

Influences of vermicomposts on field strawberries: Part 2. Effects on soil microbiological and chemical properties

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Abstract

The effects of applications of food waste and paper waste vermicomposts on some soil chemical and biological properties were evaluated in field plots planted with strawberries. Six-week old strawberries (*Fragaria ananasa*, var. Chandler) were transplanted into 4.5 m² raised beds under a plastic tunnel structure measuring 9.14 × 14.6 × 3.6 m. Vermicompost were applied at rates of 5 or 10 t ha⁻¹ supplemented with inorganic fertilizers to balance fertilizer recommendations for strawberries of 85–155–125 kg NPK ha⁻¹. Effects of vermicomposts on strawberry growth and yields have been reported previously [Arancon, N.Q., Edwards C.A., Bierman P., Welch, C., Metzger, J.D., 2004. The influence of vermicompost applications to strawberries: Part 1. Effects on growth and yield. *Bioresource Technology* 93:145–153]. Total extractable N, NH₄-N, NO₃-N and orthophosphates did not differ significantly between treatments, except on the last sampling date (harvest date) in which significantly greater amounts of NH₄-N, NO₃-N and orthophosphates ($P \leq 0.05$) were recorded in vermicompost-treated soils than in the controls. Two major results of vermicompost applications to soils were increases in dehydrogenase activity and microbial biomass-N which were not dose-dependent. Increased dehydrogenase activity and microbial biomass-N was correlated positively with the increased amounts of NH₄-N, NO₃-N and orthophosphates in the vermicompost-treated plots than in the controls. Increases in microbial populations and activities are key factors influencing rates of nutrient cycling, production of plant growth-regulating materials, and the build-up of plant resistance or tolerance to crop pathogen and nematode attacks.

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1. Introduction

The quality and value of agricultural organic soil amendments are often measured in terms of their contributions to nutrient supplies and soil fertility. However, they can also have significant effects on the microbiological and chemical properties of the soil, which are indirectly responsible for supporting crop growth. In particular the microbiological properties of soils can influence soil organic matter decomposition and soil

enzymatic activities (Nannipieri et al., 1990). The addition of organic materials to the soil has been reported to increase biomass C, basal respiration, the ratio of biomass C to total organic C, and metabolic quotients indicating the activity of soil microorganisms (Pascual et al., 1997). Other workers have reported increased microbial populations (Barakan et al., 1995) and activity (Zink and Allen, 1998) after addition of organic matter to soils.

Vermicomposts, which are stabilized organic materials produced by interactions between earthworms and microorganisms, in a non-thermophilic process, have been reported to enhance plant germination growth and yields in greenhouse crops (Edwards and Burrows,

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1988; Buckerfield et al., 1999; Atiyeh et al., 2000a,b,c,d, 2001; Edwards and Arancon, 2004a,b; Edwards et al., 2004). Applications of vermicomposts to field soils have also been reported to increase crop growth and yields (Buckerfield and Webster, 1998; Mba, 1983; Masciandro et al., 1997; Venkatesh et al., 1998; Vadiraj et al., 1998; Kale et al., 1992; Arancon et al., 2003b, 2004). Such increased productivity of crops, in response to vermicomposts amendments, have been attributed to greater availability of mineral nutrients, than in commercial plant growth media containing only inorganic nutrients (Edwards and Burrows, 1988; Werner and Cuevas, 1996), as well as their rich microbial populations (Edwards, 1983; Tomati et al., 1987; Carlile and Wilson, 1993). The presence of plant growth-influencing substances, such as plant growth hormones and humic acids in vermicomposts has also been suggested as a possible factor contributing to increased plant growth and yields (Tomati et al., 1988; Muscolo et al., 1999; Arancon et al., 2003a). The objectives of the research reported here were to follow changes in soil microbial and chemical properties such as ammonium N, nitrate N, microbial biomass N, orthophosphates and dehydrogenase enzyme activity after addition of vermicomposts to soil.

2. Methods

2.1. Location of experimental sites

The first site (Site A) was located in the OSU South Centers of Piketon, Ohio. The experimental soil has been designated in the US soil survey as a DoA—Doles silt loam, with 0–3% slopes. It is a deep, nearly level and somewhat poorly drained soil. Typically, the soil surface is a brown, friable silt loam about 20 cm deep and beneath this the subsoil is about 18.5 m. The second site (Site B) was located at the Ohio Agricultural Research and Development Center, Fremont, OH. The soil on the experimental site is a Hoytville silty clay loam soil. It is characterized as nearly level, very poorly drained, moderately fine-textured, with a high organic matter content, moderate available water capacity and slow or ponded runoff.

2.2. Field lay-out and design

Raised soil beds were constructed, measuring 1.5×3.0 m (4.5 m^2 per plot). Commercially produced food waste and paper waste-based vermicomposts were used in the trials. Food waste vermicompost was provided by Oregon Soil Corporation (Portland, OR) and paper waste vermicompost was provided by American Resource Recovery, (Stockton, CA). Vermicomposts were applied to plots at two dosage rates: equivalent

to 5 t ha^{-1} and 10 t ha^{-1} . Plots treated with N, P, and K at 85–155–125 kg/ha were used as controls for comparison. All of the vermicompost-treated plots were supplemented with appropriate amounts of inorganic fertilizer to equalize the total recommended full fertilizer rate. Vermicomposts and inorganic fertilizers were applied and incorporated into the top 10 cm of the entire bed.

Plastic mulch and drip irrigation systems were constructed over the raised beds after the vermicomposts and fertilizers were applied. Mini-sprinklers were used, as well as cotton mesh row covers for frost protection. Six-week old strawberry (*Fragaria ananasa*) plugs var. 'Chandler' were transplanted into the plots on 10 September 1999. Twenty-four plants were transplanted into each bed with 38 cm between plants with three rows spaced 38 cm between rows. Plants in the middle row were planted in a staggered design with respect to the outer rows to maximize distances between plants. Treatments were replicated four times in a randomized complete block design. The experimental trials were under high plastic tunnel hoop house structures measuring $9.14 \times 14.6 \times 3.6$ m. They were unheated and were ventilated by rolling up the sides on bright sunny days.

