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The Effects of Composted Poultry Wastes on Nitrogen Mineralization and Biological Activity in a Silt Loam Soil

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Abstract: Poultry manure or its compost are rich in plant nutrients and have a special potential to meet N and P requirements of agricultural plants. A laboratory study was carried out for 84 days at 30°C to asses the effect of application rate of composted poultry manure on soil respiration, dehydrogenase activity and nitrogen mineralization in a silt loam soil. Poultry compost rates were 0, 20, 40 and 60 Mg ha^{-1}. Soil biological characteristics such as CO_2 production, dehydrogenase activity and mineralization of organic-N into NH_4^+-N and NO_3^- -N were determined on daily base during the first week and then in week interval. The results showed that CO_2 production, dehydrogenase activity and mineral nitrogen of soils increased with respect to application rate of poultry compost. The mineralization rate was remarkably high in the first weeks and the mineralized-ammonium was immediately converted into NO_3^--N that accumulated during the course of experiment. Therefore, it is suggested that organic residues having narrow C:N ratio should not be applied at high amounts when there is no requirement for N by a growing crop.

Key words: Poultry compost, CO_2 production, nitrogen, mineralization, dehydrogenase (DHG) activity

INTRODUCTION

Organic wastes, such as various animal manure and crop residues, could be recycled through application to agricultural land as a source of plant nutrients, especially N, as well as a soil amendment to enhance the future crop production by improving soil quality in both conventional and organic farming. This also contributes to the sustainability and reduces inorganic fertilizer requirement in conventional agriculture. Adding organic wastes to the soil can increase total N, organic matter, microbial population, enzyme activity, moisture retention, pH buffering capacity and crop yield (Dick and Crist, 1995; Edwards, 2002). The microorganisms affect soil fertility trough their nutrient cycling processes, which are consequence of microorganisms exudates and enzymes. Therefore, amounts of CO_2 production and enzyme activity are accepted as bio-fertility indicators of soils (Schinner, 1968).

Animal wastes have advantage over plant residues in turns of mineralization ability (Cameron *et al*., 1997). On the other hand, 90% of N in poultry manure mineralizes in the first year that provides advantage to poultry manure over cattle manure (30%) and swine manure (75%) to meet N requirement of plants (Gordillo and Cabrera, 1997a). Poultry manure or compost contains significant amount of N in both inorganic and organic forms. While inorganic nitrogen forms are readily available for plant uptake, the release of N from organic fractions is dependent on many soil characteristics (i.e., texture, pH) and environmental factors (temperature, moisture etc.) (Gordillo and Cabrera, 1997a, b; Cordovil *et al*., 2001) as well as chemical properties of poultry manure. On the other hand, nitrogen mineralization potential of poultry manure was reported to be much higher than that of farmyard manure and sewage sludge (Dick *et al*., 1988) and due to low C:N ratio, mineralization rate of poultry manure is very high during the first week following the addition. Moreover, composting poultry manure changes the mineralization characteristics (Tyson and Cabrera, 1993). These characteristics of poultry manure make it difficult to manage in different agricultural soils.

Additions of the organic residues stimulate the biological activity, enzyme activity and nitrogen mineralization in soils (Kara, 1996, 2000; Zaman *et al*., 1999). To achieve environmentally and economically sound application of organic wastes, it is therefore, crucial to understand the rate of N mineralization affected by the

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rates of organic residues. Therefore, the rates of applied poultry compost have a critical importance to avoid from any environmental hazard (i.e., nitrate leaching into groundwater and surface waters) and to enhance soil fertility. Thus, the objective of this research is to study the effects of composted poultry industry wastes on CO_2 evolution, dehydrogenase enzyme activity and nitrogen mineralization in a silt-loam textured soil.

MATERIALS AND METHODS

Poultry Compost (PC): The organic residue used in this study was a composite of biologically fermented poultry litter, chicken wings, bones and legs. The composted poultry wastes had a pH of 6.8, total nitrogen of 6.3%, total C of 32.7%, C:N ratio of 5.2, soluble salts of 2.2% and water saturation capacity of 200%.

Soil: A composite surface layer (0-20 cm) of soil was collected from Gelemen State Farm, Samsun, Turkey. Soil has been formed on the coastal sand under semi-arid climate conditions. The average annual temperature and mean annual precipitation are 14.4°C and 690 mm. Some chemical and physical properties of the soil were determined according to methods given by Sparks (1996) and Klute (1986). The results were tabulated in Table 1.

