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Influences of vermicomposts on field strawberries: 1. Effects on growth and yields

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Abstract

Vermicomposts processed commercially from food wastes and paper wastes were applied, to 4.5 m^2 field plots, under high plastic hoop tunnels, at rates of 5 or 10 $t\,ha^{-1}$ to evaluate their effects on the growth and yields of strawberries (*Fragaria ananasa*) var. 'Chandler'. The vermicomposts were incorporated into the top 10 cm of soil and supplemented, based on chemical analyses, with amounts of inorganic NPK fertilizers calculated to equalize the initial fertilizer rates of 85–155–125 $kg\,ha^{-1}$ NPK applied to the inorganic fertilizer plots. All treatments were replicated four times, in a completely randomized design, at two field sites on Doles silt loam or Hoytville silty clay loam at Piketon and Fremont, Ohio, respectively. Vermicompost applications increased strawberry growth and yields significantly; including increases of up to 37% in leaf areas, 37% in plant shoot biomass, 40% in numbers of flowers, 36% in numbers of plant runners and 35% in marketable fruit weights. These responses seemed not to be dose-dependent, since strawberries at one site grew fastest and yielded most in response to the 10 $t\,ha^{-1}$ vermicompost application rate, whereas they responded positively and similarly to both the 5 and 10 $t\,ha^{-1}$ rates of applications at the other site. These responses could not have been mediated by availability of macronutrients, since all plots were supplemented with inorganic fertilizers, to equalize macronutrient inputs for all treatments, but based on other research in our laboratory could have been due to production of plant growth regulators by microorganisms during vermicomposting.

Keywords: Vermicomposts; Microorganisms; Strawberry growth and yield; Humic acids; Compost; Earthworms

1. Introduction

The use of organic amendments, such as traditional thermophilic composts, has long been recognized as an effective means of improving soil structure, enhancing soil fertility (Follet et al., 1981), increasing microbial diversity and populations (Barakan et al., 1995), microbial activity (Zink and Allen, 1998), improving the moisture-holding capacity of soils and increasing crop yields. Effects on microorganisms have also been associated with their capability to suppress soil-borne plant diseases (Hoitink and Fahy, 1986) plant parasitic nematode populations and increased crop yields (Johnston et al., 1995).

Vermicomposts are finely-divided mature peat-like materials with a high porosity, aeration, drainage, and water-holding capacity and microbial activity which are stabilized by interactions between earthworms and microorganisms in a non-thermophilic process (Edwards and Burrows, 1988). Vermicompost contains most nutrients in plant-available forms such as nitrates, phosphates, and exchangeable calcium and soluble potassium (Orozco et al., 1996; Edwards, 1998). Vermicomposts have large particulate surface areas that provide many microsites for microbial activity and for the strong retention of nutrients (Shi-wei and Fu-zhen, 1991). Vermicomposts are rich in microbial populations and diversity, particularly fungi, bacteria and actinomycetes (Edwards, 1998; Tomati et al., 1987). We have

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shown in our laboratory that vermicomposts consistently promote biological activity which can cause plants to germinate, flower and grow and yield better than in commercial container media, independent of nutrient availability (Atiyeh et al., 2000a,b). For instance, substitution of small amounts of vermicomposts into soil-less bedding-plant potting mixtures (MM360), has resulted in significant increases in the germination and growth of marigolds, tomatoes and peppers, in greenhouse trials, when all necessary nutrients are available, even at substitution rates as low as 5–30%, into the medium (Atiyeh et al., 2000a,b, 2002a). Vermicomposts contain plant growth regulators and other plant growth-influencing materials produced by microorganisms (Tomati et al., 1988, 1990; Grappelli et al., 1987) including humates (Atiyeh et al., 2002b). Krishnamoorthy and Vajrabhiah (1986) reported the production of cytokinins and auxins in organic wastes that were processed by earthworms. Vermicomposts also contain large amounts of humic substances (Senesi et al., 1992; Masciandaro et al., 1997) and some of the effects of these substances on plant growth have been shown to be very similar to the effects of soil-applied plant growth regulators or hormones (Muscolo et al., 1999). However, most research on the use of vermicompost however, has been in the greenhouse, and few workers have reported on the use and effects of vermicomposts in the field.

The main aims of the research in this paper were to assess the effects of the application of different types and rates of vermicomposts, on the growth and yields of field-grown strawberries, under field conditions independent of nutrients.

2. Methods

The field research was at the Piketon Research and Extension Center, Piketon, Ohio and at the Ohio Agricultural Research and Development Center (OARDC) Vegetable Research Center in Fremont, Ohio.

The Piketon Center is in Pike County, Ohio. The experimental soil is a Doles silt loam on 2% slopes. It is a deep, nearly level and somewhat poorly-drained soil with about 1.5% organic matter. The subsoil is about 18.5 m deep. The OARDC Vegetable Research Branch is located in Fremont, Sandusky County in north-central Ohio. The experimental site has a Hoytville silty clay loam soil about 30 cm deep. It is nearly level, very poorly-drained, moderately fine-textured with an organic matter content of about 5%, moderate available water capacity and slow or ponded runoff.

