed by different letters are significantly different at $p<0.05$.

** Significant at $p<0.05$

treatment. Because the soil was more loose, seed placement may have been deeper in the incorporation plots and this may also have affected seedling vigor.

There was a significant interaction between poultry manure and application method on the total number of snap bean plants per plot, shoot dry weight, and total dry weight (Table 4.12, 4.13, and 4.14). Data in Table 4.12 show that number of plants decreased significantly when poultry manure was incorporated into the soil. The number of plants per plot decreased as rate of poultry manure incorporated into the soil increased. There was a possibility that the incorporated poultry manure released sufficient NH_3 to kill snap bean plants during germination (Chapter 2). The decrease in total number of plants per plot resulted in decrease yield and total biomass per plot. However, per plant weight and yields were similar (Table 4.13 and 4.14). The effect of the poultry manure rates was not significant in band application. When poultry manure was applied on the surface 5 cm from the seed row, NH_3 was released to the atmosphere without having an adverse effect on germination and seedling establishment.

Table 4.12. Effect of poultry manure rate and application method on the total number of snap bean plants per plot (interaction effect).

Manure applied	Method of application	
	Incorporated	Banded
-- Mg ha^{-1} --	-- Number of plant --	
0	49**a***	51**a**
12.5	38**b**	50**a**
25.0	33**b**	50**a**

* Mean separation by LSD 0.05. Numbers within a row or column followed by different letters are significantly different at $p<0.05$.

Table 4.13. Effect of poultry manure rate and application method on the snap bean shoot dry weight per plot (interaction effect).

Manure applied	Method of application	
	Incorporated	Banded
-- Mg ha^{-1} --	--------- g ---------	
0	354**b***	385**ab**
12.5	277**c**	363**ab**
25.0	284**c**	388**a**

* Mean separation by LSD 0.05. Numbers within a row or column followed by different letters are significantly different at $p<0.05$.

Table 4.14. Effect of poultry manure rate and application method on the snap bean whole plant dry weight per plot (interaction effect).

Manure applied	Method of application	
	Incorporated	Banded
-- Mg ha^{-1} --	--------- g ---------	
0	588**b***	658**a**
12.5	471**c**	634**ab**
25.0	467**c**	654**a**

* Mean separation by LSD 0.05. Numbers within a row or column followed by different letters are significantly different at $p<0.05$.

3.3.2. Growth and Yield of Cabbage

Leaf compost and poultry manure rate had no significant effect on growth and yield of cabbage grown in a Houghton muck (Table 4.15). Only the method of application had a significant effect on growth and yield. Growth and yield of cabbage decreased significantly when poultry manure and/or leaf compost was incorporated. For the incorporation method the soil was rototilled while for band application it was not. This caused the soil in the incorporation treatments to be more loose and drier than with band application. Hence, the seed-soil contact was not as good and the seed may have been placed deeper in the soil. These conditions may have reduced the absorption of water by the seed and, hence, slowed germination and early growth.

Table 4.15. Effect of poultry manure, leaf compost and application method on the growth and yield of cabbage (main effect).

Growth and yields	Applic. method		Poultry manure	Leaf compost
	Incorp.	Banded		
Large leaves (#/plant)	8.9b*	9.5a	ns	ns
Head diameter (cm)	14.4b	15.6a	ns	ns
Head FW (kg/head)	1.6b	1.8a	ns	ns
Total plant FW/plot (kg)	34.6b	40.1a	ns	ns
Yield per plot (kg)	20.3b	23.4a	ns	ns

* Mean separation by LSD 0.05. Numbers within a row followed by different letters are significantly different at $p<0.05$.

3.3.3. Growth and Yield of Onion

Leaf compost and poultry manure rate had no significant effect on growth and yield of onion grown in a Houghton muck. Only the method of application had a significant effect on growth and yield. Growth and yield of the onion plants decreased significantly when poultry manure and/or leaf compost was incorporated (Table 4.16). For the incorporation method the soil was rototilled while for band application it was not. This caused the soil in the incorporation treatments to be more loose and drier than with band application. Hence, the seed-soil contact was not as good and the seed may have been placed deeper in the soil. These conditions may have reduced the absorption of water by the seed and, hence, slowed germination and early growth and reduced total plants per plot. The decrease in number of plants per plot caused the increase of the individual plant growth, hence, increased the bulb size. However, the yield per plot was significantly decreased due to the fewer number of plants per plot.

Table 4.16. Effect of poultry manure, leaf compost and application method on the growth and yields of onion (main effect).

Growth and yields	Applic. methods		Manure applied			Leaf compost
	Incorp.	Banded	0	12.5	25.0	
# of leaves/plant:						
6 weeks	5.0b*	5.3a	5.1a	5.1a	5.2a	ns
9 weeks	9.4a	9.5a	9.4a	9.4a	9.5a	ns
12 weeks	12.8b	13.9a	13.4a	13.3a	13.5a	ns
Bulb FW.(g/plant)	255a	195b	219a	223a	224a	ns
Yield/plot (kg)	16.3b	20.4a	18.0a	19.4a	17.8a	ns
Total bulbs/plot	67b	106a	86a	91a	81a	ns

* Mean separation by LSD 0.05. Numbers within a row followed by different letters are significantly different at $p<0.05$.