2.3. Data collected

Eight 2.5 cm diameter \times 20 cm deep soil cores were taken at random from the strawberry root zones of each plot. Four sets of samples were taken from Site A: at transplanting, and 110 days, 160 days and 220 days after transplanting to the end of harvesting) and at Site B: at transplanting, 150 days and 200 days after transplanting and at the end of harvesting.

Extractable N ($\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$) were quantified using a modified indophenol blue technique (Sims et al., 1995). Soluble P was assessed using $\text{NH}_4\text{-HCl}$ reagent (Olsen and Sommers, 1982). Color in the sample filtrates was developed with stannous chloride and ammonium paramolybdate and hypochlorite reagents. Absorbance was measured using a Bio-Tek EL211sx automated microplate reader. A more complete nutrient analysis was made for other vermicompost samples after nitric acid/perchloric acid digestion (Singer and Hanson, 1969). The extracts were analyzed for P, K, Ca, Mg, B, Cu, Fe, Mn, Mo, and Zn using inductively coupled plasma-atomic emission spectroscopy (ICP-AES) (Munter and Grande, 1981). Total C and N were measured in vermicomposts by dry combustion using a Carlo-Erba apparatus.

Microbial biomass was measured in chloroform-fumigated 5 g soil samples (Brookes et al., 1985). Fumigated samples were extracted and digested after a five-day chloroform fumigation, using potassium sulfate and potassium persulfate, respectively. Nitrate-N was

measured colorimetrically using a modified indophenol blue technique (Sims et al., 1995) with a Bio-Tek EL211sx automated microplate reader. Dehydrogenase enzymatic activity (DHA) was measured using a modified method of Casida (1977), and the accumulation of the end product after sample incubation, triphenyl formazan (TPF), was determined with a Bio-Tek EL211sx automated microplate reader.

2.4. Statistical analysis

Analyses of variance were done on all soil parameters, the means of parameters were grouped for comparisons, and differences were separated least significant difference (LSD) using SAS (SAS Institute, Inc., Cary, NC, USA 1990). Significant differences were determined at $P \leq 0.05$.

3. Results

The total extractable N did not differ significantly ($P \leq 0.05$) between treatments from either experimental site, except in samples taken on the last sampling date, where soils treated with paper waste vermicompost at a rate of 10 t ha⁻¹ contained more extractable N on site A (Fig. 1) and soils treated with food waste vermicomposts at the rate of 10 t ha⁻¹ significantly had the greatest amount of extractable N ($P \leq 0.05$) on site B (Fig. 2). There was a trend to decreased amounts of NH₄-N in all plots on site A on all sampling dates and amounts did not differ significantly between treatments (Fig. 3). The amounts of NH₄-N followed a similar trend except on the last sampling date when soils treated with paper waste vermicomposts, at the rate of 5 t ha⁻¹ had significantly greater amount of NH₄-N ($P \leq 0.05$; Fig. 4). The same pattern of decreasing amounts of NO₃-N occurred in all treatments from both sites (Figs. 5 and 6). In both sites, soils treated with paper waste vermicomposts at

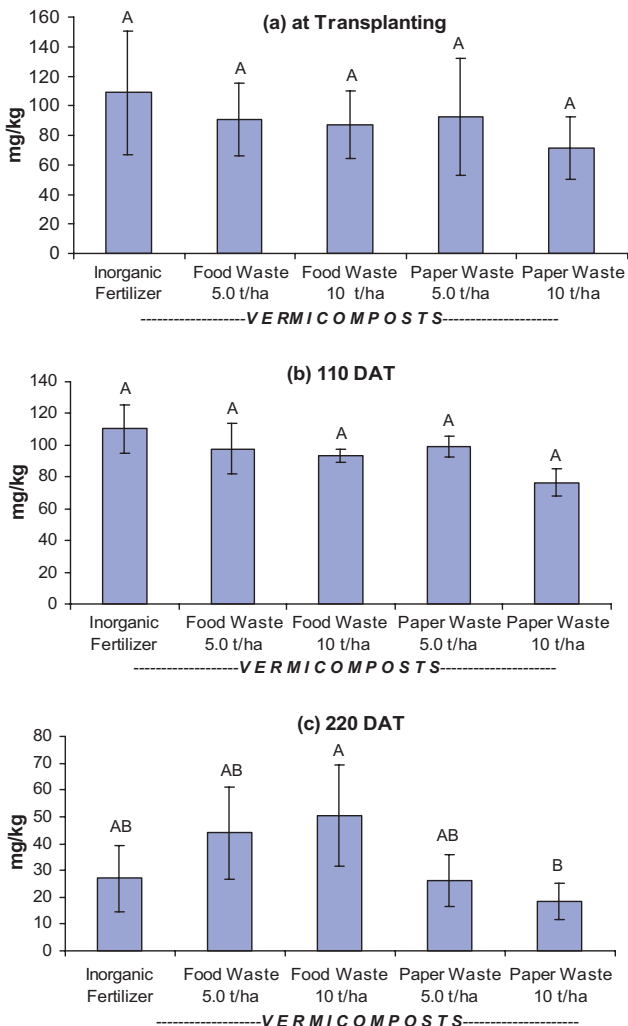


Fig. 1. Total extractable N in strawberry plots on Site A (Piketon, OH) at three sampling dates: at transplanting, 160 and 220 DAT (days after transplanting). Columns followed by the same letter(s) do not differ significantly ($P \leq 0.05$).

