Pedobiologia 49 (2005) 297—306

Available online at www.sciencedirect.com

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Pedobiologia

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Effects of vermicomposts produced from cattle manure, food waste and paper waste on the growth and yield of peppers in the field

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Received 1 November 2004; accepted 1 February 2005

KEYWORDS
Peppers;
Vermicomposts;
Dehydrogenase activity;
Microbial biomass;
Humic acids;
Plant growth regulators

Summary

Commercially processed vermicomposts, produced from food wastes, paper wastes and cattle manure, were applied to 8.25 m^2 field plots, at rates of 10 or 20 t/ha in 1999 and 5 or 10 t/ha in 2000, to evaluate their effects on the growth and yields of peppers (*Capsicum annuum*) var. King Arthur. The vermicomposts were incorporated into the upper 10 cm of soil and supplemented, based on chemical analyses, with amounts of inorganic NPK fertilizers calculated to equalize initially with the rates of 95-95 NK kg/ha applied to the inorganic fertilizer control plots. Phosphorus was determined to be adequate in soils at the experiment site so was not added. All treatments were replicated four times in a randomized complete block design. The vermicompost applications increased the growth and yields of peppers significantly; including increased leaf areas, plant shoot biomass, marketable fruit weights and decreased yields of non-marketable fruit. Application of vermicomposts to soils increased their microbial biomass and dehydrogenase activity. Humic materials and other plant growth-influencing substances, such as plant growth hormones, produced by microorganisms during vermicomposting, and produced after increased microbial biomass and activity in soils, may have been responsible for the increased pepper growth and yields, independent of nutrient availability.

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doi:10.1016/j.pedobi.2005.02.001

Introduction

There has been a growing movement to decrease rates of inorganic fertilizer applications to soils by using soil nutrients more efficiently and by the increased use of organic matter. Among various sources of organic matter, vermicomposts have been recognized as having considerable potential as soil amendments. Vermicomposts are products of organic matter degradation through interactions between earthworms and microorganisms. The process accelerates the rates of decomposition of the organic matter, alters the physical and chemical properties of the material, and lowers the C:N ratio, leading to a rapid humification process in which the unstable organic matter is fully oxidized and stabilized (Albanell et al., 1988; Orozco et al., 1996). The end product, termed vermicompost, has been humified rapidly through the fragmentation of the parent organic materials by earthworms, thereby increasing the surface area for colonization by microorganisms (Edwards and Neuhauser, 1988; Edwards, 1998). Vermicomposts are finely divided peat-like materials with a high porosity, aeration, drainage, and water-holding capacity and usually contain more mineral elements than commercially available soil-less plant growth media (such as Metro-Mix 360, Scotts, Inc., Marysville, OH). Many of these elements are changed into forms that can be taken up more readily by the plants, such as nitrates, exchangeable phosphorus, and soluble potassium, calcium, and magnesium (Edwards and Burrows, 1988). They are rich in bacteria, actinomycetes, fungi (Edwards, 1983; Tomati et al., 1987) and cellulose-degrading bacteria (Werner and Cuevas, 1996). Greenhouse experiments at The Ohio State University have demonstrated that vermicomposts can increase the germination, growth and yields of various vegetables and ornamentals significantly and consistently (Edwards and Burrows, 1988; Atiyeh et al., 1999, 2000a–d, 2001, 2002; Buckerfield et al., 1999; Subler et al., 1998).

The small number of field experiments reported in the literature have shown that amending soils with vermicomposts can increase the growth and yield of some crops such as cowpeas (Mba, 1983), cress (Masciandaro et al., 1997), grapes (Buckerfield and Webster, 1998; Venkatesh et al., 1998), *Chichorium* (Vadiraj et al., 1998), bananas (Athani et al., 1999), strawberries (Arancon et al., 2004) and tomatoes (Arancon et al., 2003b). The main objective of the field experiments reported here was to investigate the effects of three types of vermicomposts, applied at two dosage rates, on the growth and yields of peppers (*Capsicum annuum*) under field conditions where macronutrients are equalized between treatments, so that growth responses to vermicomposts are not nutrient-mediated.