Treatments and analyses: Three different rates of PC, equivalent to 20, 40 and 60 Mg ha^{-1}, were mixed thoroughly with 500 g oven dry soil and placed in pots. The soil without PC was used as the control. There were three replicates of each treatment. Soil samples wetted to field capacity and kept constant during the course of the incubation period. Then, tightly closed containers were incubated at (30°C) for 84 days in constant temperature room. Sub-soil samples were taken daily interval in the first week and once a week, afterwards.

Produced CO_2 was trapped in $Ba(OH)_2$ solution (Isermeyer, 1952) and the excess of $Ba(OH)_2$ were determined by back titration with the 0.045 N HCl solution that each ml of it equivalent to 1 mg CO_2 evolution.

Dehydrogenase, which is an endo-enzyme, activity was estimated colorimetrically by the method given by Casida *et al.* (1964) after completing reaction of the fresh soil samples with reductant TTC solution. Mineral nitrogen forms in soils (NH_4^+ and NO_3^-) were extracted with 2 M KCl solution and were determined by steam distillation (Mulvaney, 1996).

Mineralization data were fitted to first order kinetics model proposed by Stanford and Smith (1972) that was also reported to successively describe mineralization from different organic wastes (Cordovil *et al.*, 2005).

$$N_m = N_0\ (1\text{-}\exp[-kt])$$

Where N_m accumulated mineralized nitrogen at time t, k mineralization constant, t is time in days and N_0 mineralization potential.

RESULTS

CO_2 production: Rates of PC and time significantly influenced the cumulative CO_2 production in the soil as illustrated in Fig. 1. As average daily CO_2 production considered, there were three stages in the decomposition process of PC: a) 1-14 days, b) 14-42 days and c) 42-84 days. Average CO_2 evolutions were determined to be 25.8, 37.7, 57.4 and, 61.2 in the first stage; 6.71, 8.78, 10.78 and 15.24 in the second stage; and 2.13, 2.75, 4.50 and 6.61 mg CO_2 day^{-1} per 100 g soil for control, 20, 40 and 60 t ha^{-1} PC applications, respectively.

Dehydrogenase (DHG) enzyme activity: The addition of PC to the soil led to a significant increase in soil DHG enzyme activity compared to control treatment. DHG activity remained higher in the higher PC applied treatments throughout the experimental period (Fig. 2). DHG enzyme activity was found to be gradually decreased with time. There was a fluctuation after the 5th week in the enzyme activity and the measured activity became close to each other in the later stages.

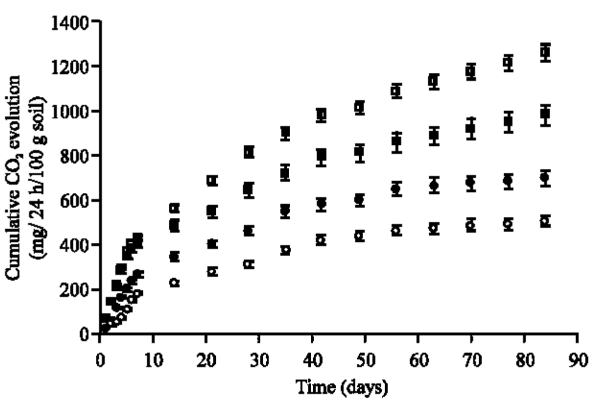

Fig. 1: The effect of poultry compost on the cumulative CO_2 evolution. ∘ control, • 20 Mg ha^{-1}, ▪ 40 Mg ha^{-1} and ▫ 60 Mg ha^{-1}

Table 1: Some chemical and physical properties of soil

pH	Texture	TDS[a] (g kg^{-1})	OC[b] (g kg^{-1})	$CaCO_3$ (g kg^{-1})	Σ N (g kg^{-1})	NO_3^--N (mg kg^{-1})	NH_4^+-N (mg kg^{-1})	Olsen-P (kg ha^{-1})
7.9	SiL[c]	0.19	3.5	37.9	5.8	49.4	22.4	20

[a]TDS: total dissolved salts, [b]OC: organic carbon, [c]SiL: silt loam

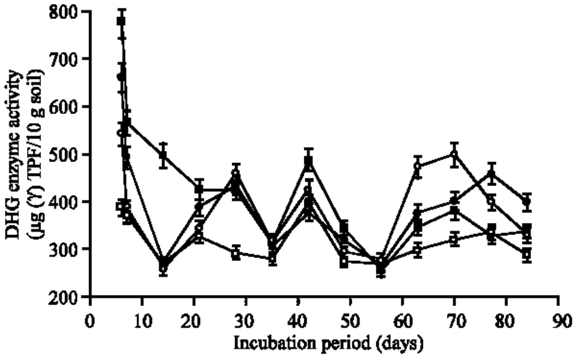

Fig. 2: The effect of poultry manure rates on DHG enzyme activity. ∘ control, • 20 Mg ha^{-1}, ▪ 40 Mg ha^{-1} and ▫ 60 Mg ha^{-1}