3.3.4. Growth and Yield of Carrot

There was an interaction effect of poultry manure and application method on total number of carrots and yield per plot. When the poultry manure was incorporated the total number of carrots (plants) and yields per plot decreased with poultry manure rate. When banded on the soil surface poultry manure had no effect on total number of carrots and yield per plot (Table 4.17 and Table 4.18). In contrast, dry weight and fresh weight per plant increased significantly with poultry manure rates (Table 4.19). Leaf compost had no effect on carrot growth and yield. These data indicate that in early growth, incorporating poultry

Table 4.17. Effect of poultry manure rate and application method on carrots per plot (interaction effect).

Manure applied	Method of application Incorporated	 Banded
-- Mg ha^{-1} --	------ # plot^{-1}	-------
0	222**a***	227**a**
12.5	151**b**	236**a**
25.0	163**b**	240**a**

* Mean separation by LSD 0.05. Numbers within a row or column followed by different letters are significantly different at $p<0.05$.

Table 4.18. Effect of poultry manure rate and application method on carrot yield per plot (interaction effect).

Manure applied	Method of application Incorporated	 Banded
-- Mg ha^{-1} --	----- kg plot^{-1}	-----
0	16.0**ab***	16.2**ab**
12.5	13.9**c**	17.2**a**
25.0	15.3**b**	17.3**a**

* Mean separation by LSD 0.05. Numbers within a row or column followed by different letters are significantly different at $p<0.05$.

manure into the soil caused some injury and killed some plants. This may have been caused by NH_3 which was released immediately after poultry manure application and became toxic to the seed in germination (Chapter 2). After several days, the level of ammonia was no longer toxic to the plant. The growth per plant increased with poultry manure rates because carrot population per plot was reduced significantly. However, the increase in biomass was only significant at 15 weeks. This indicates that applying up to 25 mg ha^{-1} poultry manure would not cause injury to carrot plants, if they were planted several days after application.

Table 4.19. Effect of poultry manure, leaf compost and application method on the growth and yield of carrot (main effect).

Growth and yields	Applic. methods		Manure applied			Leaf compost
	Incorp.	Banded	0	12.5	25.0	
Fresh wt./plant:						
6 weeks (g)	17a*	18a	17a	17a	19a	ns
9 weeks (g)	76a	74a	73a	78a	75a	ns
15 weeks (g)	179a	141b	147b	167a	166a	ns
Dry wt./plant:						
6 weeks (g)	2.2a	2.3a	2.2a	2.2a	2.4a	ns
9 weeks (g)	8.8a	8.4a	8.4a	8.9a	8.5a	ns
15 weeks (g)	17.5a	14.6b	15.0b	16.6a	16.5a	ns
Yield/plot (kg):	15.1b	16.9a	16.1a	15.5a	16.3a	ns
Carrots/plot:	179b	234a	224a	193b	201b	ns

* Mean separation by LSD 0.05. Numbers within a row followed by different letters are significantly different at $p<0.05$.

4. SUMMARY AND CONCLUSIONS

General conclusions from these studies are that method of applying poultry manure and leaf compost had no significant effect on the extractable macro and micronutrient concentrations in the top 20 cm. Incorporation of the organic materials caused injury during germination and hence, decreased total number of plants and yield per plot for all crops. The decrease in germination may also have been related to drier and more loose soil conditions for the incorporation treatments. However, incorporation of organic residues increased the concentration of N, K, Ca, Mg, Fe, and Mn in snap beans tissue and did not cause injury to the growth of individual established plants. Therefore, with good tillage and irrigation management to avoid germination injury, incorporation of organic materials will be better than surface banding.

Application of poultry manure had no effect on total yield of all crops because the original nutrient concentrations in the soils studied were adequate for the crops grown. Application of poultry manure increased soil pH, CEC, and macro and micronutrient concentrations in the soil and in snap bean tissue. In addition, there was an interaction effect between application method and poultry manure rate on P concentration in the Capac soil, K concentration in snap bean pods, total plant dry weight, and total number of carrot and snap bean plants per plot. When incorporated, increasing poultry manure rate increased P and K concentrations in the Capac soil and in snap bean pods, respectively. When banded on the soil surface, poultry manure rate had no effect on these parameters. Although incorporated poultry manure caused germination injury which significantly decreased total number of plants per plot and total plant dry weight, it did not affect growth of established plants. Data from lab and greenhouse study (1990) showed that release of NH_3 decreased markedly several days after poultry manure application. Seedling injury can be avoided by planting several days (ca. 10 days) after poultry manure application. Therefore, considering its potential to supply more nutrients, incorporation of poultry manure into the soil is recommended over surface application to increase nutrient availability, crop growth and production. However, further study is needed to determine the proper time to plant after poultry manure application.

Adding leaf compost had no significant effect on N, P, K, Ca, and Mg concentrations in snap bean tissue, or P and K availability in the soil, and had no effect on growth and yield of all crops. However, adding leaf compost did increase the CEC, Ca , Mg, and Mn availability in the soil. Considering the need to maintain soil buffering capacity to reduce nutrient leaching, leaf compost is recommended in the soil with a low CEC. At the rates used in this study, combining leaf compost with poultry manure did not alter the effect of poultry manure on germination. The amount of leaf compost applied was probably not enough to fix NH_3 released from poultry manure or reduce injury to the germinating seed. Therefore, further study is needed to evaluate the effect of higher rates of leaf compost on reducing ammonia toxicity.

