CHAPTER 2

LITERATURE REVIEW

EFFECT OF POULTRY LITTER-YARD WASTE COMPOST ON CORN GROWTH AND EXTRACTABLE PHOSPHORUS

In the last decade, poultry production has drastically increased due to the world population growth and to the high demand for low fat meat. Poultry industries generate million tons of wastes per year associated with the demand for poultry production. Consequently, poultry litter (PL) applied to agricultural land in the southeastern United States has generated environmental concern since large poultry growers are located in small geographic areas (Kingery et al., 1994; Simpson, 1991). The largest potential market for composted poultry waste has been identified as application to agricultural land for agronomic or horticultural crop production.

Napit (1990) calculated that, after supplying the crop needs with locally produced litter, there was an annual surplus of 63,400 t of PL in some Virginia's counties. Therefore, the expansion of the poultry industry in established areas of high poultry production causes environmental problems. The mismanagement of poultry waste can cause N and P build up at the soil surface and movement to ground and surface water, which decreases the water quality.

Yard waste (YW) accounts for about 18% of the municipal solid waste in United States. Composting of YW has become a widely used method for recycling this waste (Slivka et al., 1992; Michel et al., 1993). In this process leaves, grasses or brushes are decomposed and the end product is used to enhance soil fertility (Dick and McCoy, 1993; Mankolo, 1994). Variations in YW result in differences in the chemical composition of the compost (Nordstedt et al., 1993). Michel et al. (1993) found that grass contains a higher level of N than leaves and could be used in the mixture to increase the amount of N in the compost. Conversely, addition of leaves and woody wastes lead to a higher C material that increases the potential to fix NO_3^- and NH_4^+

through microbial protein synthesis (Hansen et al., 1992). Composting YW and PL could be an effective method to decrease the time of composting to balance the C:N ratio in the end product, which is one of the main factor indicative of compost quality (Dick and McRoy 1993; Barkdoll and Nordstedt, 1991).

Effect of poultry litter on soil fertility

Poultry litter and poultry manure are by far the largest waste products from the poultry industry and are commonly used as source of nutrients for crop production (Simpson, 1991). Poultry litter is a combination of excreta and material used for bedding such as wood shavings, sawdust, and wheat straw, whereas poultry manure is mainly the excreta. Research has been carried out to evaluate the beneficial effects of nutrients in PL on crop production (Edwards and Daniel, 1992; Liebdardt, 1976). The elemental composition of PL varies with the type of bedding material, the feed consumed by the broiler, and the number of flocks grown on the same litter (Perkins et al., 1964; Hileman, 1967). Differences in elemental composition can cause a significant uncertainty about the fertilizer value of the waste. The only reliable method to predict effects of PL present on crop production is to analyze the waste before land application.

Sims and Wolf (1992) reported that total N and P contents in poultry waste are among the highest of all animal wastes. Similar results were observed in studies by Overcash et al. (1983b) where N and P contents in PL varied from 0.2 to 0.8% and 0.1 to 0.25%, respectively. As a "thumb rule" the percent N in fresh PL is about 75% in the organic form and 25% in inorganic form (Simpson, 1991). Transformation of organic and inorganic N forms in PL amended soils varies with environmental factors such as temperature, pH, moisture content, O_2 level, and microbial activity. The organic forms of N must be mineralized before they can be absorbed by plants.

Nitrogen mineralization

Mineralization, the conversion of organic N to inorganic N, is one of the principal

processes governing the presence of N in the soils. The rate at which mineralization of organic N in PL occurs has been studied for several decades and is necessary for proper plant nutrition and groundwater management. The N mineralization rate in PL was estimated at 90% during the first year; the rate depends on the duration of mineralization, the raw material and environmental conditions such as temperature and microbial population (Pratt, 1973). As a consequence the variability of environmental factors and microbial activity makes prediction of N availability more difficult. The rate at which the organic N mineralizes and the NH_4-N content in the poultry waste determine the amount of plant available N.