2.1. Experimental design

The strawberries were grown under high polyethylene tunnels supported by a hoop house structure 9.14 m wide, 14.6 m long and 3.6 m high. The hoop houses were unheated and could be ventilated by rolling up the sides on bright sunny days. Raised soil beds 1.5×3 m (4.5 m^2 per plot) were constructed. Commercially produced food waste and paper waste-based vermicomposts were used in the trials. Food waste vermicompost, which was produced by the breakdown of organic wastes by interactions between earthworms and microorganisms in a continuous flow reactor (Edwards, 1998), was provided by Oregon Soil Corporation (Portland, OR) and the paper waste vermicompost produced in outdoor windows was provided by American Resource Recovery (Stockton, CA). The vermicomposts were applied at one of two rates: equivalent to 5 or 10 $t\,ha^{-1}$. Vermicomposts were analyzed for major nutrients and based on these analyses vermicompost-treated plots were supplemented with appropriate amounts of inorganic fertilizer, to equalize the total recommended full rate of available nitrogen, phosphorus, and potassium (85–155–125 $kg\,NPK\,ha^{-1}$) among treatments. The vermicompost/inorganic fertilizer mixtures and the inorganic fertilizers were applied and incorporated into the top 10 cm of soil in the whole experimental bed in each plot.

Plastic mulch and drip irrigation systems were installed on the raised beds after the vermicompost and fertilizer applications. Mini-sprinklers were used in addition to cotton mesh row covers for frost protection. Six-week old strawberry plugs (var. 'Chandler') were transplanted at Piketon Research Station on 10 September 1999 and three weeks later similar plugs were transplanted at the Fremont Vegetable Research Branch. Twenty-four plants were transplanted into each bed with 38 cm between plants in the row 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.

2.2. Sampling and data collection

Samples, each consisting of three randomly-selected whole strawberry plants per plot, were harvested for the assessment of mean leaf areas, numbers of floral buds, numbers of runners and fresh and dry shoot weights, 110 days after transplanting at Piketon, and 150 days after transplanting in Fremont. A similar second set of whole plant samples was taken at the end of fruit harvesting, 220 days after transplanting from the Piketon experiment and 200 days after transplanting, at Fremont. All leaves were removed from the plants and passed through an LI300 (LiCOR, USA) leaf area measuring machine. Leaves and stems placed in paper bags, dried at 60 °C for 92 h and weighed to measure dry weights. All ripe fruits were harvested, graded into marketable and non-marketable groups, and weighed.

Fruits were classified as non-marketable when fruits showed signs of decay due to diseases, insect feeding or other malformations on the fruit surfaces. The relative proportions of non-marketable fruits were expressed as percentages of the total number of fruits harvested. Non-marketable fruits were not diagnosed for specific diseases or types of insect feeding.

Vermicompost samples were analyzed for elemental nutrient content following nitric acid/perchloric acid digestion (Singer and Hanson, 1969). Extracts were analyzed for P, K, Ca, Mg, B, Cu, Fe, Mn, Mo, and Zn by inductively coupled plasma-atomic emission spectroscopy (ICP-AES) (Munter and Grande, 1981). Total carbon and nitrogen were measured in vermicomposts by dry combustion using a Carlo-Erba nitrogen analyzer 1500 series 2 (Costech Analytical Technologies, CA, USA). Extractable nitrogen (NO_3-N and NH_4-N) was determined using a modified indophenol blue technique (Sims et al., 1995). Soluble phosphorus was extracted using a NH_4-HCl reagent. Color in the sample filtrates was developed with stannous chloride and ammonium paramolybdate and absorbance was measured using

Table 1
Nutrient composition of food and paper waste vermicomposts

	C (%)	N (%)	P (%)	K (%)	Mg (%)	S (%)	Fe (%)	Mn (%)	B (μg/g)	Na (μg/g)	Cu (μg/g)
Food waste vermicompost	19.5	1.3	2.7	9.2	4.4	2.6	23.3	609.8	23.3	842.4	50.1
Paper waste vermicompost	17.2	1	2.7	6.2	4.5	1.8	6.2	605.4	31.4	986.2	47.1