Materials and methods

Two field experiments were organized at the Ohio State University Research Center at Piketon, Ohio in 1999 and 2000. The experimental site had a soil type of a DoA- Dole Silt Loam. Commercially produced cattle manure, food waste and paper waste vermicomposts were applied to soils, in two sets of plots at rates of either 10 or 20 t/ha in 1999 and 5 or 10 t/ha in 2000. One set of replicate plots received a full recommended rate of inorganic fertilizers. A second set of replicate plots received 20 t/ha in 1999 of traditional thermophilic leaf composts and 10 t/ha in 2000.

Raised soil beds 1.5 m wide, 5.5 m long and 0.15 m high were constructed. The same plots were used in the second year. Vermicomposts were applied before transplanting the peppers and supplemented with amounts of inorganic fertilizer to correspond with the recommended full rate of 95-95 kg NK/ha that was applied to the inorganic fertilizer-treated plots. Thirty percent of the total N and K from vermicompost and compost (Table 1) was assumed to be as plant-available for each year and these values were the basis for the inorganic fertilizer supplementation. Ten percent of the total N and K from vermicomposts applied in 1999 was assumed to be in plant-available forms, in addition to 30 percent N and K availability from vermicom-

Table 1. Composition of nutrient elements of vermicomposts and leaf composts

	N (%)	P (%)	K (%)	B (μg/g)	Ca (μg/g)	Fe (μg/g)	Mg (μg/g)	Mn (μg/g)	Na (μg/g)	S (μg/g)	Zn (μg/g)
Food waste vermicompost	1.3	2.7	9.2	23	18614	23264	4364	610	842	2587	279
Cow manure vermicompost	1.9	4.7	1.4	58	23245	3454	5802	160	3360	5524	516
Paper waste vermicompost	1.0	1.4	6.2	31	9214	17811	7661	447	613	1929	127
Biosolids compost	1.7	1.8	6.4	33	27965	7714	7185	364	930.0	6291	1281
Yard waste compost	0.5	1.8	6.6	50	89207	9031	21229	324	121	2860	120

post applications in 2000. Vermicomposts, composts and inorganic fertilizers were incorporated into the top 15 cm of the beds in the plots with a roto-tiller. Soil tests showed that the available phosphorus was 48 ppm (Bray P1 Method) available in adequate amounts for commercial pepper production of peppers, so no P fertilizer was applied in either year. The full fertilizer rates applied to the inorganic fertilizer control were 95 kg/ha total N (as ammonium nitrate) and 95 kg/ha total K (as potassium chloride) of which 34 kg N/ha (in the form of a urea–ammonium nitrate solution) was applied to all plots through ferti-irrigation 30 days after transplanting. In the second year, the full preplant rate of 95 kg/ha total N was applied to all plots to correct for lower amounts of immediately available N in the organically amended plots early in the growing season of the first year.

Twenty four pepper seedlings (var. 'King Arthur'), 4-weeks-old, were transplanted into two rows in each raised bed on May 25, 1999 and May 27, 2000. Seedlings were planted in a staggered pattern relative to plants in the other row, spaced 38 cm between plants and 38 cm between rows. Treatments were replicated four times in a randomized complete block design. Guard rows of peppers planted in plots measuring 1.5×5.5 m (8.25 m^2 per plot) were left between each block.

Plant sampling

Four whole plant samples per plot were harvested, 155 days after field transplanting in 1999 (October 27, 1999) and 128 days after transplanting in 2000 (October 3, 2000) for determination of the total leaf areas and shoot dry weights. All leaves were removed and passed through a portable leaf area measuring machine LI 3100 (LI-COR Inc., Lincoln, Nebraska, USA) for leaf area measurements. All leaves and stems were placed in paper bags, oven-dried at 60 °C for 92 h and weighed for measurement of dry shoot weights. Pepper fruits from four designated plants per plot were harvested and graded into marketable and non-marketable categories by visual inspection and weighed for yields in each category. Fruits were classified as non-marketable when signs of rots, insect feedings and malformations were present on the fruit surface.