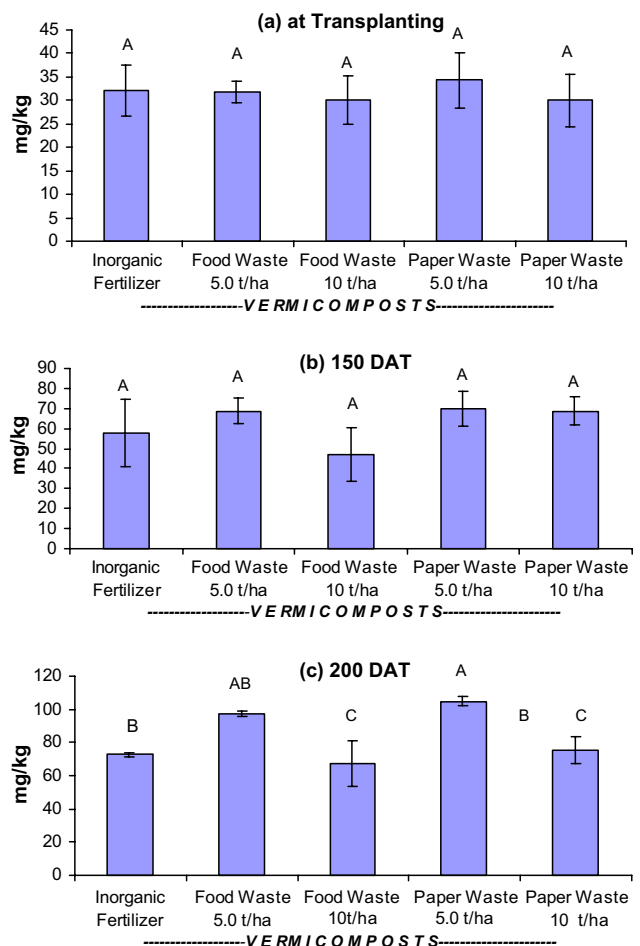


Fig. 2. Total extractable N in strawberry plots on Site B (Fremont, OH) at three sampling dates: at transplanting, 100 and 200 DAT (days after transplanting). Columns followed by the same letter(s) do not differ significantly ($P \leq 0.05$).

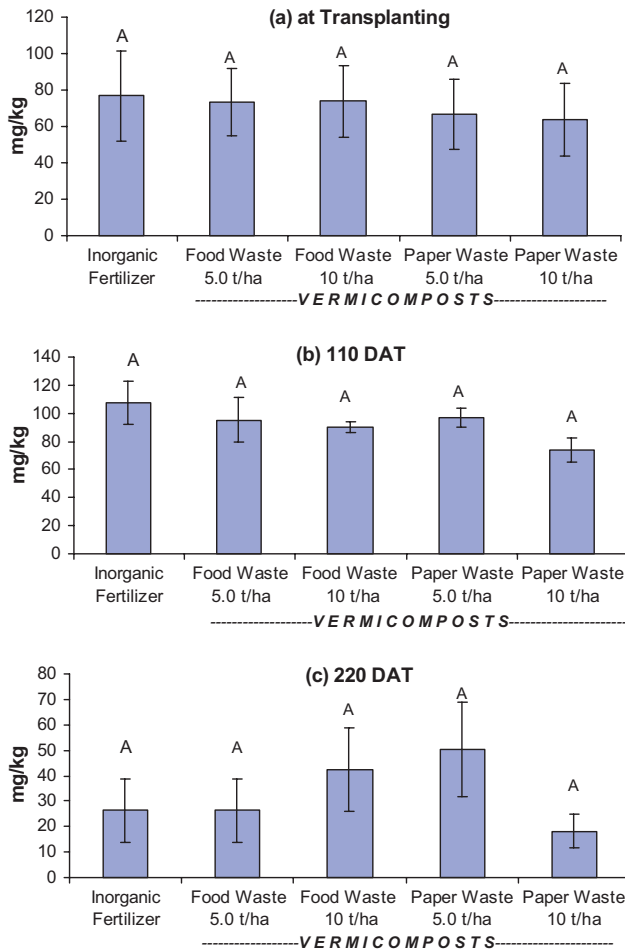


Fig. 3. NH₄-N in strawberry plots on Site A (Piketon, OH) at three sampling dates: at transplanting, 160 and 220 DAT (days after transplanting). Columns followed by the same letter(s) do not differ significantly ($P \leq 0.05$).

the rate of 5 t ha^{-1} significantly more of NO₃-N ($P \leq 0.05$) than soils treated with inorganic fertilizers only in site B (Fig. 6).

Soils treated with food waste vermicompost and paper waste vermicompost at the rate of 10 t ha^{-1} had significantly more microbial biomass N ($P \leq 0.05$) at transplanting than controls, but soils treated with food waste vermicompost consistently maintained most microbial biomass N on all sampling dates (Fig. 7). At site B, microbial biomass N did not differ significantly between treatments ($P \leq 0.05$) except that on the last sampling date when significantly greater amounts of microbial biomass N ($P \leq 0.05$) occurred in all plots that received both types of vermicomposts (Fig. 8).

Soils treated with food waste vermicompost at the rate of 5 t ha^{-1} had significantly more orthophosphates ($P \leq 0.05$) than those from all other treatments at transplanting and a trend of significantly increased amounts of P ($P \leq 0.05$) occurred in soils that received vermicomposts compared with soils that received inorganic fertilizers only, 110 days after transplanting on site A (Fig.