Chesteir et al. (1986) reported that more than 40 to 45% of total N from the poultry manure existed in inorganic form after 26 weeks of mineralization. Furthermore, they classified organic N into rapidly, near-term and long-term mineralizable groups. The uric acid in PL, which is readily degraded, was rapidly mineralized within days, the near-term form required weeks, and the long-term form required years to mineralize. Similarly, Bitzer and Sims (1988) found that 69% of organic N in poultry waste was mineralized in 140 days after incorporation into a sandy loam. Castellanos and Pratt (1981) reported that 48% of N in incorporated poultry manure can be mineralized within 10 weeks. Gale and Gilmour (1986) predicted more than 60% N mineralization in 28 days, whereas Sims (1986) reported more than 90% mineralization in a period of 150 days. Factor such as differences in bedding material in PL may have accounted for time of mineralization and for the variation in mineralization rates (Sims and Wolf, 1992).

It is generally, considered that the organic N in PL mineralizes at the rate of 50% during one growing season while the N mineralization rate of poultry manure during one growing season is about 90% (Simpson, 1991). At the end of the composting process, the stable materials may have a relatively low N mineralization rate and, therefore, slower mineralization rates might occur with composts than with PL or manure. As an example, Doran et al. (1977) estimated the mineralization rate of the stable compost to be between 2 to 10 % the first year and about 5% the second year (McCoy et al., 1986).

Effect of yard waste compost on soil fertility

Incorporation of composted YW may cause an improvement of soil physical and chemical properties of soil and, therefore, would be beneficial for plant growth. Composted YW contains more than 55% of organic matter and, consequently addition of YW increases soil organic matter content (Michel et al., 1993). In mineral soils, YW application increases the number of small pores that hold water needed by plants (McConnell, 1993) and, thereby, decreases the soil bulk density. The reduction in bulk density in mineral soils depends on rates of compost application, soil texture, and degree of compaction. Application of 49 t ha^{-1} of municipal sewage waste was found to decrease the bulk density by about 4% in a loam soil (Mays et al., 1978). Others beneficial effects from organic matter application are the changes in pH and the neutralization of some toxic substances (Golueke, 1972).

Due to the woody plant content, YW tends to be high in C content and low in N content. This high C:N ratio may cause N immobilization and, hence, N deficiency where YW is applied to soil (Hansen et al., 1993; Dick and McCoy 1993). High amounts of N are retained through microbial protein synthesis during composting at high C:N ratios (Golueke, 1972). A C:N ratio of 25 and above has been advised to slow the composting process and to reduce the loss of N (Hortenstine and Rothnell, 1973; Mays et al., 1973; Hansen et al., 1993; De Bertoldi et al., 1983).

Compost

Composting is a biological process to decompose the organic fraction of waste (Golueke, 1972). Advantages of composting are reduction in volume, pathogens, flies and odor, and production of a stable end product. Changes in elemental composition and losses of organic matter and N through volatization and immobilization reactions were observed when composting PL and cereal grain straw or sawdust (Galler and Davey, 1971; Kroodsma et al., 1987; Hansen et al., 1993). Loss of N can positively decrease the amount of leaching and negatively affect the plant N uptake. Incorporation of poultry waste has been reported to decrease N volatilization

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(Giddens and Rao, 1975). Sims and Wolf (1992) found that cation exchange sites retained NH_4^+ when the PL was incorporated into soil.

The decomposition of organic materials is a function of the type of raw materials and the environmental conditions such as temperature, O_2 content, moisture content, and initial C:N ratio (Keener et al., 1993). The heat generated by the metabolism of the microorganisms during the composting process can raise the temperature within the composting mass to above 75° C. Temperature above 60° C can be detrimental for microorganisms and therefore slows the decomposition process (Finstein et al., 1986; Finstein and Morris, 1975; Mckinley and Vestal, 1984). Barkdoll and Nordstedt (1993) found that a high temperature (60° C) was maintained during composting for a longer period of time when PL and YW were combined than with YW alone. The activity of thermophilic microbes at higher temperatures ($55-60^o$ C) and of mesophilic at lower temperatures (42° C) favors a rapid decomposition of the combined waste. This relationship was observed through measurement of the size of particles and the C:N ratios which are the parameters indicative of compost quality (Dick and McCoy 1993).

Barkdoll and Nordstedt (1991b) reported that the C:N ratio of freshly ground YW was 93 or above depending on the type of materials. Under these high C:N ratios, N becomes limiting for microbial activity that is required for optimum decomposition of organic matter. Poultry manure was effective in lowering the C:N ratio because of its high N content. Addition of carbonaceous material such as YW increases the potential for retention of NH_3-N through microbial protein synthesis. A decrease in NH_3-N release from uric acid in manure by NH_3-N incorporation into protein would increase the amount of N retained in the finished compost (Edwards and Daniel 1992). Too low a C:N ratio leads to a N loss in the form of NO_3^- while too high a C:N ratio slows the composting process by limiting the microbial population (Hansen et al., 1993; Michel et al., 1993; Richard and Chadsey, 1990). The organic matter content in compost is predominant in humic substances such as humic acids, fulvic acids, humin materials and polysaccharide (Golueke, 1972). Degradation of humus increases the plant availability of N, P, K, and micronutrients in compost.