Soil sampling and analysis

Eight 2.5 cm diameter $\times$ 20 cm deep soil cores were taken from the root zones in each plot at transplanting and every 4 weeks thereafter up to harvesting. Moist soil samples were passed through a 2 mm aperture-sieve and stored in a cold room at 4 °C until analyzed chemically. Extractable nitrogen (NO_3-N and NH_4-N) was determined using a modified indophenol blue technique (Sims et al., 1995). Five-gram soil samples were extracted with 0.5 M K_2SO_4 for 1 h and filtered through Whatman No. 42 filter paper. Filtrates were collected and stored into scintillation vials. NO_3-N and NH_4-N were determined by color development by adding citrate, salicylate and hypochlorite reagents into the samples. Absorbance was measured using Bio-Tek EL311sx automated microplate reader. Soluble phosphorus was assessed using NH_4-HCl reagent. Microbial biomass nitrogen was measured in chloroform-fumigated soil samples (Brookes et al., 1985). Fumigated samples were extracted and digested 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 EL311sx automated microplate reader.

Statistical analyses

A one-way analysis of variance (ANOVA) in general linear model was made for all parameters. Differences between treatments were separated by Least Significant Differences (LSD) using SAS (SAS Ins., 2001).

Results

Growth and yields of pepper

In 1999, peppers planted in plots treated with paper waste and cow manure vermicomposts at 10 or 20 t/ha yielded significantly more ($P \leqslant 0.05$) than those grown in plots treated with inorganic fertilizers only (Fig. 1a), except those in plots treated with food waste vermicomposts. The yields from peppers amended with the traditional thermophilic leaf compost did not differ significantly ($P \leqslant 0.05$) from those planted in plots treated with paper and cow manure vermicomposts. Soils treated with only inorganic fertilizers produced peppers with significantly more non-marketable fruits and smaller shoot dry weights ($P < 0.05$) than peppers grown in the vermicompost or compost-treated plots (Fig. 1b and c). Marketable yields in 2000, were significantly greater ($P \leqslant 0.05$) from peppers grown in soils that received vermicompost and compost treatments than from those treated