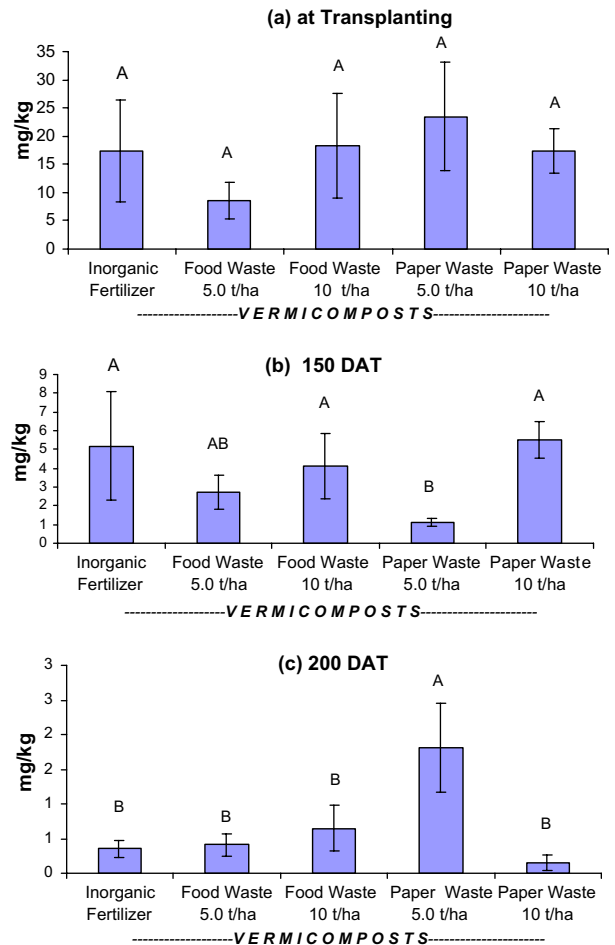


Fig. 4. NH₄-N in strawberry plots on Site B (Fremont, OH) at three sampling dates: at transplanting, 100 and 200 DAT (days after transplanting). Columns followed by the same letter(s) do not differ significantly ($P \leq 0.05$).

9). At harvest, soils treated with food waste vermicompost applied at the rate of 10 t ha^{-1} had most P. On site B, soils treated with food waste vermicomposts at rates of 10 t ha^{-1} and paper waste at rates of 5 t ha^{-1} had significantly more orthophosphates ($P \leq 0.05$) than soils that received inorganic fertilizers only (Fig. 10).

Dehydrogenase enzyme activity did not differ significantly in soils between any plots at transplanting on site A (Fig. 11). Soils from the food waste vermicompost-treated plots supported significantly more dehydrogenase activity, 110 days after transplanting compared with the inorganic control. Dehydrogenase activity was significantly more in soils from food waste vermicompost-treated plots ($P \leq 0.05$) 110 days after transplanting and was significantly greater ($P \leq 0.05$) in all vermicompost-treated plots than in the inorganically fertilized plots at harvest. On site B, soils from the inorganic control soils had significantly more dehydrogenase activity than those from vermicompost-treated plots at transplanting (Fig. 12). However, all plots that received vermicompost treatments had significantly more dehy-

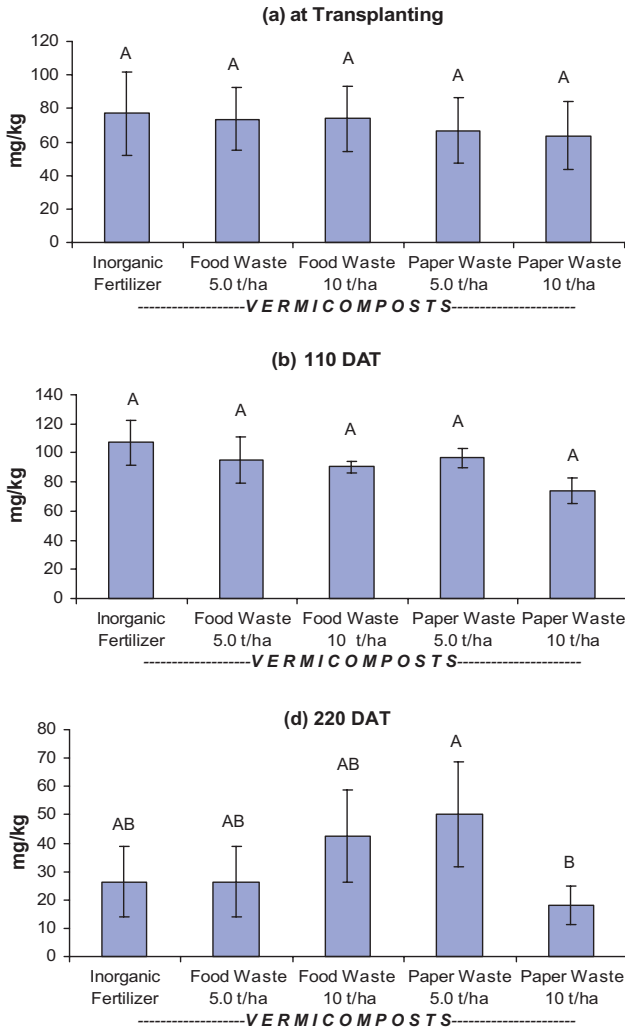


Fig. 5. NO₃-N in strawberry plots on Site A (Piketon, OH) at three sampling dates: at transplanting, 160 and 220 DAT (days after transplanting). Columns followed by the same letter(s) do not differ significantly ($P \leq 0.05$).

drogenase activity ($P \leq 0.05$) at harvest than in plots that received inorganic fertilizers only. There were positive significant correlations between dehydrogenase activity and microbial biomass N, microbial biomass N and P contents, between total extractable N and dissolved organic N, and between nitrate-N and dissolved organic N ($P \leq 0.05$, Table 1).

4. Discussion

The amounts of total extractable N in soils from the vermicompost-treated plots did not differ significantly from those in the inorganic control soils. This was presumably because of the inorganic fertilizer supplements applied to the vermicompost-treated plots which were aimed at equalizing the available nutrients in soil, with those in the inorganic controls, in terms of N, P and