INTEGRATED INTERPRETATIVE SUMMARY

The following summary comments and suggestions are based on the laboratory, greenhouse and field studies conducted for this dissertation.

Poultry manure is a by product of the poultry industry which can be a source of plant essential nutrients. The N and P in poultry manure were released more slowly into the soil than from inorganic fertilizer, but K was released equally from the two sources. Nitrogen uptake by cabbage plants treated with N fertilizer was significantly higher than by those provided all the N from poultry manure. There were no significant differences in N, P and K concentration in plant tissue between plants treated with poultry manure and those treated with commercial fertilizer. In addition, P (except in the low P soil) and K uptake by cabbage, and total biomass production were not significantly different between the poultry manure and commercial fertilizer treatments. Increasing the amount of poultry manure applied, gradually increased soluble P in the soils studied. To get equal P solubility in the soil to that attained with fertilizer, poultry manure should be applied 2.5 to 4 times the P supplied by fertilizer. However, these higher amounts did not improve biomass over that produced when poultry manure was applied to supply the same amount of P as from inorganic fertilizer. Therefore, it appears that applying poultry manure to meet the P fertilizer recommendation is adequate for optimizing crop production.

Planting immediately after poultry manure application may cause injury to germinating seed. Incorporation of poultry manure at 12.5 Mg ha^{-1} or more increased the extractable macro and micro-nutrient concentrations in the soil and in plant tissue. Increasing the rate of poultry manure to 25 Mg ha^{-1} increased soil pH and CEC. However, seedling establishment was reduced due to changes in either the physical and/or chemical properties of the soil. When left on the soil surface between the planted rows, poultry manure had no effect on these parameters. Once established, the incorporated manure had no further adverse effect on the growth of individual plants. Immediately after incorporation into the soil, the level of NH_3 release can be quite high from the poultry manure but the release decreases markedly after several days. Therefore, seedling injury can be avoided by planting more than 10 days after poultry manure incorporation. Considering its potential to supply nutrients, incorporation of poultry manure into the soil is recommended over surface application to increase nutrient availability, crop growth and production. The cation exchange capacity (CEC) of a soil can have a significant effect on the degree of soluble salt and NH_3 injury to germinating seeds. In a loam soil with a CEC of 8 cmol kg^{-1}, up to 56 Mg ha^{-1} poultry manure was able to be incorporated without concern for salt and NH_3 toxicity to germinating seed and plant growth compare to coarser texture soil (CEC = 4 cmol kg^{-1}).

Adding leaf compost at 25 Mg ha^{-1} increased the CEC and Ca, Mg, and Mn availability in the soil, but reduced the concentration of N, P, and K in soil solution. Plant growth and nutrient uptake was increased by addition of leaf compost. The effect of leaf compost on increasing plant growth and nutrient uptake was only significant in the low P soil (high pH= 8.2) studied. A decrease in N, P and K concentration in soil solution following leaf compost application may reduce the potential for their leaching to ground water. Therefore, although leaf compost does not contribute much nutritionally, its application has the potential for improving plant growth and groundwater quality. Considering the need to maintain soil buffering capacity to reduce nutrient leaching, and to increase plant growth and nutrient uptake, leaf compost is especially recommended for soil with a low CEC or high pH. At the rates studied (up to 25 Mg ha^{-1}) combining leaf compost and poultry manure did not alter the adverse effect of poultry manure on germination. Additional study is needed to further clarify the beneficial and adverse effects of using high rates of leaf compost in combination with poultry manure or other animal manures.

REFERENCES

Abbott, J.L., and J.C. Lingle. 1968. Effect of soil temperature on the availability of phosphorus in animal manure. Soil Sci. 105:145-152.

Abbott, J.L., and T.C. Tucker. 1973. Persistence of manure phosphorus availability in calcareous soil. Soil Sci. Soc. Amer. Proc. 37:60-63.

Adams, F. 1974. Soil solution. p.441-481. *In* E.W. Carson (ed.) The plant root and its environment. University Press of Virginia, Charlottesville.

Adams, P.L., T.C. Daniel, D.R. Edwards, D.J. Nichols, D.H. Pote, and H.D. Scott. 1994. Poultry litter and manure contributions to nitrate leaching through the Vadose zone. Soil Sci. Soc. Amer. J. 58:1206-1211.

Adriano, D.C., A.C. Chang, P.F. Pratt, and R. Sharpless. 1973. Effect of soil application of dairy manure on germination and emergence of some selected crops. J. Environ. Qual. 2:396-399.

Adriano, D.C., P.F. Pratt, and S.E. Bishop. 1971. Nitrate and salt in soils and ground waters from land disposal of dairy manure. Soil Sci. Soc. Amer. Proc. 35:759-762.

Aleem, M.I.H., and M. Alexander. 1960. Nutrition and physiology of *Nitrobacter agilis*. Appl. Microbiol. 8:80-84.

Avnimelech, Y. 1986. Organic residues in modern agriculture. p. 1-10. *In* Y. Chen and Y. Avnimelech (ed.) The role of organic matter in modern agriculture. Martinus Nijhoff, Dordrecht.

Ayers, A.D. 1952. Seed germination as affected by soil moisture and salinity. Agron. J. 44:82-84.