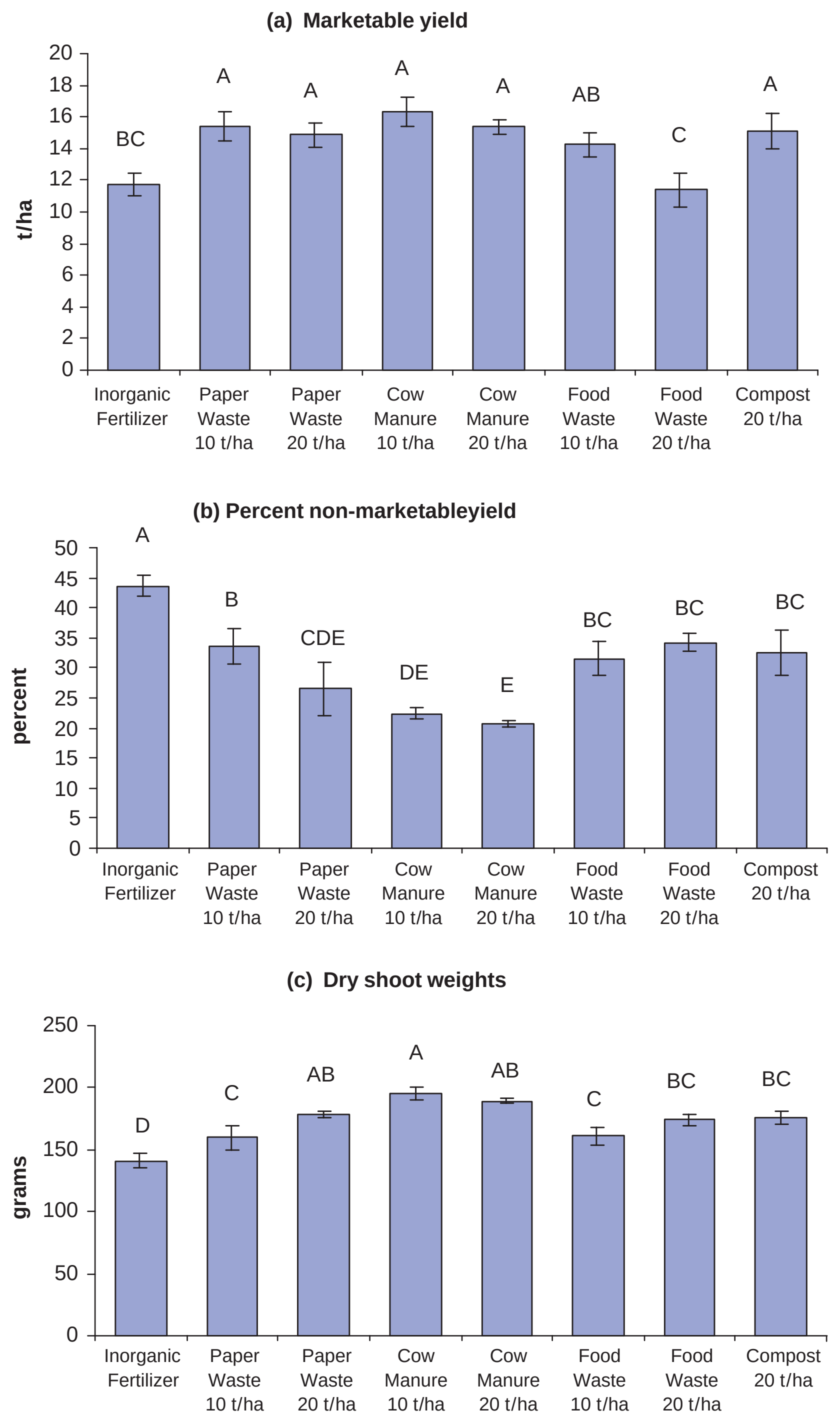

Figure 1. Marketable yields, percentage non-marketable yields and shoot dry weights (Means $\pm$ SE) of peppers at harvest in 1999. Columns designated with same letter(s) are not significantly different at $P<0.05$.

with inorganic fertilizers only (Fig. 2a). However, peppers planted in soils treated with cattle manure vermicompost applied at rates of 5 t/ha and food waste vermicompost applied at rates of 10 t/ha, had significantly smaller proportions of non-marketable peppers ($P<0.05$) than those of peppers planted in soils treated with inorganic fertilizers only and treated with cow manure vermicompost at 19 t/ha (Fig. 2b). Soils with cattle manure vermicomposts, applied at a rate of 10 t/ha, produced pepper plants with significantly larger shoot dry weights ($P\leqslant 0.05$) than those of plants in soils treated with inorganic fertilizers only but similar to all other treatments (Fig. 2c).