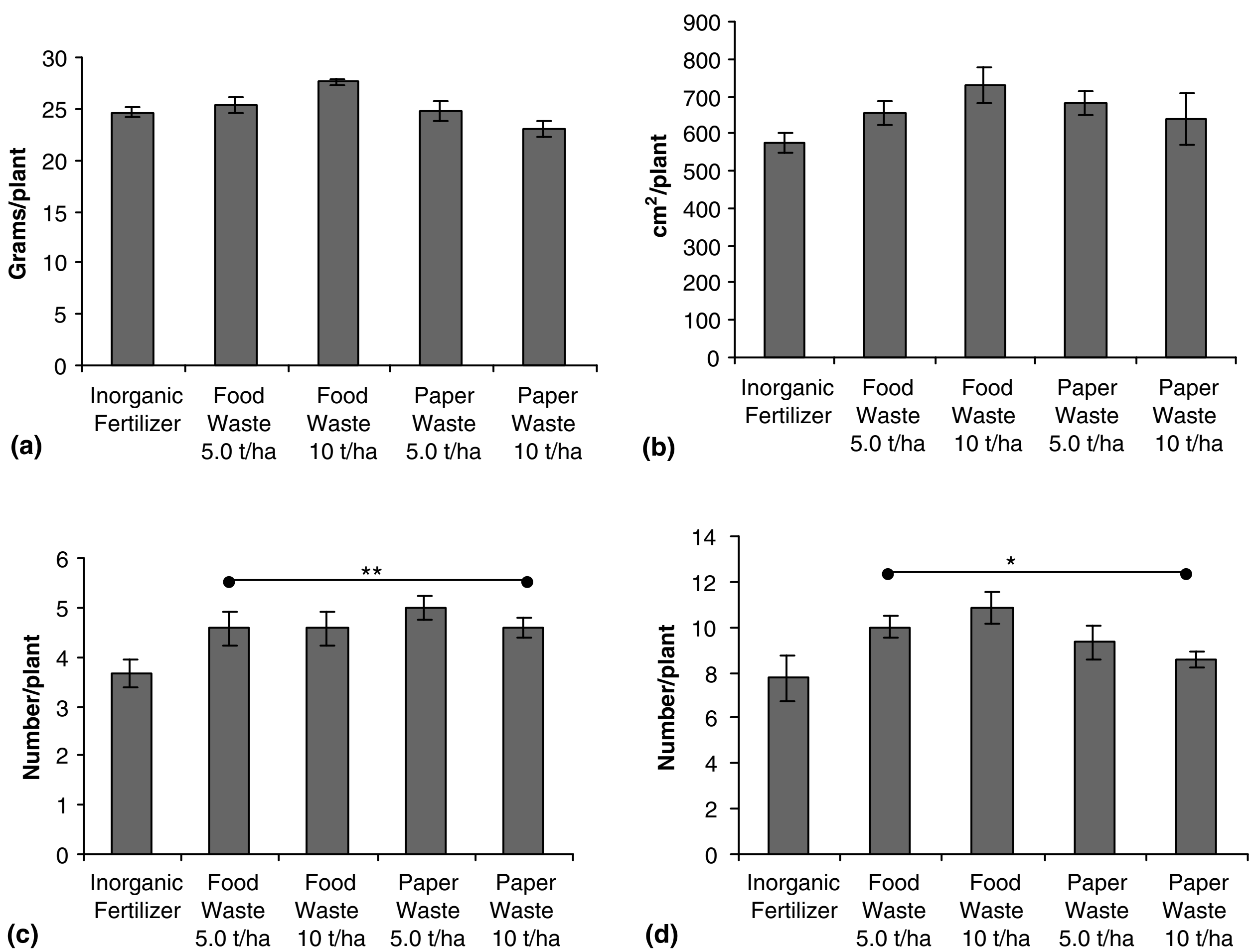

Fig. 1. Shoot dry weights, leaf areas, number of runners and number of flowers of strawberries grown in soils treated with food waste and paper waste vermicomposts and inorganic fertilizer control, 110 days after transplanting at Piketon, OH. Means of vermicompost treatments were grouped for orthogonal contrast versus means of plants from inorganic fertilizer treatments. Significant differences are designated with asterisk/s: (*) at $P \leqslant 0.05$ and (**) at $P \leqslant 0.01$. (a) Dry shoot weights, (b) leaf areas, (c) numbers of runners and (d) numbers of flowers.

Bio-Tek EL211sx automated microplate reader. Microbial biomass was measured in chloroform-fumigated vermicompost (Brookes et al., 1985). Dehydrogenase enzymatic activity (DHA), was measured using a modified method of Casida (1977), where the accumulation of the end product after sample incubation, triphenyl formazan (TPF), was determined with a Bio-Tek EL211sx automated microplate reader.

An analysis of variance (ANOVA) in a 2×2 factorial with a control was performed on each variate, and the means were grouped for orthogonal contrasts: (a) inorganic controls versus vermicomposts (significance is reflected on figures); (b) paper waste vermicompost versus food waste vermicomposts; and (c) 5 $t\,ha^{-1}$ versus 10 $t\,ha^{-1}$ were also grouped for orthogonal contrasts using SAS (SAS Ins., 1990). Significance was defined as $P \leqslant 0.05$ unless indicated otherwise.

3. Results

The unamended food waste vermicompost contained more C, N, Ca, Fe, K and S (Table 1) than the paper waste vermicompost, whereas the paper waste vermicompost had more B, Na and Zn than the food waste vermicompost. The concentrations of Mn, Mg and P and Cu were similar in both types of vermicomposts.