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Land application of compost alters the physical properties of soils. Application of composted PL, YW or a composted combination of these materials, would decrease soil bulk density due to the increase in organic matter content (Weil and Kroontje, 1979). Incorporation of 110 Mg ha^{-1} poultry waste over a 5-year period decreased bulk density from 1.1 to 0.8 g cm^{-3} in a clay loam soil. In contrast, Hileman (1973) reported that annual application of PL did not affect the bulk density. Tester (1990) observed an increase in total porosity from incorporation of a sludge compost in a loamy sandy soil. Researchers also noted increases in both water holding capacity (Hortenstine and Rothwell, 1972) and plant available water from compost application (Epstein et al., 1976).

Modification of soil structure was explained by Haynes (1986) as the association of particles into aggregates with a concomitant increase in number of pores for air and water movement. Chen et al. (1988) reported that a mixture of composted cattle manure and peat contained higher levels of P as compared with peat alone. Application of composted materials increases soil CEC (McConnell, 1993; Hortenstine and Rothwell, 1973). Humic and fulvic acids formed in the organic matter present in the compost solubilize nutrients and increase CEC. An increase in CEC may enhance the ability of soil to hold nutrients and, thus, to increase plant uptake and to decrease leaching during irrigation or rainfall. Improvement in the physical, chemical and biological properties of soil from addition of compost is an important factor affecting the efficiency of compost application. The use of compost as an organic fertilizer blends well into a sustainable agricultural approach and prevents overuse of a mineral amendments.

Phosphorus

Application of PL to crop land usually has been based on the N requirement of crops (Moore et al., 1994; Edwards and Daniel, 1992; Chang et al., 1991; King et al., 1990). The relatively low N:P ratio of poultry waste may result in an increase in soluble P in soil except in highly deficient P soils with a high P fixation capacity (Sims and Wolf, 1992). Soil test procedures often indicate excessive P in cultivated fields amended with poultry manure (Mozaffari

and Sims, 1994; Sharpley, 1993; Sims and Wolf, 1992; Sharpley et al., 1994).

Phosphorus is relatively immobile in soil with little leaching to groundwater in most mineral soils. In those soils, P in poultry waste is rapidly hydrolyzed and chemically precipitated or adsorbed. Phosphorus management for high applications should be based on the chemical, physical, and biological reactions of P in soil (Edwards and Daniel, 1992; Reddy et al., 1978). The amount of P in soil depends on precipitation/adsorption reactions, mineralization rates, and plant uptake. Recent studies have shown little focus on P as compared with N transformations in poultry waste amended soils (Edwards and Daniel, 1992; Sharpley et al., 1993; Sims and Wolf, 1992; Sharpley et al., 1994a).

Phosphorus is found in organic and inorganic, and soluble and insoluble soil forms. In some soils water soluble inorganic P is rapidly converted into water insoluble P (Reddy et al., 1980). They observed that water soluble P increases with high poultry litter application in loamy sand and clay loam soils. With time P concentration decreases as a result of adsorption and precipitation reactions. Therefore, when P is applied to soil, there is little downward movement of P until surface layer saturation. As a result, little P movement occurs to groundwater through leaching, and most P contamination of water bodies results from surface runoff and erosion.

Phosphorus Mineralization

Inorganic P is the unique form of P that can be absorbed by plants. Therefore the transformation of organic to inorganic P through the mineralization process is fundamental to maintenance of an adequate P level in soil for plant growth (Tate, 1984; Dalal, 1977). Anderson (1975) indicated that some organic compounds containing P such as phosphohumic complexes could also contribute to plant nutrition and promote plant growth.