Ayers, A.D., and H.E. Hayward. 1948. A method for measuring the effects of soil salinity on seed germination with observation on several crop plants. Soil Sci. Soc. Amer. Proc. 13:224-226.

Barber, S.A. 1974. Influence of the plant root and ion movement in soil. p. 525-564. *In* E.W. Carson (ed.) The plant root and its environment. Univ. Press of Virginia, Charlottesville.

Barber, S.A. 1984. Soil nutrient bioavailability. A mechanistic approach. John Wiley & Sons Inc. N.Y. 395 p.

Binford, G.D., D.D. Baltensperger, R.A. Nielsen, and F.N. Anderson. 1993. Corn yields and nutrient levels resulting from long-term application of manure and fertilizer. p 266. *In* Agronomy Abstracts. Cincinnati, OH.

Bingham, F.T., H.D. Chapman, and A.L. Pugh. 1954. Solution - culture studies of nitrite toxicity to plants. Soil Sci. Soc. Amer. Proc. 18:305-308.

Bishop, R.F., L.B. MacLeod., L.P. Jackson, C.R. MacEachern, and E.T. Goring. 1962. A long-term field experiment with commercial fertilizer and manure. II. Fertility levels, crop yields, and nutrient levels in corn, oats, and clover. Can. J. Soil Sci. 42:49-60.

Bitzer, C.C., and J.T. Sims. 1988. Estimating the availability of nitrogen in poultry manure through laboratory and field studies. J. Environ. Qual. 17:47-54.

Black, C.A. 1968. Soil-plant relationships. John Wiley & Sons Inc. N.Y. 2nd Edition. 792 p.

Brady, N.C. 1986. The nature and properties of the soils. MacMillan Publ. Co. N.Y. 9th Edition. 750 P.

Brage, B.L., M.J. Thompson, and A.C. Caldwell. 1952. Long-time effect of applying barnyard manure at varied rates on crop yield and some chemical constituents of soil. Agron. J. 44:17-29

Bray, R.H., and L.T. Kurtz. 1945. Determination of total, organic, and available forms of phosphorus in soils. Soil Sci. 59:39-49.

Bremner, J.M. 1965. Inorganic nitrogen. p.1179-1237. *In* C.A. Black (ed.). Methods of soil analysis. Part 2. Agron. No.9. ASA and SSSA, Madison, WI.

Bremner, J.M., and C.S. Mulvaney. 1982. Nitrogen-total. p.595-624. *In* A.L. Page et al. (ed.). Methods of soil analysis. Part 2. Agron. No. 9. ASA and SSSA, Madison, Wl.

Brown, J.R., and D. Warncke. 1988. Recommended cation tests and measures of cation exchange capacity. p. 15-16. *In* Dahnke (ed.) Recommended chemical soil test procedures for the North Central Region. North Central Regional Publication no. 221. North Dakota Agric. Exp. Stn., North Dakota State Univ., Fargo, ND.

Chen, Y., and F.J. Stevenson. 1986. Soil organic matter interaction with trace elements. p. 73-116. *In* Y. Chen and Y. Avnimelech (ed.) The role of organic matter in modern agriculture. Martinus Nijhoff, Dordrecht.

Chen, Y., and Y. Avnimelech. (Ed). 1986. The role of organic matter in modern agriculture. Martinus Nijhoff, Dordrecht. 306 p.

Chui, K.T. 1962. Influence of humus components upon the differentiation of the growing point of wheat. p. 121-129. *In* S. Prat and V. Rypacek (ed.) Studies about humus. Symposium humus and plant. Publ. House of the Czechoslovak Acad. of Sci. Prague.

Cooper, J.R., R.B. Reneau, Jr., W. Kroontje, and G.D. Jones. 1984. Distribution of nitrogenous compounds in a Rhodic Paleudult following heavy manure application. J. Environ. Qual. 13:189-193.

Cope, Jr. J.T., D.G. Sturkie, and A.E. Hiltbold. 1958. Effects of manure, vetch, and commercial nitrogen on crop yields and carbon and nitrogen contents of a fine sandy loam over a 30-year period. Soil Sci. Soc. Amer. Proc. 22:524-527.

Correll, M.D., D.M. Miller, B.R. Wells, R.J. Norman, and T. Alvisyahrin. 1991. Reclamation of precision graded soils by organic and inorganic amendments. p 284. *In* Agronomy Abstracts. Denver, CO.

Court, M.N., R.C. Stephen, and J.S. Waid. 1962. Nitrite toxicity arising from the urea as fertilizer. Nature 194:1263-1265

Cox, D.A., and J.G. Seeley. 1984. Ammonium injury to poinsettia.: Effects of NH_4-N:NO_3-N ratio and pH control in solution culture on growth, N absorption and N utilization. J. Amer. Soc. Hort. Sci. 109:57-62.

Cripps, R.W., S.K. Winfree, and J.L. Reagan. 1992. Effects of sewage sludge application method on corn production. Commun. Soil Sci. Plant Anal., 23:1705-1715.

Dahnke, W.C., and D.A. Whitney. 1988. Measurement of soil salinity. p. 32-34. *In* W.C. Dahnke (ed.) Recommended chemical soil test procedures for the North Central Region. North Central Regional Publ. No. 221. North Dakota Agric. Exp. Stn., North Dakota State Univ., Fargo.