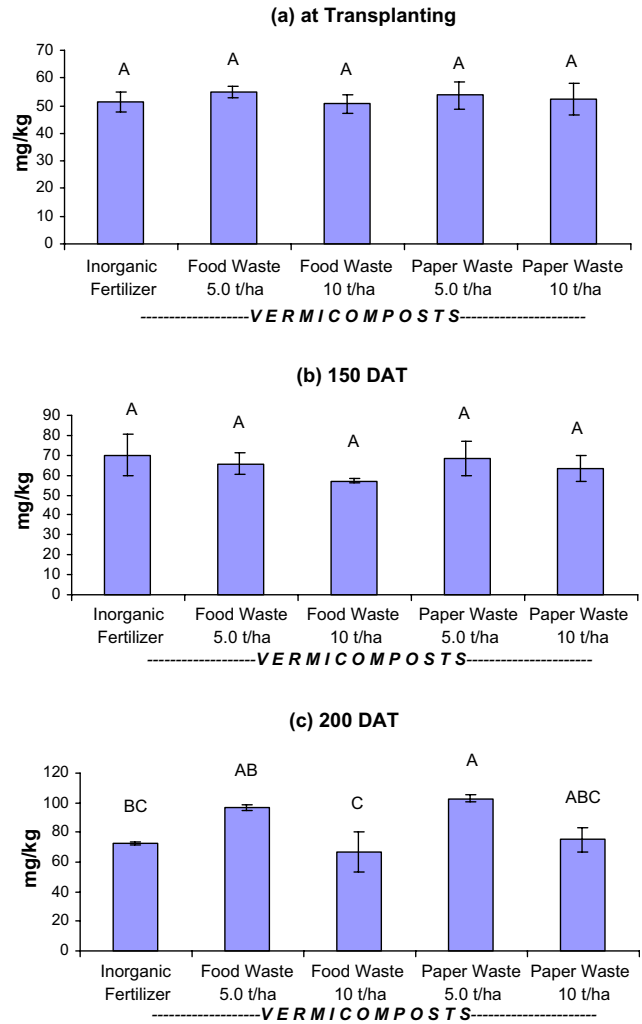


Fig. 6. NO₃-N in strawberry plots on Site B (Fremont, OH) at three sampling dates: at transplanting, 100 and 200 DAT (days after transplanting). Columns followed by the same letter(s) do not differ significantly ($P \leq 0.05$).

K. The amounts of total extractable soil N consisted mainly of nitrate-N rather than ammonium N. The marked decreases in extractable N in soils from the inorganic control plots and the paper waste vermicompost-treated plots, relative to soils from the food waste vermicompost-treated plots, may have been due to larger amounts of total C and N in the food waste vermicompost that could have provided a larger source of N for mineralization. Hence, the food waste vermicompost might have produced more residual N in soil than the inorganic fertilizer, or materials with a lower overall source of total N content, such as paper waste vermicompost. There have been other reports of increases of N in soil after additions of vermicomposts (Nethra et al., 1999).

A similar trend was recorded for soil orthophosphates, because soils from all of the vermicompost-treated plots contained significantly more orthophosphates

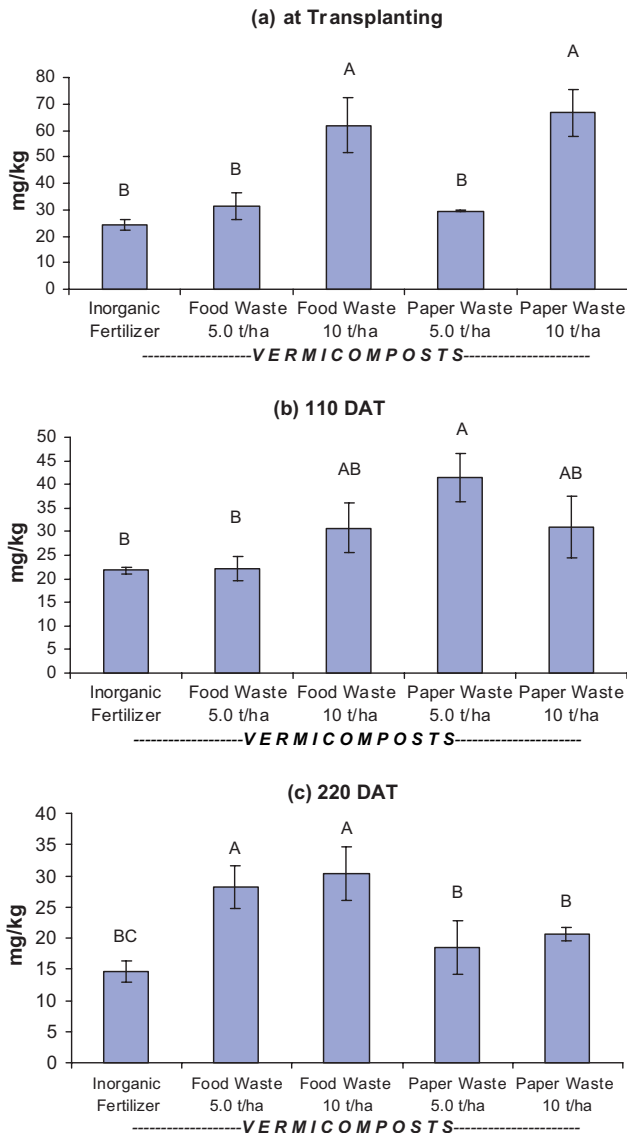


Fig. 7. Microbial biomass-N in strawberry plots on Site A (Piketon, OH) at three sampling dates: at transplanting, 160 and 220 DAT (days after transplanting). Columns followed by the same letter(s) do not differ significantly ($P \leq 0.05$).

than soils from control plots at harvest, although all plots received equal amounts of P at transplanting. This implied that the continuous inputs of orthophosphates to the soil were probably from slow release from the vermicomposts. Both types of vermicomposts contained similar amounts of total P which may explain why there were similar amounts of soluble P in soils from the vermicompost-treated plots at harvest. A trend for amounts of dissolved organic N to decrease in soils from the vermicompost-treated plots, may be the result of mineralization of nutrients from N pools, since those water-soluble compounds that may be found in the organic fraction of vermicomposts are degraded easily by microorganisms (Cook and Allan, 1992). In our experiments, increases in the amounts of orthophosphates in