Total P concentrations have been shown to increase drastically in soils amended with manure or other wastes (Sharpley, 1995). In mineral soils, organic P was estimated to comprise about 60% of total P (Tiessen et al., 1993). Overall a greater increase was observed in inorganic P than organic P concentration after application of organic P, which reflects mineralization of the

organic material in soil. After mineralization the release of inorganic P from organic wastes can be followed by adsorption or precipitation reactions which alter the P availability and affect the rate of P uptake by crops. In contrast, Li et al. (1990) reported that organic metabolites such as organic acids produced during mineralization may prevent precipitation and dissolve non labile P in soils. Direct incorporation of organic material in a soil results in an assimilation of P by both plants and microorganisms (Birch, 1961). Phosphorus in microorganisms is in the form of nucleic acids, phospholipid and some sugar phosphates, which mineralize easily as compared with phytates in plants (Dalal, 1977; Tate, 1984).

Most of the soil organic P is in the form of the inositol phosphate or to an extent di-, tri- and tetra-phosphates of inositol. Inositol phosphates primarily of plant origin range up to 60% of the total soil organic P (Tate, 1984). The inositol phosphates are less mobile than soil phospholipids and exist in the form of insoluble salts that may retard the mineralization process (Bowman and Cole, 1978). Li et al. (1990) reported that the quantity of P mineralized was related to the initial quantity of P in soils. Hedley et al. (1982) suggested an additional application of organic matter to" build up" P levels in deficient soil.

Higher P mineralization rates cause depletion of organic P in cultivated than in virgin soils (Tiessen et al., 1982, 1983; Tate 1984). The breakdown of soil aggregates through cultivation leads to a greater degree of aeration that encourages microbial activity and therefore increases the decomposition of organic material (Dalal, 1977). Similar results were reported by Sharpley and Smith (1985) who found an increase in total P and a decrease in organic P in the surface soil horizon with cultivation.

Long term application (8-35 years) of beef feedlot and poultry manure caused an eight-fold increase in total N and P content in several types of soils (Sharpley et al., 1984, 1993). Tester et al. (1979) found that the extractable P in a soil compost mixture changed little in the early incubation period because of a slow P mineralization rate. Long-term application of manure at the Rothamsted has been shown to increase soluble P more than with superphosphate application when both are applied at approximatively the same P rate (Olsen and Barber, 1977;

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Meek et al., 1979). Meek et al. (1982) reported a decrease of about 9% per year of $NaHCO_3$-extractable P after discontinuance of the manure application.

Measurement of a P mineralized rate for organic P may become important in P nutrition of plants (Friesen and Blair, 1988). The interactions of mineralized P with inorganic constituents in soil such as Al, Fe, and Ca leads to difficulty in assessment of the total contribution of organic P to plant availability of soil P. In acid soils inorganic P exist mainly as Al bound P and Fe bound P and in neutral to calcareous soils inorganic P precipitates as Ca phosphates (Lindsay and Moreno, 1960).

Micronutrients

Manure is a source of Fe and Zn as well as other micronutrients. Tan et al. (1969) reviewed the literature regarding the use of poultry manure to correct Fe and Zn deficiencies. They found that manure may supply micronutrients and chelating agents that increase micronutrient solubility.

Environmental concerns

There are concerns regarding surface and groundwater quality impacts when PL is used to maintain soil fertility. Previous work has related field losses of animal waste constituents to application rate, weather conditions, type of soil, and other variables (Reddy et al. 1980). Runoff and loss of PL constituents increase with the rainfall intensity and with the rate of application. These relationships indicate an impact of environmental and management variables on runoff intensity. Sandy soil with low water holding capacities are very permeable and, therefore, have a high potential for leaching of nutrients to groundwater (Sims et al., 1985).

In areas with large PL production, economic and logistical contraints often push farmers to apply all the wastes locally. Therefore, over-application of PL could occur. Excessive quantities of manure may be detrimental to the environment due to the potential NO_3-N leaching. The build up of N at the soil surface from over application of PL may lead to surface and

groundwater degradation from excessive N (Edwards and Daniel, 1992; Sharpley et al., 1993; Sims and Wolf, 1994). Adverse effects are associated with NO_3-N pollution include methemoglobinemia, animal health, and eutrophication (Edwards and Daniel, 1992; Robinson and Sharpley, 1995). Many studies were designed to investigate NO_3-N leaching from agricultural application of PL. Liebhardt et al., (1979) applied PL at the rate 13.5 Mg ha^{-1} and above, and found a consistent and relatively high amount of NO_3-N level in groundwater. Similarly, Kingery et al. (1994) detected high concentrations of NO_3-N near bedrock from long-term application of PL.