Dry shoot weights and leaf areas of plants in plots treated with vermicompost did not differ from those in plots receiving inorganic fertilizers, whereas there were more ($P \leqslant 0.05$), runners and flowers on plants in plots grown with vermicompost treatments than on those grown with inorganic fertilizers only (Fig. 1) 110 days after transplanting. There were no significant differences in: shoot dry weights, leaf areas and numbers of runners between plants in plots amended with vermicomposts and those that received only inorganic fertilizers (Fig. 2). Marketable strawberries yields were greater ($P \leqslant 0.05$) on plants grown in plots treated with vermicomposts than from plants grown in plots treated with only inorganic fertilizers (Fig. 3). No significant differences were recorded between treatments in the numbers of fruits, weights of largest fruits and percentages of non-marketable fruits. Strawberry plants in plots treated with inorganically-amended food waste vermicomposts had significantly greater dry shoot weights ($P \leqslant 0.05$) than those of plants in plots treated with inorganically-amended paper waste vermicomposts (Table 2). There were no significant differences in dry shoot weights, leaf areas and numbers of runners and flowers between plants grown with 5 or 10 $t\,ha^{-1}$ of vermicomposts. However, there was a significant interaction ($P \leqslant 0.05$) between the types of vermicomposts applied and their rates of application (Table 2). Strawberry plants grown in plots treated with 10 $t\,ha^{-1}$ food waste vermicompost had greater dry shoot weights than plants grown in plots receiving 5 $t\,ha^{-1}$. Plants in plots treated with 5 $t\,ha^{-1}$ paper waste vermicomposts had greater dry shoot weights than plants in plots treated with 10 $t\,ha^{-1}$. Two hundred twenty-two days after transplanting, strawberry leaf areas, number of runners, marketable yields and number of fruits were significantly greater ($P \leqslant 0.05$) on plants grown in plots treated with food waste vermi-

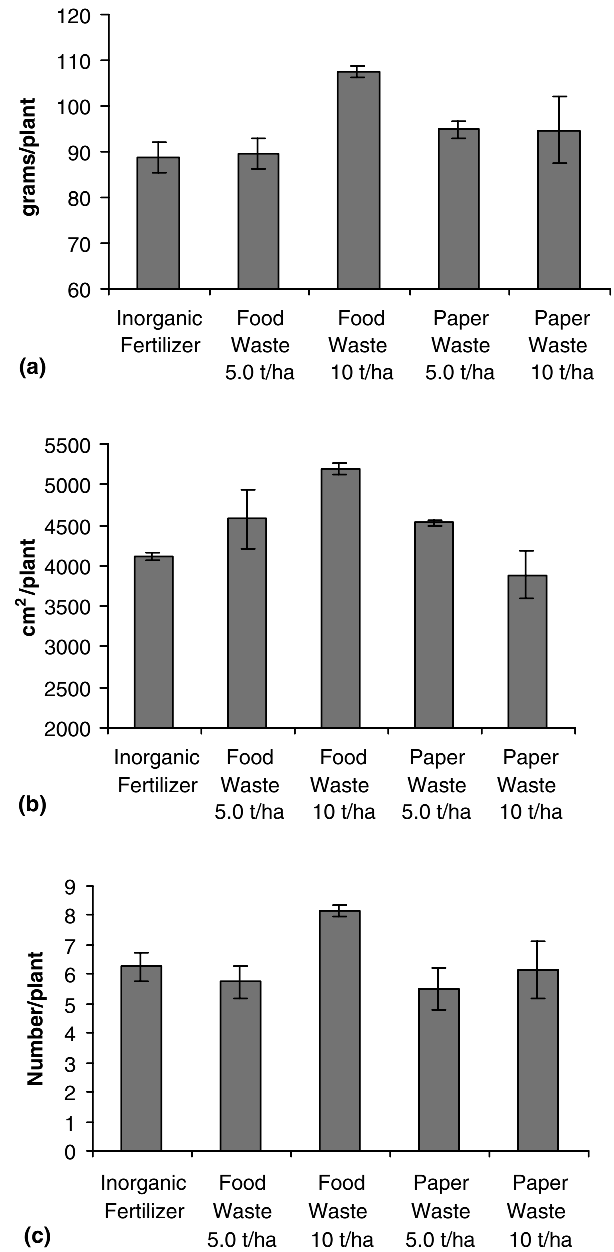

Fig. 2. Shoot biomass, leaf areas and number of runners and of strawberries grown in soils treated with food waste and paper waste vermicomposts and inorganic fertilizer control, 220 days after transplanting at Piketon, OH. Means of vermicompost treatments were grouped for orthogonal contrast versus means of plants from inorganic fertilizer treatments. Significant differences are designated with asterisk/s: (★) at $P \leqslant 0.05$ and (★★) at $P \leqslant 0.01$. (a) Shoot dry weights, (b) leaf areas and (c) number of runners.