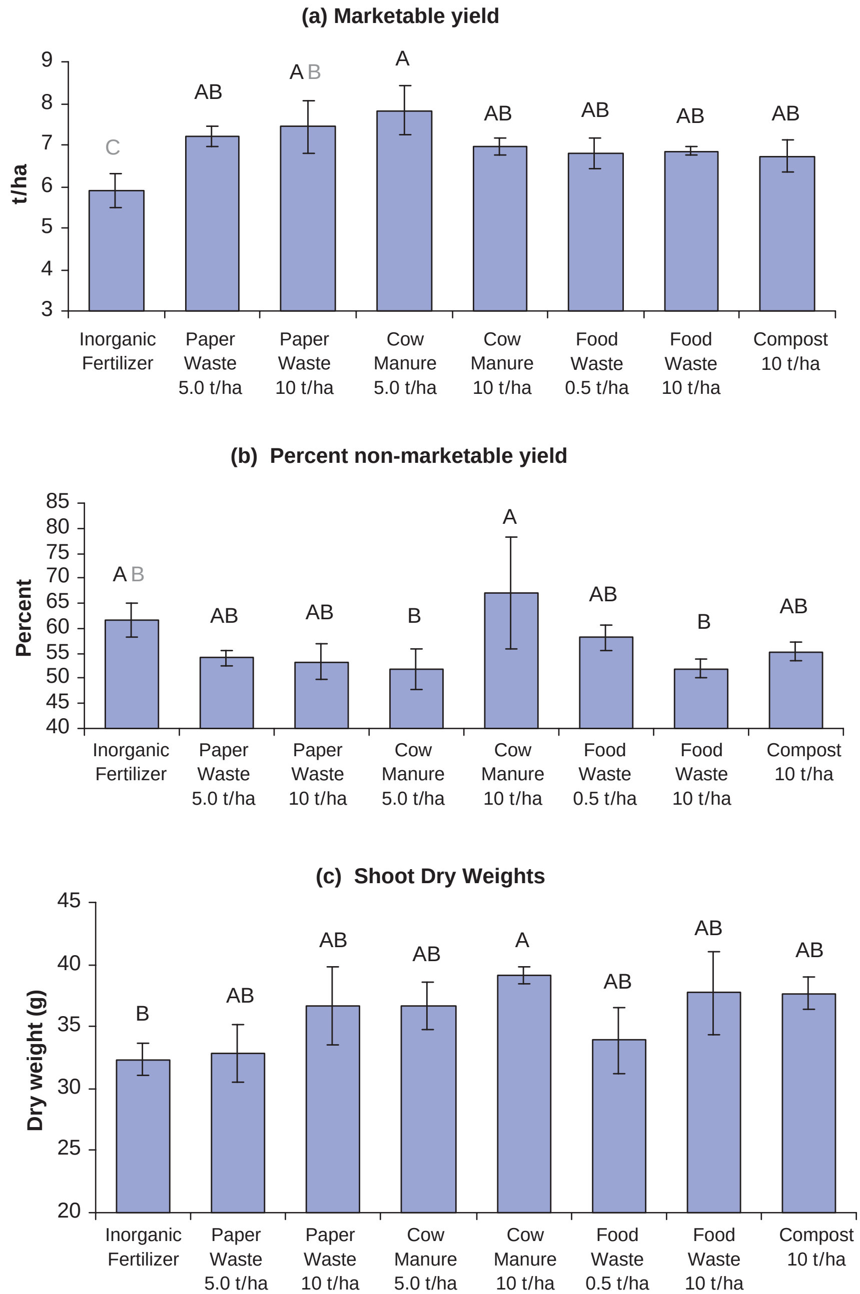

Figure 2. Marketable yields, percentage non-marketable yields and shoot dry weights (Means ± SE) of peppers at harvest in 2000. Columns designated with same letter(s) are not significantly different at $P<0.05$.

Effects of vermicomposts on soils

Amounts of nitrate in soils from plots treated with cattle manure vermicompost were significantly greater ($P\leqslant 0.05$) than in soils from the other treatments (Fig. 3a) in 1999. Most of the soils treated with vermicomposts or composts had significantly more microbial biomass N ($P\leqslant 0.05$) than soils treated with inorganic fertilizers only (Fig. 3b). There was a trend for greater dehydrogenase activity to occur in soils treated with vermicomposts, compared to that in soils treated with inorganic fertilizers only, particularly in soils treated with cow manure vermicompost applied at a rate of 10 t/ha which had significantly more dehydrogenase activity ($P<0.05$) than soils treated with inorganic fertilizers only (Fig. 3c). All of the soils treated with vermicomposts had significantly greater amounts of orthophosphates ($P<0.05$) than soils treated with inorganic fertilizers only (Fig. 3d).