Day, P.R. 1965. Particle fractionation and particle size analysis. p. 545-567. *In* C.A. Black et al. (ed.) Methods of soil analysis. Part 2. Agron. No.9. ASA, Madison, WI.

Eckert, D.J. 1988. Recommended pH and lime requirement tests. p. 6-8. *In* W.C. Dahnke (ed.) Recommended chemical soil test procedures for the North Central Region. North Central Regional Publication no. 221. North Dakota Agric. Exp. Stn., North Dakota State University, Fargo.

Ells, J.E., A.E. McSay, and S.M. Workman. 1991. Toxic effects of manure, alfalfa and ammonia on emergence and growth of cucumber seedlings. Hort Sci. 26:380-383.

Field, J.A., R.B. Reneau, and W. Kroontje. 1985. Effects of anaerobically digested poultry manure on soil phosphorus adsorption and extractability. J. Environ. Qual. 14:105-107

Francis D.D., J.S. Schepers, and M.F. Vigil. 1993. Management and utilization of manure N and P for a continuous corn system. p. 271. *In* Agronomy Abstracts. Cincinnati, OH.

Freney, J.R., and J.R. Simpson (Ed). 1983. Gaseous loss of nitrogen from plant-soil systems. Martinus Nijhoff, The Hague. 317 p.

Fried, M., and R.E. Shapiro. 1956. Phosphate supply pattern of various soils. Soil Sci. Soc. Am. Proc. 20:471-475.

Gaur, A.C., and K.K.R. Bhardwaj. 1971. Influence of sodium humate on the crop plants inoculated with bacteria of agricultural importance. Plant and Soil 35: 613-621.

Giddens, J., and A.M. Rao. 1975. Effect of incubation and contact with soil on microbial and nitrogen changes in poultry manure. J. Environ. Qual. 4:275-278.

Grove, J.H. 1992. Water table nitrate in a Fragiudalf: effect of cover crop, fertilizer N and dairy manure. p. 279. *In* Agronomy Abstracts. Minneapolis, MN.

Guminski, S., J. Sule, and J. Glabiszewski. 1983. Influence of sodium humate on the uptake of some ions by tomato seedlings. Acta Soc. Bot. Polaniae 52: 149-164.

Halstead, R.L., and F.J. Sowden. 1968. Effect of long-term addition of organic matter on crop yields and soil properties. Can. J. Soil Sci. 48:341-348.

Han, X.G., and D.C. Wolf. 1990. Mineralization and nitrification in two Arkansas soils amended with poultry litter. p 38. *In* Agronomy Abstracts. San Antonio, TX.

Harris, J.G., M.D. Ransom, R.E. Lamond, and C.W. Rice. 1991. Source and fate of N under no-tillage and conventional tillage corn production. p 289. *In* Agronomy Abstracts. Denver, CO.

Havenstein, G. 1988. National poultry waste management symposium. Proceedings. Dept. of Poultry Sci. Ohio State Univ. Columbus, OH. p. 1-3.

Hedlin, R.A., and A.O. Ridley. 1964. Effect of crop sequence and manure and fertilizer treatments on crop yields and soil fertility. Agron. J. 56:425-427.

Herron, G.M., and A.B. Erhart. 1965. Value of manure on an irrigated calcareous soil. Soil Sci. Soc. Am. Proc. 29:278-281.

Hileman, L.H. 1971. Effect of rate of poultry manure application on selected soil chemical properties. Livestock waste management and pollution abatement. Proceedings International Symposium on Livestock Wastes. ASAE Publications, St. Joseph, MI. p. 247-248.

Hodgson, J.F., W.L. Lindsay, and J.E. Trierweiler. 1966. Micronutrient cation complexing in soil solution. II. Complexing of zinc and copper in displaced solution from calcareous soil. Soil Sci. Soc. Amer. Proc. 30:723-726.

Hue, N.V. 1992. Correcting soil acidity of a highly weathered Ultisol with chicken manure and sewage sludge. Commun. Soil Sci. Plant Anal. 23:241-264

Huhnke, R.L. 1982. Land application of livestock manure. Oklahoma State Univ. Ext. Serv. Fact Sheet 1710. Oklahoma State Univ., Stillwater.

Jackson, W.A., R.A. Leonard and S.R. Wilkinson. 1975. Land disposal of broiler litter: Changes in soil potassium, calcium and magnesium. J. Environ. Qual. 4:202-206.

Jackson, W.A., S.R. Wilkinson, and R.A. Leonard. 1977. Land disposal of broiler litter: Changes in concentration of chloride, nitrate nitrogen, total nitrogen, and organic matter in a Cecil sandy loam. J. Environ. Qual. 6:58-62.

Johnston, A.E., and G.E.G. Mattingly. 1976. Experiments on continuous growth of arable crops at Rothamsted and Woburn Experimental Stations: Effects of treatments on crop yields and soil analysis and recent modification in purpose and design. Ann. Agron. 27:927-956.

Jokela, W.E. 1992. Nitrogen fertilizer and dairy effects on corn yield and soil nitrate. Soil Sci. Soc. Amer. Proc. 56:148-154.