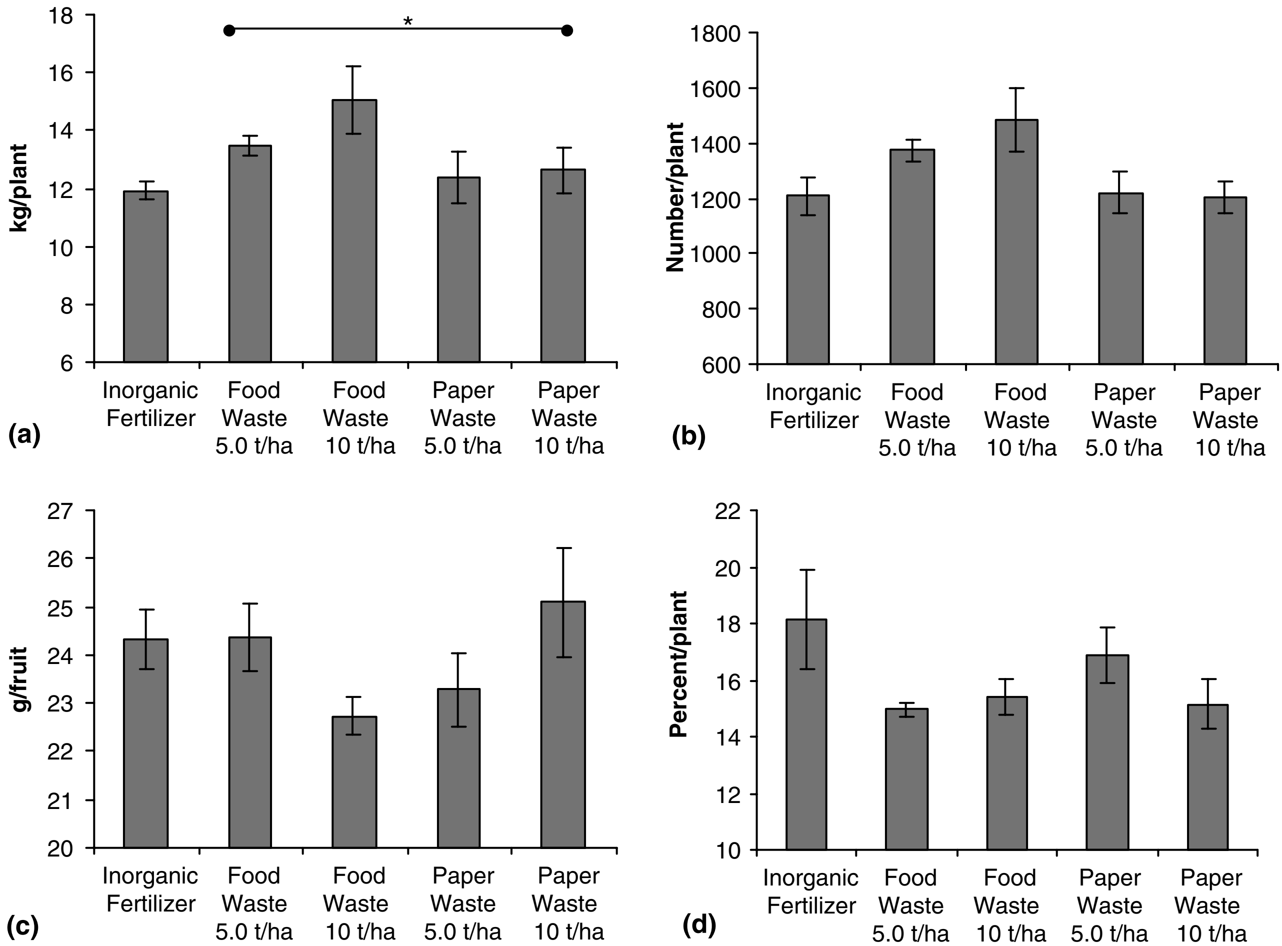

Fig. 3. Yield and yield attributes of strawberries grown in soils treated with food waste and paper waste vermicomposts and inorganic fertilizer control, 220 days after transplanting at Piketon, OH. Means of vermicompost treatments were grouped for orthogonal contrast versus means of plants from inorganic fertilizer treatments. Significant differences are designated with asterisk/s: (★) at $P \leqslant 0.05$ and (★★) at $P \leqslant 0.01$. (a) Marketable yield, (b) number of fruits, (c) weight of largest fruit and (d) percent non-marketable fruit.

Table 2
Orthogonal contrasts of growth parameters, yields and yield attributes of strawberry plants at Piketon, OH

	Paper waste versus food waste	5 t ha^{-1} versus 10 t ha^{-1}	Rate× vermicompost interaction
110 days after transplanting			
Dry shoot weight	**	ns	*
Leaf area	ns	ns	ns
Number of runners	ns	ns	ns
Number of flowers	ns	ns	ns
220 days after transplanting			
Dry shoot weight	ns	ns	ns
Leaf area	*	ns	ns
Number of runners	*	*	*
Marketable yields	*	*	ns
Number of fruits	**	*	ns
Weight of largest fruit	ns	ns	ns
Non-marketable yields	ns	ns	ns

Significant differences are designated with asterisk/s: (*) at $P \leqslant 0.05$ and (**) at $P \leqslant 0.01$ and ns (not significant).

composts than on plants grown in plots treated with paper waste vermicomposts. Plants grown in plots treated with 10 t ha^{-1} food waste vermicomposts had significantly more runners and fruits and greater marketable yields ($P \leqslant 0.05$) than plants in plots grown in plots receiving with 5 t ha^{-1} food waste vermicomposts.