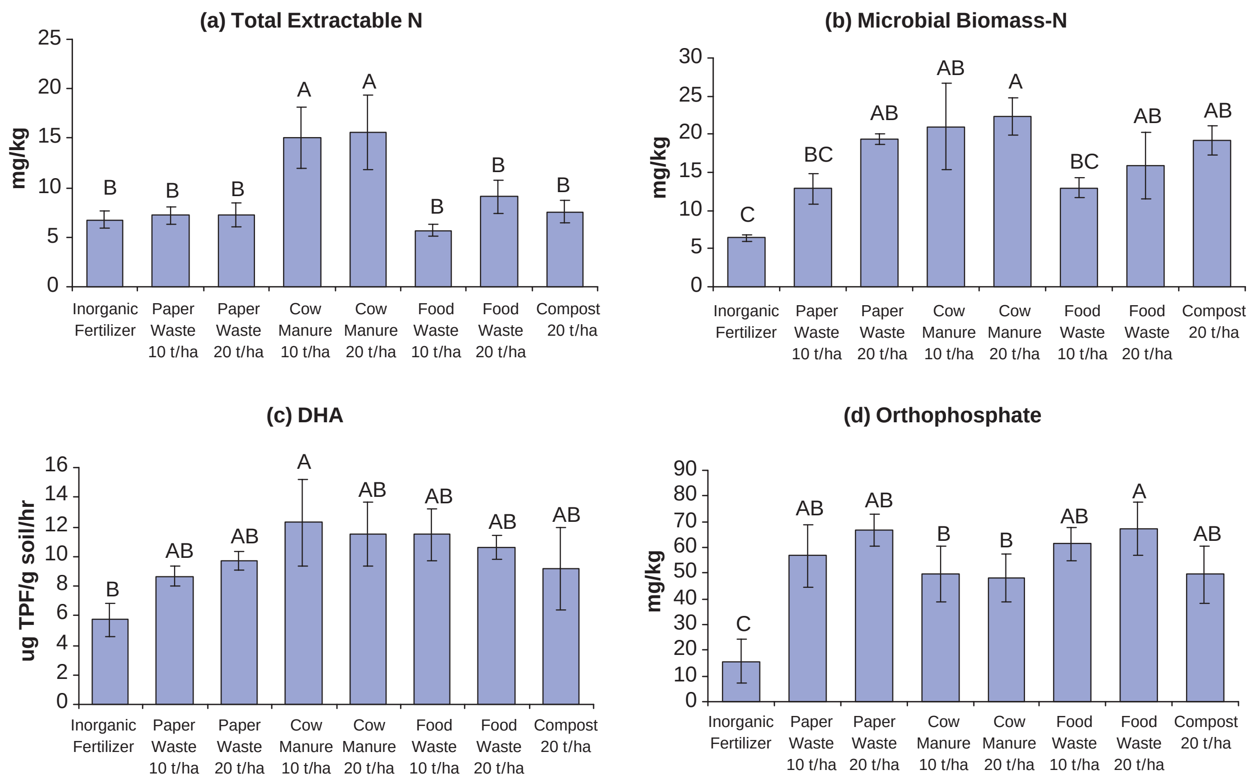

Figure 3. Nitrate-N, microbial biomass-N, dehydrogenase activity and orthophosphates (Means±SE) in soils planted with pepper at harvest in 1999. Columns designated with same letter(s) are not significantly different at $P<0.05$.

The overall amounts of nitrates in soils in the 2000 experiment did not differ significantly among treatments. The soils from most of the plots treated with vermicomposts and traditional compost had significantly more microbial biomass N ($P<0.05$) than those treated with inorganic fertilizers only. Soils treated with paper waste vermicompost at a rate of 10 t/ha, had significantly more dehydrogenase activity than those treated with inorganic fertilizers only ($P<0.05$) (Fig. 4c). Soils treated with vermicomposts and traditional compost had significantly more orthophosphates ($P<0.05$) than soils treated with inorganic fertilizers only (Fig. 4d), except soils treated with cow manure vermicomposts at 5 t/ha.

Discussion

There have not been many reports of increased crop growth in soils amended with vermicomposts. Cabbages grown in compressed blocks made from pig waste vermicompost, later transplanted to the field, were larger and more mature at harvest compared to those grown in a commercial blocking material (Edwards and Burrows, 1988). In a field experiment treated with either cassava peel mixed with guava leaves or vermicomposts from poultry droppings, Mba (1983) reported more shoot biomass and increased seed yields of cowpeas in response to vermicompost. Masciandaro et al. (1997) investigated direct applications of vermicomposts, produced from sewage sludge, to soils and reported a greater growth index of garden cress (*Lepidium sativum*), in soils treated with vermicomposts, than in those with no vermicompost applications. A surface application of vermicompost derived from grape marc, that was spread under grape vines and covered with straw and paper mulches increased the yields of a grape variety (Pinot Noir) by up to 55% (Buckerfield and Webster, 1998). These increased yields comprised large increases in both bunch-weights and numbers of fruit clusters with no losses in flavor. In a grape experiment at a second site, vermicomposts from animal manures, applied under straw mulches, increased Chardonnay grape yields by up to 35% and the vermicompost applications tended to have greater effects on grape yields when applied under mulches than when applied directly to the soil surface and left exposed. This may have been because of degradation of the vermicomposts and microbial activity on exposure to sun and air. Venkatesh et al. (1998)