Research on nonsource pollution of surface waters has identified the importance of soil P management (Simpson, 1991; Edwards and Daniel, 1992; Sharpley et al., 1993; Kingery et al., 1993; Sims and Wolf, 1994). Although N and P cause the eutrophication in surface water, P is more limiting than N due to the potential for NO_3-N leaching in freshwater ecosystem (Sharpley et al., 1994). Under field conditions, P transport occurs in solution and in association with eroded soil particles. Olsen and Khasawneh, (1980) found that P concentration in solution is maintained low in most agricultural land and, therefore, a small portion may be lost through leaching. Moore and Miller (1994) stated that land spreading of animal manure is a major source of runoff of P from agricultural land. Continual use of manure or excess P application to supply N needs of crops results in high P concentration in soil. Therefore determination of application rate to provide proper management is needed for most organic wastes.

The amount of PL applied to agricultural land is often based upon the N content and therefore leads to excessive amount of P for crop production (Mays et al., 1973; Sims and Wolf, 1992). Among the problems that arose from heavy application of PL were leaching and runoff of P and NO_3-N (Robinson and Sharpley, 1995; Edwards and Daniel, 1993; Sims et al., 1995; Sharpley et al., 1994). Zublena et al. (1990) analyzed soil P from different depths and found that P accumulated in the upper soil layer. The high P in runoff from high poultry waste application enhanced the potential for P degradation of surface and groundwater (Edwards and Daniel, 1992 ; Sharpley et al., 1993; Sims and Wolf, 1992; Robinson et al., 1995; Bigar and Corey, 1969;

Duda and Funan, 1983). Bonazzi et al. (1980) measured heavy N losses through volatilization, whereas Zublena (1990) found that P undergoes little change during the composting process. Eventually, P losses may occur from compost materials during rainfall by leaching of soluble P (Sharpley and Smith, 1989). High concentrations of solution P promote the movement to surface water and causes growth of algae and, thereby, eutrophication in lakes and reservoirs (Edwards and Daniel, 1992; Moore and Miller, 1994; Sharpley et al., 1994; Sims and Wolf, 1994). Management strategies to minimize P loss in comparison to N in soil has been of little concern until recently (Robinson and Sharpley, 1995).

Other detrimental effects may result from land application of PL. Poor management can be damaging for crop production by decreasing the germination of seeds (Liebhardt et al., 1979), by inducing undesirable nutrient balance (Zindel and Flegal, 1970), and by causing nuisance of flies and odor (Finstein, 1986). Production of an odorless product is a positive attribute of composting (Edwards and Daniel, 1994).

Crop production

Poultry litter application has been found to increase yields of corn (Shortall and Liebhardt, 1975), as well as bermuda grass (*Cynodon dactylon L. Pers*.), tomatoes (*Lycopersicom esculentum*), and cabbage (*Brassica oleracea L. Capitata*), (Warman, 1989). Application of PL at heavy rates was reported to decrease germination and corn growth when compared to lower rates of application (Shortall and Liebhardt, 1975). The decrease in corn yield was attributed to the toxic concentration of NH_3 and to the detrimental effect of salts accumulation. High salt concentration inhibits uptake of water into roots that may caused poor performance of crop treated with animal wastes.   Weil et al. (1979) found that NH_3 concentration of 800 mg kg^{-1} of soil from high PL application were toxic to corn on a Davidson soil. Ammonia in soil solution results in severe plant toxicity by reducing seed germination, root growth, and respiration (Mengal and Kirkby, 1987).

Furthermore, studies have shown that, at equal rates, application of composted organic

material leads to better plant growth than fresh or dried waste (Volgtmann et al., 1973). Addition of composted waste has been reported to increase crop yields (Tester, 1990). Application of corn as a test crop municipal sludge compost at rates of 100 to 450 t ha^{-1} increased corn grain yields from 10 to 35 % (Shiralipour et al., 1993). Application of composted products to forage sorghum (*Sorghum bicolor L.*) increased the yield from 10 to 35 %. Similar results were reported for wheat (*Triticum aestivum L.*), barley (*Hordeum vulgare L.*), oats (*Avena sativa L.*), and rye (*Secale cereale L.*) (Roe et al., 1993; Mays et al., 1973). The increases in crop yield were attributed to improved soil structure, which led to more favorable water holding capacity, to a decrease of compaction on mine tailings, and to addition of essential elements (Clap et al., 1986; McConnell et al., 1993).

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