In the Fremont experiment, strawberries grown in plots treated with inorganically-amended vermicomposts had significantly greater dry shoot weights and leaf areas and more flowers ($P \leqslant 0.05$) 110 days after transplanting, than plants in plots receiving only inorganic fertilizers (Fig. 4). Plants in plots treated with vermicomposts had significantly greater dry shoot weights more runners ($P \leqslant 0.05$) (Fig. 5), greater marketable yields and the weight of the largest fruits was greater ($P \leqslant 0.05$) (Fig. 6) than in those grown in plots treated with inorganic fertilizers only, 220 days after transplanting. There were no significant differences in any of the growth parameters measured, in plants grown in soils treated with paper waste vermicomposts, compared

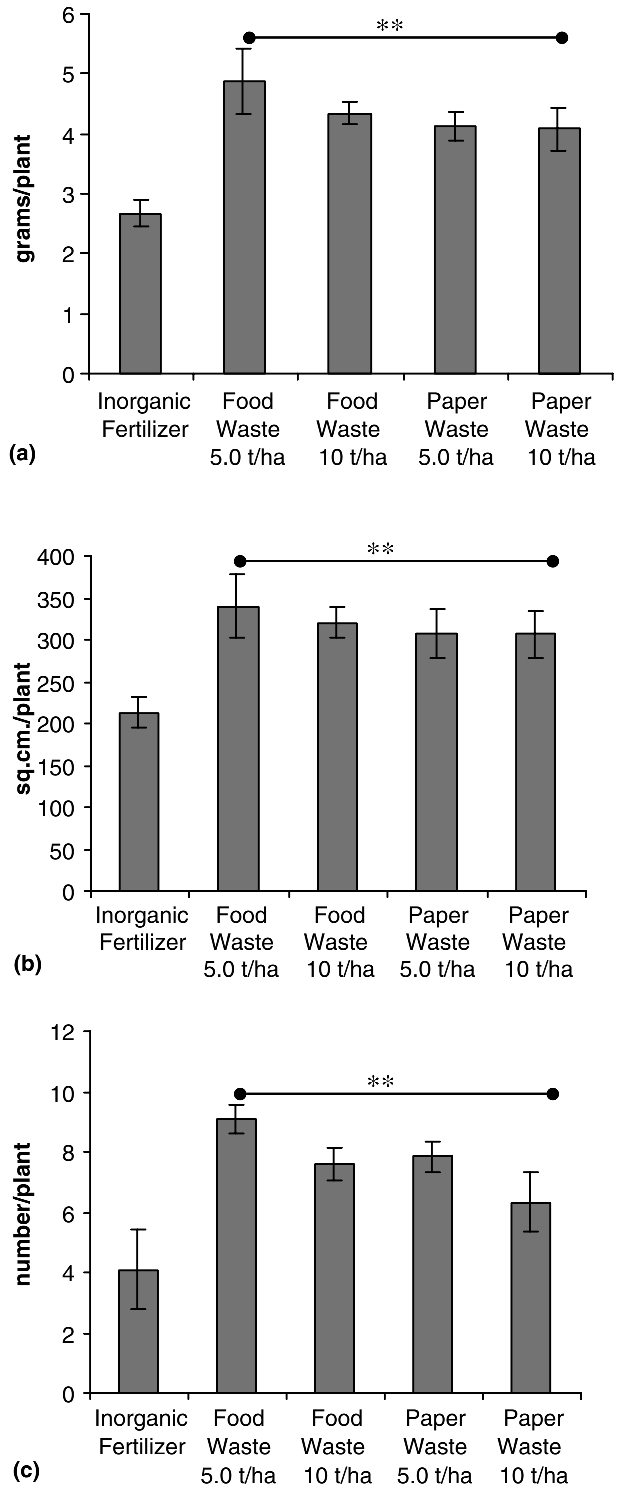

Fig. 4. Shoot biomass, leaf areas and number of flowers of strawberries grown in soils treated with food waste and paper waste vermicomposts and inorganic fertilizer control, 150 days after transplanting at Fremont, OH. Means of vermicompost treatments were grouped for orthogonal contrast versus means of plants from inorganic fertilizer treatments. Significant differences are designated with asterisk/s: (*) at $P \leqslant 0.05$ and (**) at $P \leqslant 0.01$. (a) Dry shoot weights, (b) leaf area and (c) number of flowers.