Jones, Jr. J. B., B. Wolf, and H.A. Mills. 1991. Plant analysis handbook. A practical sampling, preparation, analysis, and interpretation guide. Micro-Macro Publ. Inc. 213 p

Keeney, D.R., and D.W. Nelson. 1982. Nitrogen-inorganic forms. p. 643-710. *In* A.L. Page et al. (ed.) Methods of soil analysis. Part 2. Agron. No. 9. ASA and SSSA, Madison, WI.

Kingery, W.L., C.W. Wood, D.P. Delaney, J.C. Williams, and G.L. Mullins. 1994. Impact of long-term land application of broiler litter on environmentally related soil properties. J. Environ. Qual. 23:139-147.

Knudsen, D., and D. Beegle. 1988. Recommended phosphorus tests. p. 6-8. *In* Dahnke (ed.) Recommended chemical soil test procedures for the North Central Region. North Central Regional Publication no. 221. North Dakota Agric. Exp. Stn., North Dakota State Univ., Fargo, ND.

Kubota, J., H. F. Rhoades, and L. Harris. 1947. Effect of different cropping and manurial practices on some chemical properties of an irrigated chestnut soil. Soil Sci. Soc. Amer. Proc. 12:304-309.

Lamaire, F. 1969. Effect of nitrites on plants. Ann. Agron. 20:317-326

Lauren, .J.G., J.M. Duxbury and S.D. Klausner. 1993. Controls on soil N mineralization & nitrate leaching potential in maize-based cropping system of New York. p 277. *In* Agronomy Abstracts. Cincinnati, OH.

Liebhardt. W.C. 1976a. Soil characteristics and corn yields as affected by previous manure applications. J. Environ. Qual.5:459-462

Liebhardt. W.C. 1976b. Nutrient concentration of corn as affected by poultry manure. Commun. Soil Sci. Plant Anal. 7:175-188

Liebhardt. W.C., C. Golt. and J. Tupin. 1979. Nitrate and ammonium concentrations of ground water resulting from poultry manure applications. J. Environ. Qual. 8:211-215.

Lindsay, W.L. 1979. Chemical equilibria in soils. John Wiley and Sons, N.Y. 449 p.

Linehan, D.J. 1976. Some effects of a fulvic acid component of soil organic matter on the growth of cultured excised tomato roots. Soil Biol. and Biochem. 8 : 511-517.

Lu, N., J.H. Edwards, and C.W. Woods. 1992. Broiler litter rate and incubation time effects on the fertility status of a Fragiudult. p 283. *In* Agronomy Abstracts. Minneapolis, MN.

Maas, E.V. 1986. Salt tolerance of plants. Applied Agric. Res. 1:12-26.

Magette, W.L. 1988. Runoff potential from poultry manure applications. p. 102-106. *In* E.C. Naber (ed.) Proc. Natl. Poultry Waste Manage. Symp., Columbus, OH. Ohio State Univ. Press. Columbus.

Malzer, G.L., T.J. Graff, and M.V. Nathan. 1993. Nitrate movement below corn and soybeans as influenced by fertilizer and turkey manure addition. p 278. *In* Agronomy Abstracts. Cincinnati, OH.

Mandal, L.N., and B. Mandal. 1987a. Transformation of zinc fraction in rice soils. Soil Sci. 143:205-212.

Mandal, L.N., and B. Mandal. 1987b. Fraction of applied zinc in rice soils at two moisture regimes and levels of organic matter. Soil Sci. 144:266-273.

Martin, W.E., and J.R. Buchanan. 1950. Phosphate test for grain land. Calif. Agric. 4: 7, 12.

Martin, W.E., and D.S. Mikkelsen. 1960. Grain fertilization in California. Calif. Agric. Exp. Stn. Bull. 775.

Meek, B.D., L.E. Graham, T.J. Donovan, and K.S. Mayberry. 1979. Phosphorus availability in a calcareous soil after high loading rates of manure. Soil Sci. Soc. Am. J. 43: 741-744.

Megie, C.A., R.W. Pearson, and A.E. Mitbold. 1967. Toxicity of decomposing crop residues to cotton germination and seedling growth. Agron. J. 59:197-199.

Metzger, W.H. 1939. The nature, extent, and distribution of fertilizer residues in the soil of some old fertility plats. Soil Sci. 47:15-26.

Miller, M.H., and A.J. Ohlrogge. 1958a. Water-soluble chelating agents in organic materials: I. Characteristics of chelating agents and their reactions with trace metals in soils. Soil Sci. Soc. Amer. Proc. 22:225-228.

Miller, M.H., and A.J. Ohlrogge. 1958b. Water-soluble chelating agents in organic materials: II. Influence of chelate-containing materials on the availability of trace metals to plants. Soil. Sci. Soc. Amer. Proc. 22:228-231.

Muhr, G.R., H.W. Smith, and M.D. Weldon. 1943. Influence of cropping, manure, and manure plus lime on exchange capacity, exchangeable calcium, pH, oxidizable material, and nitrogen of fine-textured soil in Eastern Nebraska. J. Amer. Soc. Agron. 35:107-113.

Mylonas, V.A., and C.B. McCants. 1980. Effect of humic and fulvic acids on growth of tobacco. 1. Root initiation and elongation. Plant and Soil 54: 485-490.

Naber, E.C. 1988. Poultry waste utilization and management in Europe. p. 19-25. *In* National poultry waste management symposium. Proceedings. Dept. of Poultry Sci. Ohio State Univ. Columbus, OH.