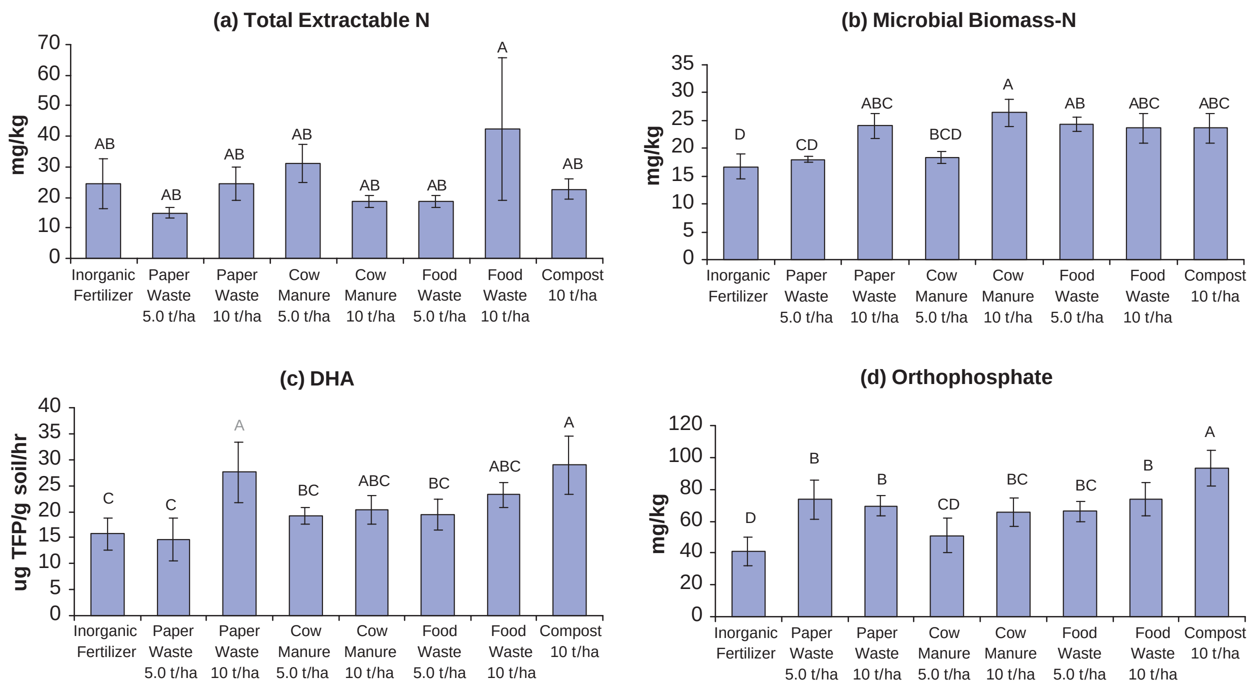

Figure 4. Nitrate-N, microbial biomass-N, dehydrogenase activity and orthophosphates (Means$\pm$SE) in soils planted with pepper at harvest in 2000. Columns designated with same letter(s) are not significantly different at $P<0.05$.

reported that yields of Thompson Seedless grapes increased significantly in response to vermicomposts applications. In experiments at The Ohio State University, Seyval grapes produced greater marketable yields, more fruit clusters per vine and bigger berry sizes, after applications of food waste or paper waste vermicomposts at rates of 2.5 or 5 t/ha, supplemented with inorganic fertilizers, than in response to inorganic fertilizers only (Arancon et al., unpublished data). The growth, flowering and yields of field strawberries increased after applications of food wastes and paper waste vermicomposts to field soils, at rates of 2.5 or 5 t/ha, supplemented with inorganic fertilizers (Arancon et al., 2004).

In our experiments, the total extractable N at harvest, for most soils in 1999 and all soils in 2000 treated with vermicompost, did not differ significantly from that in soils treated with inorganic fertilizers, but this was due to the supplementation of vermicomposts with inorganic fertilizers prior to transplanting. These supplements can be considered to eliminate N as the major factor contributing to the differences in growth and yield of peppers obtained in our experiments. The increased amounts of orthophosphates in soils treated with vermicomposts and traditional compost can be explained by the P present in our vermicomposts (Table 1). These increases in amounts of orthophosphates could not have been a major factor influencing the growth and yield increases of peppers since it was predetermined from tests that there were adequate amounts of orthophosphate for commercial pepper production.