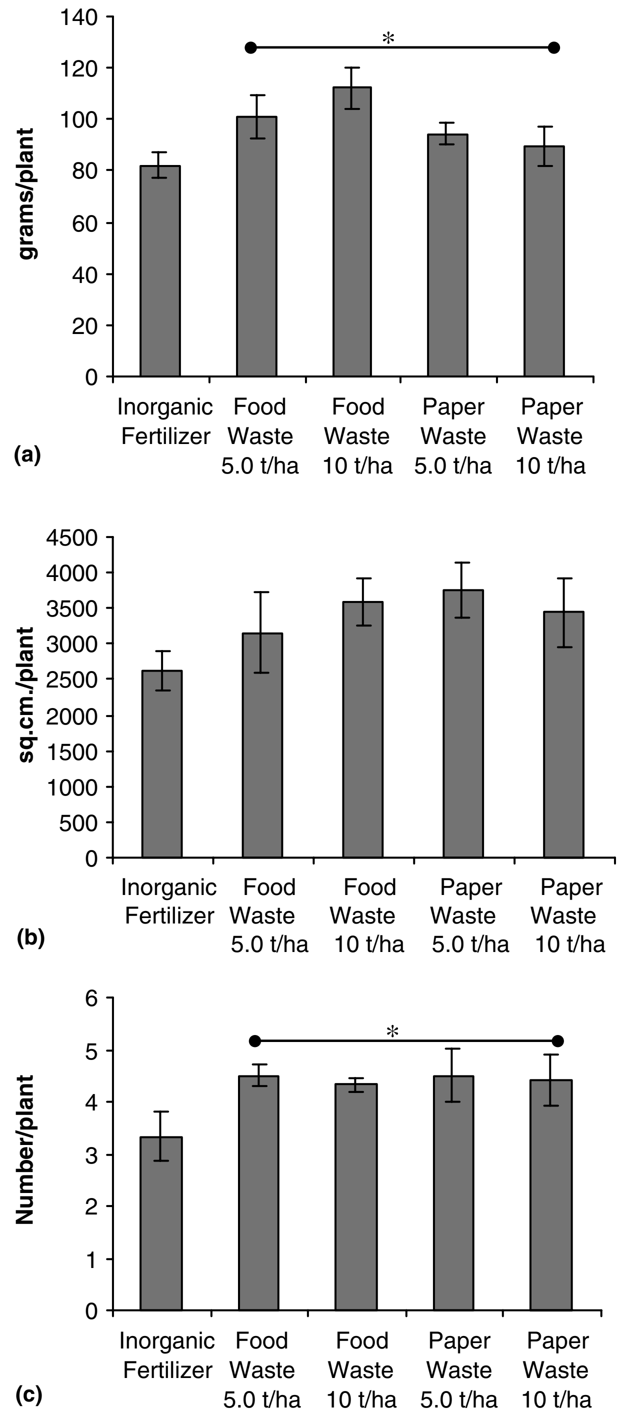

Fig. 5. Shoot biomass, leaf areas and number of runners of strawberries grown in soils treated with food waste and paper waste vermicomposts and inorganic fertilizer control, 200 days after transplanting at Fremont, OH. Means of vermicompost treatments were grouped for orthogonal contrast versus means of plants from inorganic fertilizer treatments. Significant differences are designated with asterisk/s: (*) at $P \leqslant 0.05$ and (**) at $P \leqslant 0.01$. (a) Dry shoot weight, (b) leaf area and (c) number of runners.