Nathan, M.V., and G.L. Malzer. 1992. Ammonia volatilization from turkey manure and urea under field conditions. p 287. *In* Agronomy Abstracts. Minneapolis, MN.

National Agricultural Statistics Service. 1994. Poultry production and value by State 1992-1993. Agriculture Statistics Board NASS, USDA (May). U.S. Gov. Print. Office, Washington, DC.

Oke. O.L. 1966. Nitrite toxicity to plants. Nature 212:528

Olsen, R.J., R.F. Hensler, and O.J. Attoe. 1970. Effect of manure application, aeration, and soil pH on soil nitrogen transformations and on certain soil test values. Soil Sci. Soc. Amer. Proc. 34:222-225.

Olsen, S.R. 1986. The role of organic matter and ammonium producing high corn yields. p. 29-54. *In* Y. Chen and Y. Avnimelech (ed.). The role of organic matter in modern agriculture. Martinus Nijhoff, Dordrecht.

Olsen, S.R., and L.E. Sommers. 1982. Phosphorus. p. 403-430. *In* A.L. Page et al. (ed.) Methods of soil analysis. Part 2. Agron. No.9. ASA and SSSA, Madison, WI.

Olsen, S.R., and S.A. Barber. 1977. Effect of waste application on soil phosphorus and potassium. p. 97-215. *In* F.L. Elliott (ed.) Soils for management of organic wastes and waste waters. Soil Sci. Soc. of Amer. Madison, WI.

Parker, M.B., H.B. Harris, H.D. Morris, and H.F. Perkins. 1969. Manganese toxicity of soybeans as related to soil and fertility treatments. Agron. J. 61:515-518.

Percival, B. 1984. Organic vegetable gardening. Tab Books Inc. PA. 309 p.

Pittman, D.W. 1930. The effect of barnyard manure on calcareous soil. J. Amer. Soc. Agron. 22:549-552

Pratt, P.F., S. Davis, and R.G. Sharpless. 1976. A four-year field trial with animal manures. I. Nitrogen balances and yields. II. Mineralization of nitrogen. Hilgardia 44:99-125.

Provin, T.L., and M.A. Tabatabai. 1991. Animal manures as sources of nitrogen for plants. p 298. *In* Agronomy Abstracts. Cincinnati, OH.

Rao, A.C.S., and W.L. Pan. 1993. Nutrient use efficiency of dairy manure application to spring barley. p 283. *In* Agronomy Abstracts. Cincinnati, OH.

Raveh, A., and Y. Avnimelech. 1979. Leaching of pollutants from sanitary landfills models. J. Water Pollution Control Fed. 51:2705-2716.

Reddy, K.R., M.R. Overcash, R. Khaleel, and P.W. Westerman. 1980. Phosphorus adsorption-desorption characteristics of two soils utilized for disposal of animal wastes. J. Environ. Qual. 9:86-92

Ritter, W.F., and A.E.M. Chirnside. 1984. Impact of land use on groundwater quality in Southern Delaware. Ground Water 22:39-47.

Rochus, W. 1971. Influence of different humic substances on growth and phosphate uptake by cereal. p. 534-551. *In* B. Novak et al (ed.) Studies about humus. Humus et planta V.

Rodale, J.I., R. Rodale, J. Olds, M.G. Goldman, M. Franzs, and J. Minnich. 1973. The complete book of composting. Rodale Book, Inc. Emmaus, Penna. 1007 p.

Rylant, K.E., J.J. Kelsoe, and C.M. Hunt. 1993. Pelletized poultry litter as a nitrogen source for turf. p 284. *In* Agronomy Abstracts. Cincinnati, OH.

Samson, G., and Visser, S.A. 1989. Surface-active effect of humic acid on potato cell membrane properties. Soil Biol. Biochem. 21:343-347.

Schnitzer, M. 1978. Humic substances: chemistry and reactions. p. 14-17. *In* M. Schnitzer and S.U. Khan (Ed). Soil organic matter. Elsevier Scientific Publ. Co. New York.

Schulte, E.E. 1988. Recommended soil organic matter tests. *p. 31-32.* *In* Dahnke (ed.) Recommended chemical soil test procedures for the North Central Region. North Central Regional Publication no. 221. North Dakota Agric. Exp. Stn., North Dakota State Univ., Fargo, ND.

Sharpley, A.N., and S.J. Smith. 1989. Mineralization and leaching of phosphorus from soil incubated with surface-applied and incorporated crop residue. J. Environ. Qual. 18:101-105.

Sharpley, A.N., S.J. Smith, and W.R. Bain. 1993. Nitrogen and phosphorus fate from long-term poultry litter applications to Oklahoma soils. Soil Sci. Soc. Amer. J. 57:1131-1137

Shortall. J.G., and W.C. Liebhardt. 1975. Yield and growth of corn as affected by poultry manure. J. Environ. Qual. 4:186-191.

Shuman, L.M. 1988. Effect of organic matter on the distribution of manganese, copper, iron, and zinc in soil fraction. Soil Sci. 146:192-198.

Siegel, R.S., A.A.R. Hafez, J. Azevedo, and P.R. Stout. 1975. Management procedure for effective fertilization with poultry manure. Compost Sci. 16:5-9

Simmons, K.E., and D.E. Baker. 1991. Nitrate movement in the soil profile receiving long-term applications of manure. p 301. *In* Agronomy Abstracts. Denver, CO.