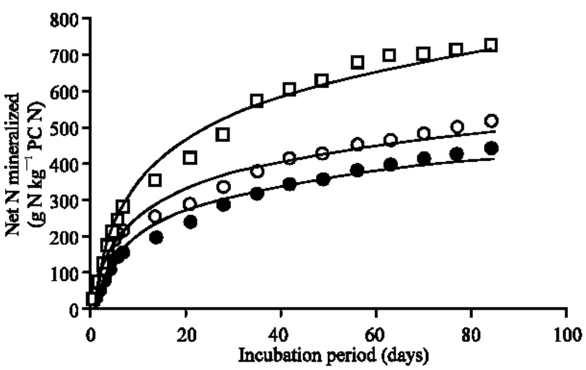

Fig. 3: Cumulative net mineralization from PC nitrogen. Points □ 20 Mg ha^{-1}, ○ 40 Mg ha^{-1} and ● 60 Mg ha^{-1} represent observed values and lines represent predicted values by one pool first-order kinetics model (R^2 = 0.982, 0.981 and 0.975 for 20, 40 and 60 Mg ha^{-1})

Nitrogen mineralization: Nitrogen mineralization from PC started just after the compost was incorporated into the soil, with a rapid mineral nitrogen accumulation by the end of the first week and followed by a slower rate of accumulation (Fig. 3). However, one pool mineralization model was successively described N mineralization from PC at different rate there were fast and slow mineralization pools. The net N mineralization was significantly ($p<0.05$) affected by the different rates of PC applications (Fig. 3). By the end of first week 38.4, 41.5 and 34.6% of total mineralizable nitrogen were released. Increasing application rates have speeded up the amount of mineralizable nitrogen but cumulative nitrogen mineralization after 84 days were 722, 513 and 441 g kg^{-1} PC nitrogen for 20, 40 and 60 mg PC ha^{-1} applications, respectively, where increasing application rates resulted in reduced mineralization percentage. The overall mineralization pattern was similar for all rates of PC as well as indigenous soil organic matter.

DISCUSSION

CO_2 evolution: Various researchers reported two or three stages in the kinetics of mineralization of poultry litter (Hadas *et al.*, 1983; Gale and Gilmour, 1986; Gordillo and Cabrera, 1997b). Three stages were also observed in this study as CO_2 evolution considered that organic N is decomposed into ammonia by heteretrophic microorganisms producing CO_2 as a result of their biological activity.

The rapid increase in the CO_2 production during the first week is most probably explained in terms of readily available C and N contents of PC and favorable environmental conditions (high temperature 30°C and sufficient available water content) for microbial growth in soil (Paul and Clarke, 1994; Kara, 2000; Olayinka, 2001). Following the addition of PC, the population of heterotrophic microorganisms that decompose organic matter for their C, N and energy requirement drastically increased and respiration rate was related with the amount of PC applied. Similarly, Olayinka (2001) reported an increase in respiration rate with the rate of cow dung. As C/N ratio reduced by the end of incubation, due to decline in readily available C sources, the activity of heterotrophic microorganisms progressively decreased down towards the level of control soil. Similar pattern was also reported many researcher for different organic wastes (Gale and Gilmour, 1986; Hadas *et al.*, 1983; Olayinka, 2001; Parham *et al.*, 2002).

DHG enzyme activity: DHG activity represents soil microbial activity at the measurement time and implements the decomposition of organic matter by microorganisms (Schinner, 1968). Dehydrogenase activity conducts a broad range of oxidative activity that is responsible for decomposition of organic matter. Its activity was reported to be related with indigenous organic matter content of soils (Camina *et al.*, 1998; Wlodarczyk *et al.*, 2002). Moreover, dehydrogenase activity of soils was closely related to microbial biomass that is governed by various management practices such as crop rotation, organic amendments, fertilization and crop residue management (Chander *et al.*, 1997). Long-term cattle manure application increased dehydrogenase activity in soil even in deeper layer (Parham *et al.*, 2002). The results obtained in this study showed that by addition of PC the number of soil microorganisms increased due to the favorable temperature, moisture and organic substrate during the first week. Therefore, in accordance with the CO_2 evolution, DHG activity reached a peak point at the beginning of the incubation and gradually decreased with respect to time. It was probably related to the exhaustion of energy rich substrates with time that cause reduction in the number of soil microorganisms and DHG enzyme activity.