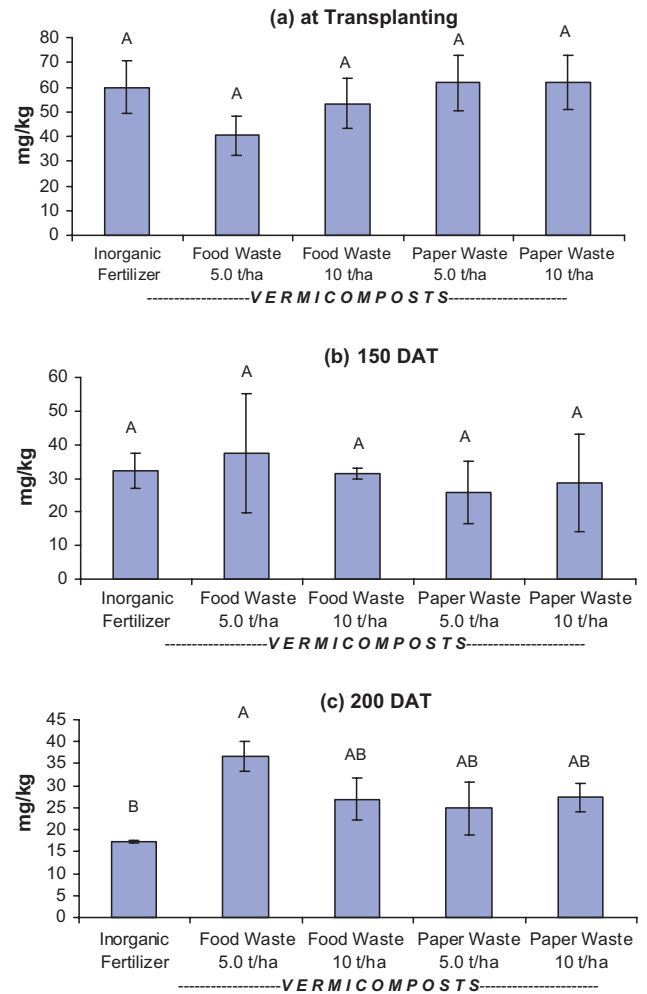


Fig. 8. Microbial biomass-N in strawberry plots on Site B (Fremont, OH) at three sampling dates: at transplanting, 100 and 200 DAT (days after transplanting). Columns followed by the same letter(s) do not differ significantly ($P \leq 0.05$).

soil from the vermicompost-treated plots could be explained by the significant correlations between the microbial biomass N and orthophosphates, indicating that release of P was due largely to the activity of soil microorganisms. Marinari et al. (2000) reported similar increases in phosphates in soil after applications of organic amendments.

The fate of the different nutrients in the soil could have been determined by interactions between several factors. Nutrient uptake by plants, together with leaching and the activity of colonizing microorganisms, may have been factors (Carlile and Wilson, 1993). Hence, the differences in the residual N and P between treatments may have been due to differences in rates of plant absorption, rates of leaching of particular nutrients or microbial immobilization of these nutrients. Rates of leaching of N differed among the treatments; the inorganic control soils having the fastest leaching of N because they contained less organic matter than soils from the vermicompost-treated

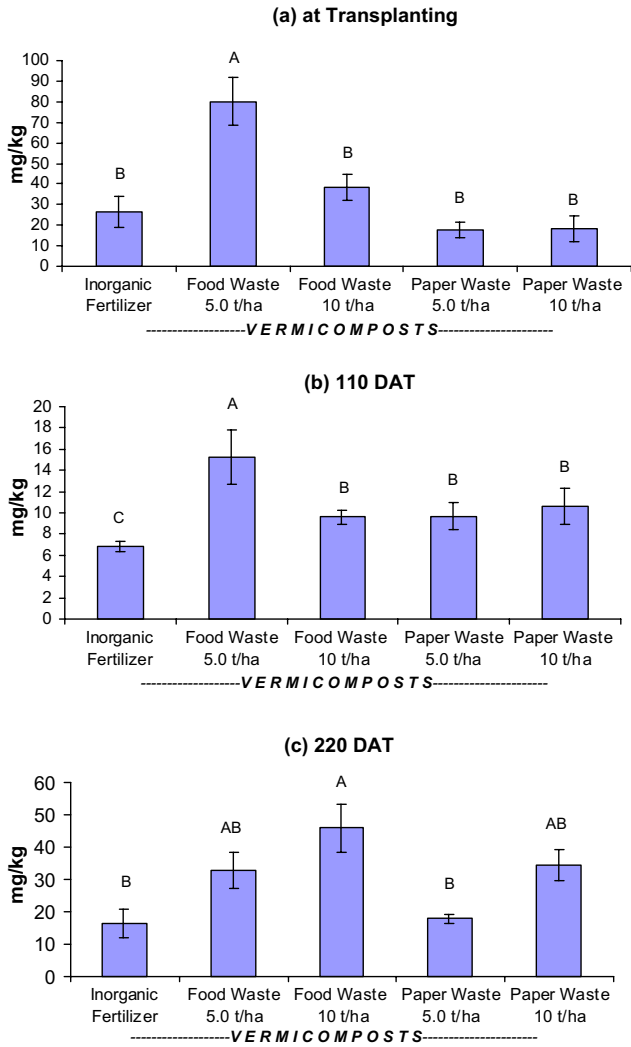


Fig. 9. Orthophosphates in strawberry plots on Site A (Piketon, OH) at three sampling dates: at transplanting, 160 and 220 DAT (days after transplanting). Columns followed by the same letter(s) do not differ significantly ($P \leq 0.05$).

plots. For instance, decreased leaching of nitrates has been reported from compost-treated soils (Maynard, 1989). Leaching of nutrients could also have been decelerated by microbial nutrient immobilization. Since there were more soil microorganisms in soils treated with vermicomposts, they could sequester nutrients and using them for metabolic activities. The immobilization of nutrients in our experiments may be explained by increases in the microbial biomass in the soils treated with vermicomposts and such increases in microbial biomass were greater in soils receiving higher rates of vermicompost applications (10 t ha^{-1}).

Microbial biomass has been used to define soil quality in long-term experiments and may be an early and sensitive indicator of soil ecological stress or a need for soil restoration in long-term field experiments (Jenkinson and Ladd, 1981; Paul, 1984). Pascual et al.