Simpson, K. 1986. Fertilizers and manures. Longman, Inc. N.Y. 254p.

Sims, J.T. 1987. Agronomic evaluation of poultry manure as nitrogen source for conventional and no-tillage corn. Agron. J. 79:563-570

Singh, B.B., and J.P. Jones. 1976. Phosphorus sorption and desorption characteristics of soil as affected by organic residues. Soil Sci. Soc. Am. J. 40:389-394.

Singhania, R.A., E. Reitz, H. Sochtig, and D.R. Sauerbeck. 1983. Chemical transformation and plant availability of zinc salts added to organic manure. Plant and Soil 73:337-344.

Smith, J.H. 1964. Relationships between soil cation-exchange capacity and toxicity of ammonia to the nitrification process. Soil Sci. Soc. Amer. Proc. 28:640-644.

Stevenson, F.J. 1982. Humus chemistry. Genesis, composition, reactions. John Wiley & Sons, Inc. 443 p.

Sweeten, J.M. 1988. Composting manure and sludge. p. 38-44. *In* National poultry waste management symposium. Proceedings. Dept. of Poultry Sci. Ohio State Univ. Columbus, OH.

Thompson, E.J., A.L.F. Oliveira, U.S. Moser, and C.A. Black. 1960. Evaluation of laboratory indexes of absorption of soil phosphorus by plants. II. Plant and Soil 13:28-38

Tyson, S.C., M.L. Cabrera, S.R. Wilkinson, and C.S. Hoveland. 1993. Uncomposted and composted broiler litter effects on tall Fescue yield and residual soil nitrate. p 289. *In* Agronomy Abstracts. Cincinnati, OH.

U.S. Environmental Protection Agency. 1976. Quality criteria for water. U.S. Gov. Print. Office, Washington, DC.

U.S. Salinity Laboratory Staff. 1954. Diagnosis and improvement of saline and alkali soils. Agric. Handbook no. 60. USDA. 160p.

Van der Watt, H.v.H., M.E. Summer, and M.L. Cabrera. 1994. Bioavailability of copper, manganese, and zinc in poultry litter.

Vines H.M., and R.T. Wedding. 1960. Some effects of ammonia on plant metabolism and a possible mechanism for ammonia toxicity. Plant Physiol. 35:820-825.

Vitosh, M.L., H.L. Person, and E.D. Purkhiser. 1986. Livestock manure management for efficient crop production and water quality preservation. Coop. Ext. Serv. Michigan State Univ. Ext. Bul. WQ12. 8 p.

Vitosh, M.L., J.F. Davis, and B.D. Knezek. 1973. Long-term effects of manure, fertilizer, and plow depth on chemical properties of soils and nutrient movement in a monoculture corn system. J. Environ. Qual. 2:296-299.

Walker, J.M., and S.A. Barber. 1960. The availability of chelated Mn to millet and its equilibria with other forms of Mn in the soil. Soil Sci. Soc. Amer. Proc. 24:485-488.

Warncke, D.D., D.R. Christenson, L.W. Jacobs, M.L. Vitosh, and B.H. Zandstra. 1992. Fertilizer recommendations for vegetable crops in Michigan. Ext. Bul. E-550B. Michigan State Univ.

Warncke, D.D. 1994. Manual of laboratory procedures. p 31. Soil & plant nutrient laboratory. Michigan State Univ.

Warren, K.S. 1962. Ammonia toxicity and pH. Nature (London) 195:47-49.

Weil, R.R., W. Kroontje, and G.D. Jones. 1979. Inorganic nitrogen and soluble salts in a Davidson clay loam used for poultry manure disposal. J. Environ. Qual. 8:86-91.

Westerman, P.W., T.L. Donnely, and M.R. Overcash. 1983. Erosion of soil and poultry manure: A laboratory study. Trans. ASAE 26:1070-1078, 1084.

Wetterauer, D.G., and R.J. Killorn. 1993. Nitrate-N concentration and electrical conductivity of soil treated with animal manure. p 291. *In* Agronomy Abstracts. Cincinnati, OH.

Whitney, D.A. 1988. Micronutrient soil tests for zinc, iron, manganese and copper. p. 20-22. *In* Dahnke (ed.) Recommended chemical soil test procedures for the North Central Region. North Central Regional Publication no. 221. North Dakota Agric. Exp. Stn., North Dakota State Univ., Fargo, ND.

Wilkinson, S.R., J.A. Studemann, D.J. Williams, J.B. Jones, Jr., R.N. Dawson, and W.A. Jackson. 1971. Recycling broiler litter on tall fescue pasture at disposal rates and evidence of beef cow health problems. *In* Livestock waste management and pollution abatement. Proc. Int. Symp. on Livestock Waste, Columbus, OH. Publ. Proc. no. 271:321-324.

Wilson, J., and T. Eltzroth. 1984. How to grow a thriving vegetable garden. America's only complete guide to home vegetable gardening. Countryside Books Publ. Clearwater, Fl. 164 p.

Young, R.A., J.C. Zubriski, and E.B. Norum. 1960. Influence of long-time fertility management practices on chemical and physical properties of a Fargo clay. Soil Sci. Soc. Amer. Proc. 24:124-128.