It is possible that the large microbial populations in vermicomposts, and the very considerable build up of microbial populations and activity in the soils treated with vermicomposts, may have influenced plant growth indirectly. Greenhouse experiments by Atiyeh et al. (2001) reported increased microbial biomass in a soil-less growth media after substitution of vermicomposts into container media (Metro-Mix 360). There are other reports of increased microbial biomass and activity in response to applying vermicompost amendments to field crops (Arancon et al., 2004, 2003a, b). In both of our pepper field experiments in 1999 and 2000, there were significant increases ($P \leqslant 0.05$) in microbial biomass in soils treated with vermicomposts and traditional compost and the size of the microbial biomass was significantly correlated positively ($r = 0.88$) with yields. Microbial activity in soils has been suggested by many authors as probably responsible for improving soil structure and influencing the root environment and plant growth indirectly. The byproducts of microbial activities may include polysacharrarides that are involved directly in the aggregation of soil particles which could also have some influence on plant growth.

Plant growth-regulating substances (PGRs) such as plant hormones are other known products of microbial activity. Bacteria, fungi, yeasts, actinomycetes and algae, are capable of producing plant hormones, or plant-growth regulating substances (PGRs), such as auxins, gibberellins, cytokinins, ethylene and abscisic acid, in appreciable quantities (Arshad and Frankenberger, 1993; Frankenberger and Arshad, 1995). Many of the microorganisms common in plant rhizospheres can produce such plant growth-regulating substances. For instance Barea et al. (1976) reported that, of 50 bacterial isolates obtained from the rhizosphere of various plants, 86% could produce auxins, 58% gibberellins and 90% kinetin-like substances that were reported to influence plant growth directly. Several workers have reported that PGRs are found in some soils and occur at varying concentrations in vermicomposts (Nielson, 1965; Tomati et al., 1983, 1987, 1988, 1990; Tomati and Galli, 1995; Nardi et al., 1988; Dell'Agnola and Nardi, 1987; Edwards and Burrows, 1988; Edwards, 1998; Krishnamoorthy and Vajranabiah, 1986). It is possible that the presence of plant growth-regulators in the vermicomposts used contributed to the increased growth and yields of peppers. Muscolo et al. (1999) reported that humic materials extracted from vermicompost could produce auxin-like effects on plants such as carrots and there are many similar reports on the literature (MacCarthy et al., 1990; Hayes and Wilson, 1997). It is also possible that humic acids in the vermicomposts used in the experiment could also have had direct positive influences on the growth and yields of the peppers. In laboratory and greenhouse experiments by Atiyeh et al. (2001), definitive evidence of the positive growth effects of humic acids, extracted from pig manure and food waste vermicomposts, were demonstrated. In their experiments, a range of doses of humic acid were extracted from vermicomposts acids by classic acid/alkali fractionation (Valdrighi et al., 1996) and applied to tomato and cucumber seedlings grown in a soil-less medium (Metro-Mix 360). The humic acids increased the growth of the tomato and cucumber plants significantly, independent of nutrients availability, and the growth increases were correlated directly up to a peak concentration of humic acids that had been incorporated into the container medium, but decreased when the concentrations exceeded 500–1000 mg/kg. Atiyeh et al. (2001) and Arancon et al. (2003a) concluded that the growth responses were due either to the ability of humic acids to have hormone-like effects on plant growth or because the humic acids may have plant growth, regulators adsorbed onto them, and that these influence growth. Their hypothesis was confirmed by an investigation by Canellas et al. (2000), who identified auxin groups incorporated in humic acids that had been extracted from cattle manure vermicompost. The effects of humic acid applications to maize plants resulted in increased growth of the maize roots and stem which they attributed to the humic/auxin combination. It seems likely that humic acids produced in the vermicomposts used in our experiment might have also increased growth and yields of peppers.

Conclusions

The increased growth and yields of peppers in the field confirm our greenhouse experiments on the positive effects of vermicomposts and traditional compost on plant growth and yield. Increased growth and yield of peppers in the field were attributed to a number of positive effects of applications of vermicomposts in field soils. One of these is the improvement of the biological properties of soils such as increased microbial biomass and activity and the sustained supply of macronutrients such as phosphorus. These increases could have a major contribution to the increased production of plant growth regulators such as humic acids and plant growth hormones adsorbed onto humic acids which may have contributed to increased growth and yields of peppers in the field.

Acknowledgments

This research was made possible with the support of the staff of The Ohio State University South Centers at Piketon especially the Director, Donald McFeeters as well as Myranda Fout and other student assistants. The funding that supported the research was from a USDA/NRI Grant No. 2001-01332.

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