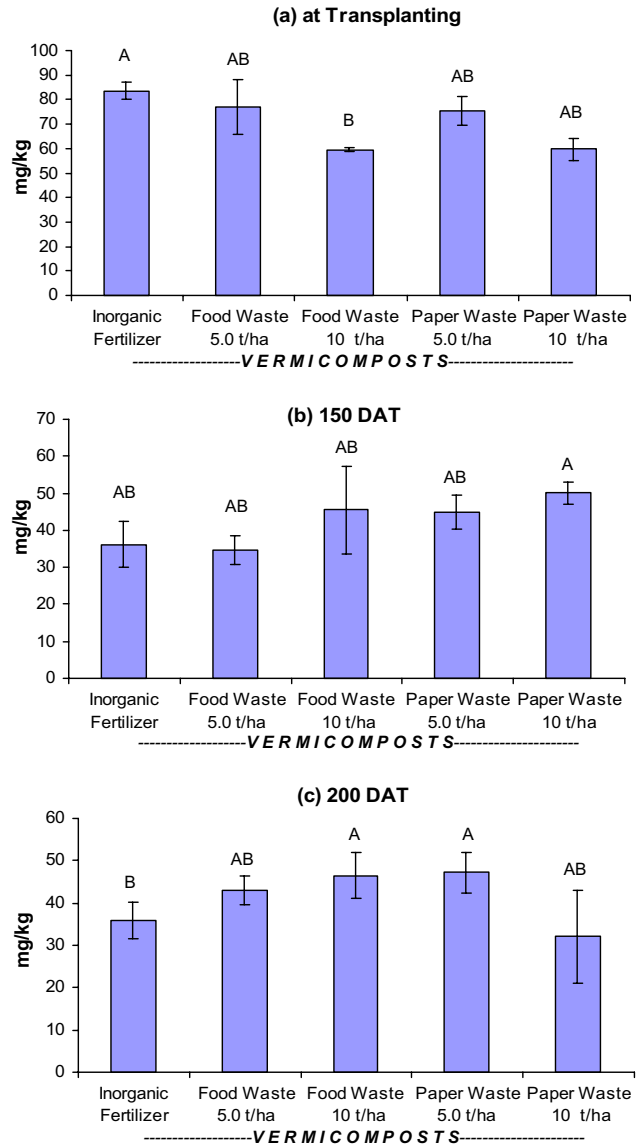


Fig. 10. Orthophosphates in strawberry plots on Site B (Fremont, OH) at three sampling dates: at transplanting, 100 and 200 DAT (days after transplanting). Columns followed by the same letter(s) do not differ significantly ($P \leq 0.05$).

(1999) reported significant increases in microbial biomass C in response to soil sewage treatments. The additions of vermicomposts to the soil increased microbial biomass N significantly, especially in response to food waste vermicompost applications. The increases in soil microbial biomass that occurred apparently did not influence the supply of nutrients to the strawberry plants by nutrient immobilization, since there was even more residual N and P in soils from the vermicompost-treated plots, than in soils from the inorganic control plots and there were positive correlations between the availability of these nutrient elements and microbial biomass.

The ecological significance of microbial activity in soils may not be evaluated simply by assessing

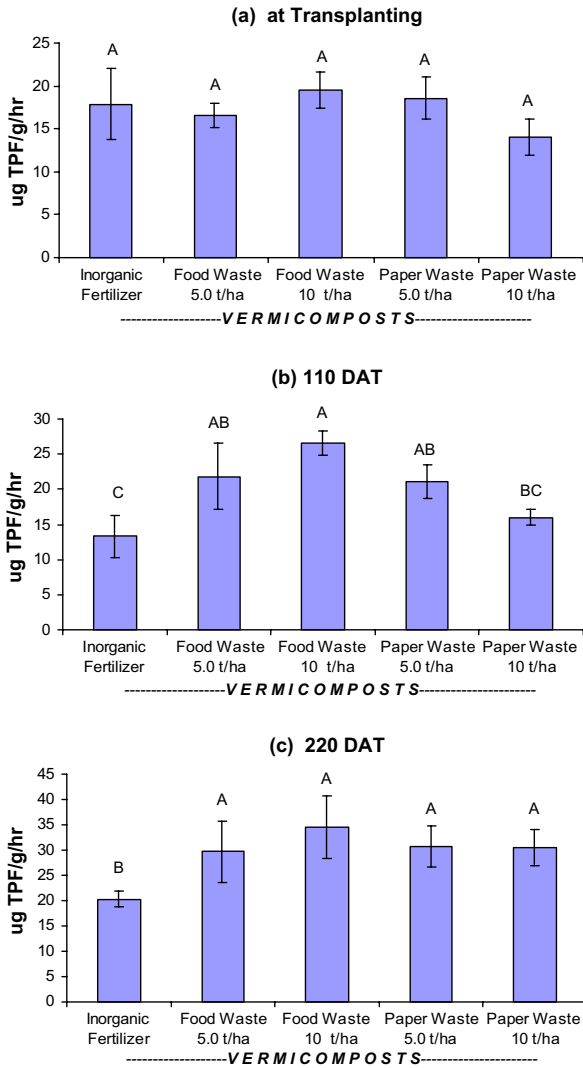


Fig. 11. Dehydrogenase activity in strawberry plots on Site A (Piketon, OH) at three sampling dates: at transplanting, 160 and 220 DAT (days after transplanting). Columns followed by the same letter(s) do not differ significantly ($P \leq 0.05$).

populations of microorganisms We measured dehydrogenase enzyme activity, since these enzymes are considered to be excellent indices of overall microbial activity (Nannipieri et al., 1990). In our field experiment, the