Changes in dehydrogenase activity can be due to modification of the composition of the microbial community (Dick and Tabatabai, 1993). Figure 2 indicating that there were likely to be three different microorganisms group decomposing added PC having different resistance to decomposition. This was also corresponded with the CO_2 evolution rate that also showed three stages.

Nitrogen mineralization: There were two mineralization pools in PC organic nitrogen that was also reported by many researchers (Gale and Gilmour, 1986; Gordillo and Cabrera, 1997a, b) but one pool mineralization model successively described the mineralization (Cordovil *et al.*, 2005). Cumulative mineralized nitrogen after 84 days varied from 441 to 722 g kg^{-1} Organic Nitrogen (ON). These results within the range reported by Bitzer and Sims (1988) who incubated 16 broiler litter with a soil at 23°C for 140 days. Castellanos and Pratt (1981) reported 485 g N kg^{-1} ON after 70 days incubation of chicken manure at 23°C. The nature of poultry manure, soil and incubation conditions (temperature, manure application rate, moisture content during the incubation) can significantly change the amount of mineralized ON (Gale and Gilmour, 1986; Gordillo and Cabrera, 1997a,b). Here in this study increasing rate of PC reduced the mineralization percentage of PC nitrogen. Though, the amount of released nitrogen from PC increased by the higher application rate where the presence of excessive substrate limited mineralization percentage of PC nitrogen.

Many researchers have reported that there was a rapid decrease in daily-mineralized N following incorporation of organic residues where microbial immobilization of readily available mineral nitrogen occurs (Kara, 1996, 2000; Olayinka, 2001). During this stage, organic nitrogen breakdown to ammonia are the dominant process and to a lesser extent nitrification can occur depending on the biological immobilization rate of ammonia. After this stage, there was an increase in the mineralized-N that indicated the release of nitrogen fixed by soil microorganisms and NO_3^- accumulation occurs. Similar results were reported by Tyson and Cabrera (1993) for composted and uncomposted poultry litter.

Inter-relationships: Relationships between N mineralization and ammonification, nitrification, CO_2 evolution and dehydrogenase activity at different sampling dates were examined and results were tabulated in Table 2. Nitrogen mineralization was found to be positively correlated with NO_3^- and NH_4^+ content of the soil and negatively correlated with CO_2 evolution. Since NO_3^- and NH_4^+ is a component of total mineral nitrogen, such significant positive relation should always be expected. However, correlation coefficients indicated that the share of NO_3^- was much higher in the total mineralization. It was the fact that mineralized NH_4^+ was rapidly converted to NO_3^- under convenient environmental conditions (Paul and Clarke, 1994; Zaman *et al.*, 1999). Negative relation between mineralization and CO_2 evolution can be explained in terms of domination of nitrification process over the experimental period besides first two weeks and immobilization of mineral N by soil microorganisms. These reasons can also lead significant positive and negative correlations between nitrate mineralization and NH_4 mineralization and CO_2 evolution, respectively, as observed in the present study.

Table 2: Correlation coefficients of CO_2 production, dehydrogenase enzyme activity, total mineralized nitrogen, NH_4^+-N and NO_3^--N

Variables	DHG	Σ Min-N	NH_4^+-N	NO_3^--N
CO_2	0.404	-0.644**	0.716**	-0.742**
DHG	1.000	-0.499*	0.111	-0.497*
Σ Min-N		1.000	-0.164	0.985***
NH_4^+-N				-0.333

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

There was a significant positive correlation between dehydrogenase enzyme activity and CO_2 evolution. Since microorganisms produce both dehydrogenase enzyme and CO_2 during decomposition of nitrogenous organic residues, such relation can be expected. Moreover, nitrate content was significantly correlated with NH_4^+ content and CO_2 evolution since nitrate formation pre-requires decomposition of organic nitrogen into NH_4^+ during which CO_2 evolves.

This study has shown that the CO_2 production, nitrogen mineralization and dehydrogenase enzyme activity increased with respect to the increasing rates of poultry wastes. Mineral nitrogen content (NH_4^+-N and NO_3^- -N) of soil increased as a function of application rate. The rate of net mineralization was higher after 28th day of incubation. After CO_2 production have started to diminish, the concentration of NH_4^+-N decreased; whereas, NO_3^--N concentration increased. The application of organic residues with small C:N ratio should be carefully performed in case not to cause any environmental hazard. PC should not be applied just before the start or during the rainy season because of its very high decomposition rate and NO_3-N formation.

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