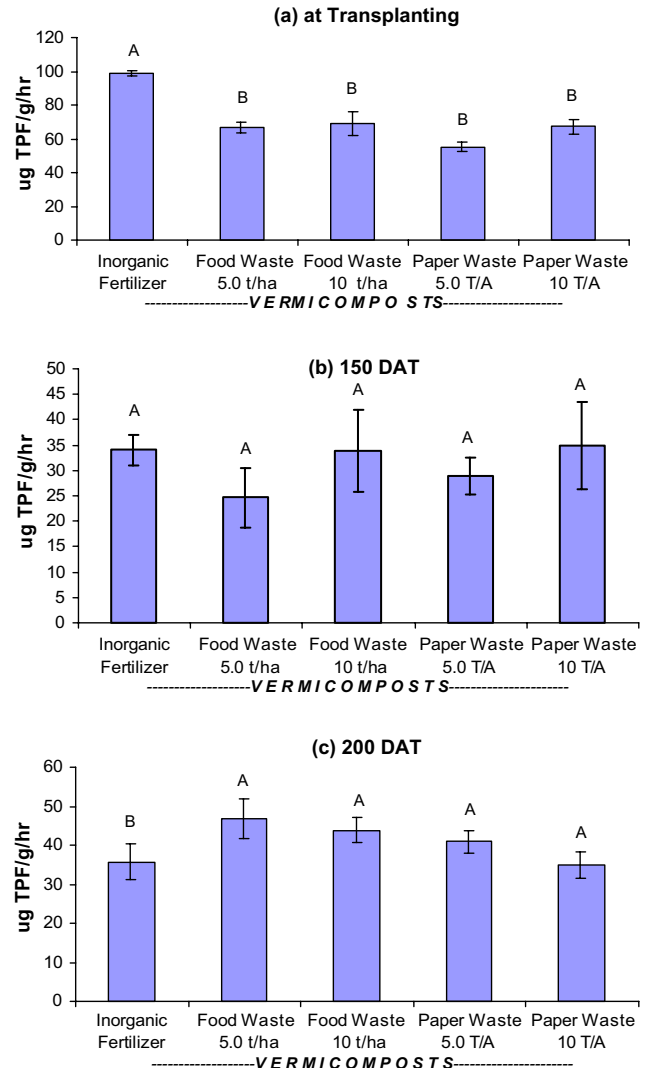


Fig. 12. Dehydrogenase activity in strawberry plots on Site B (Fremont, OH) at three sampling dates: at transplanting, 100 and 200 DAT (days after transplanting). Columns followed by the same letter(s) do not differ significantly ($P \leq 0.05$).

dehydrogenase activity increased in soils treated with vermicomposts, particularly those with the food waste vermicompost. Levels of dehydrogenase activity were correlated positively and significantly with amounts of

Table 1
Correlation coefficients of soil properties measured in strawberry plots

	Dehydrogenase activity	Micobial biomass-N	Total extractable-N	Ammonium nitrogen	Nitrate nitrogen	Dissolved organic-N
Micobial biomass-N	0.422*					
Total extractable-N	0.207	0.265				
Ammonium-nitrogen	0.265	0.018	0.214			
Nitrate-nitrogen	0.215	0.259	0.566*	0.198		
Dissolved organic-N	0.166	0.143	0.559*		0.559*	
Orthophosphate	0.381	0.528*	0.302	0.09	0.303	0.132

Coefficient numbers followed by an asterisk (*) are significantly correlated at 0.05.

soil microbial biomass especially towards the later growth stages of the strawberry plants. There have been many reports that organic fertilizers can increase soil microbiological activity (Bolton et al., 1985; Fraser et al., 1988; Marinari et al., 2000). Many enzymatic activities have been reported to be correlated with total organic C in soils (Frankenberger and Tabatabai, 1981). Serra-Wittling et al. (1995) reported increases of dehydrogenase activity in compost-soil incubations, with the highest level of dehydrogenase activity coinciding with a flush of mineralization. They attributed these increases to intense activity of the soil microorganisms in degrading easily metabolizable compounds, with subsequent decreases in activity, attributed to the decreases in quantities of easily biodegradable substances. Pascual et al. (1997) reported significant increases in dehydrogenase activity after amending soil with composts for 8 years compared with activity in unamended soils. Masciandaro et al. (1997) reported increases in soil dehydrogenase activity after vermicompost applications to soils at rate of 90 t ha⁻¹. Increases in soil dehydrogenase activity at the later strawberry growth stage, 110 days after transplanting were probably due to mineralization of N and P because of the positive correlations between dehydrogenase activity, microbial biomass and the concentrations of N and P. Dehydrogenase activity in soils from Site B followed a different pattern because dehydrogenase activity was greater in inorganic control soils than in vermicompost-treated soils. A significantly lower soil dehydrogenase activity that occurred in vermicompost-treated plots at transplanting may also have been due to an inhibitory effect resulting from the introduction of 'foreign' soil microorganisms from the vermicomposts to the exotic microflora which may have triggered competition among microorganisms. However, this could have been overcome at the later stages of strawberry growth especially at harvest.

5. Conclusions

The overall amounts of the major elements such as N and P in the vermicompost-amended soils appeared to be similar to those in soils treated with inorganic fertilizers only, throughout the growth cycle of the strawberries, except for isolated cases where orthophosphates occurred at higher levels in vermicompost-amended soils. Any mineralization that may have taken place in the vermicompost-amended soils did not make the amounts of available N and P greater than those in the inorganic fertilizer-treated plots, during the active growth and development stage of strawberry crops. These conditions eliminate the contributions of major elements, such as available N and P, to any plant growth and yield responses. There was a tendency for vermi-

compost-amended soils to retain more of the available N and P at the end of the growth cycle of the strawberries, which was probably due to the presence of more organic matter which allowed greater nutrient retention. However, the availability of nutrients at the end of the harvest stage of strawberries will probably no longer have made any major contributions to yield.

Two of the major contributions of vermicomposts to the field soils were the increased microbial populations and activities which are key factors in rates of soil nutrient cycling, production of plant growth-influencing materials, the build-up of plant resistance or tolerance to crop disease and nematode attacks. This could have been achieved by the rich microbial populations in the vermicomposts that inoculated and spread through the soil. A trend for increasing dehydrogenase activity and greater microbial biomass occurred in the vermicompost-amended soils and these were not dose-dependent. Additionally, another critical contribution of the increases in microbial diversity and activity, as well as their role in nutrient cycling is the production of plant growth-influencing materials and the protection of plants from pathogenic organisms by competition and antagonism.

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