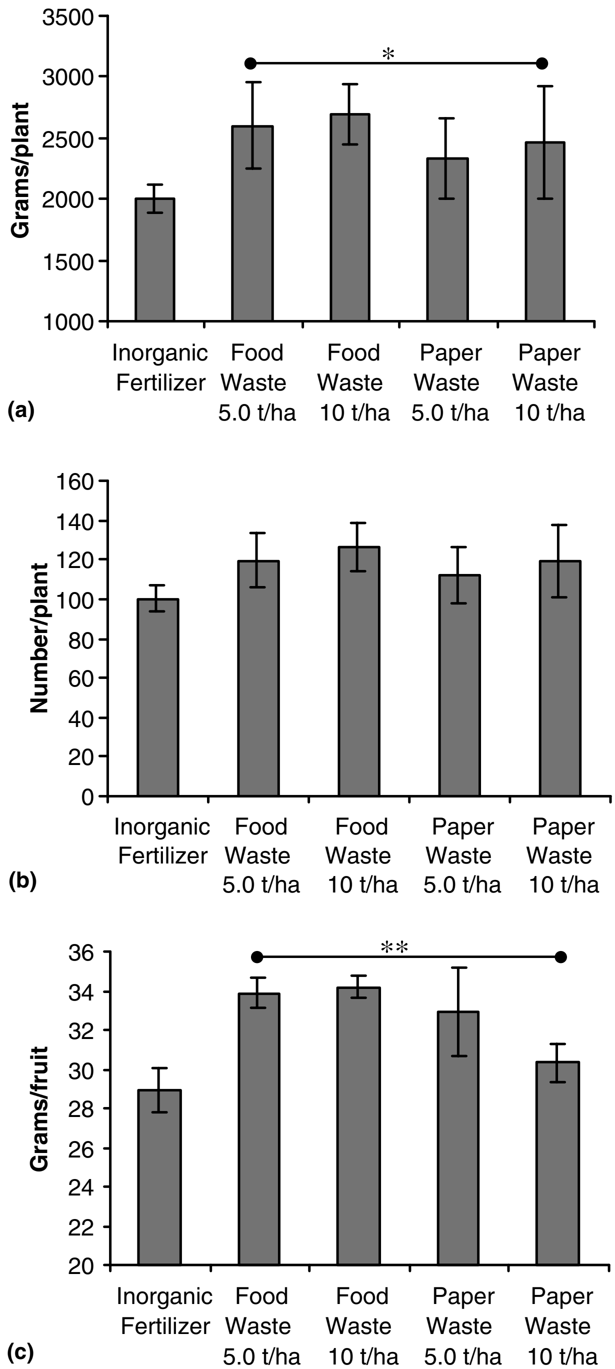

Fig. 6. Yield and yield attributes of strawberries grown in soils treated with food waste and paper waste vermicomposts and inorganic fertilizer control, 200 days after transplanting at Fremont, OH. Means of vermicompost treatments were grouped for orthogonal contrast versus means of plants from inorganic fertilizer treatments. Significant differences are designated with asterisk/s: (*) at $P \leqslant 0.05$ and (**) at $P \leqslant 0.01$. (a) Marketable yields, (b) number of fruits and (c) weight of largest fruit.

with those in soils receiving food waste vermicomposts. There were no significant growth differences between plants in plots that received 5 $t\,ha^{-1}$ vermicompost compared with those in plots that received 10 $t\,ha^{-1}$ vermicomposts.

Soil analyses showed that there were significant increases in microbial biomass and activity in plots treated with vermicomposts over those receiving only inorganic fertilizers but no significant differences in concentrations of extractable nitrogen, orthophosphates and extractable potassium.

4. Discussion

The substitution of vermicomposts into greenhouse container media in our laboratory has always been associated with increases in germination, seedling growth and flowering of ornamentals and growth and yield of vegetables even at low substitution rates and independent of nutrient supply (Atiyeh et al., 2000a,b, 2001). In those experiments, we postulated that the positive effects of vermicomposts on plant growth and yield were not due to nutrients but due to the availability of plant growth-influencing materials, such as plant growth regulators and humic acids, produced by the greatly increased microbial populations resulting from earthworm activity. It was confirmed in a later greenhouse experiment that small concentrations of humic acids, extracted from vermicomposts and substituted into container media, increased the growth of plants in a similar pattern independent of nutrient supply (Atiyeh et al., 2002a). The increases in growth and yield of strawberries in our current experiment could not be explained by the availability of macronutrients in soils treated with vermicomposts, because they were equalized at transplanting, relative to those in the plots treated with inorganic fertilizers. Analyses of the soil, after application of vermicomposts and inorganic fertilizers, confirmed that the concentrations of macronutrients in all plots were not significantly different.

We postulate that the increased microbial populations resulting from earthworm activity in the vermicomposts may have influenced plant growth indirectly. Soils treated with vermicomposts had a significantly greater microbial biomass ($P \leqslant 0.05$) than soils that received inorganic fertilizer only. It has been shown that microorganisms can produce materials that may affect plant growth such as substances acting as plant hormone analogues or growth regulators (Frankenberger and Arshad, 1995; Brown, 1995). There is a very substantial body of evidence demonstrating that microorganisms, including bacteria, fungi, yeasts, actinomycetes and algae, are capable of producing plant growth regulators (PGRs) such as auxins, gibberellins, cytokinins, ethylene and abscisic acid in appreciable quantities (Frankenberger and Arshad, 1995). According to Tomati et al. (1983), large quantities of plant hormones such as gibberellins, auxins, and cytokinins are produced during vermicomposting. Tomati et al. (1983, 1987) showed positive effects of vermicomposts on the growth of *Begonias* and *Coleus*, especially a stimulation of rooting, time of flowering, and lengthening of internodes. However, scientific data on the type or extent of growth effects produced by plant growth regulators produced by soil microbial activity is still sparse (Frankenberger and Arshad, 1995).

The increased amounts of humic materials in vermicomposts could also have been responsible for the increased growth and yields of strawberries we recorded. Muscolo et al. (1999) reported that humic materials extracted from vermicomposts produced auxin-like cell growth and nitrate metabolism of carrots (*Daucus carota*). Masciandaro et al. (1997) reported positive growth responses of plants to additions of humic material extracted from vermicomposts. These humic substances occur naturally in mature animal manure, sewage sludges or paper-mill sludges but their amounts and rates of production are increased dramatically by vermicomposting. Other workers have reported significant plant growth enhancements, in response to humate applications to soils, under conditions of adequate nutrition (Valdrighi et al., 1996; Goenadi and Sudharama, 1995). In laboratory experiments, Atiyeh et al. (2002b) produced definitive evidence of dose-related effects of humic acids, extracted from pig manure and food waste vermicomposts on plant growth. A range of humates extracted from pig manure vermicompost, applied to vegetable seedlings grown in a soil-less medium, increased the growth of tomato and cucumber plants significantly, even when the nutrient supply was not limiting. We speculated that the growth responses were due either to the ability of humic acids to act as plant-growth regulators and promote growth or because the humates may have hormonal plant growth regulators adsorbed onto them. Recently, Canellas et al. (2000) identified exchangeable auxin groups from humic acids extracted from cattle manure, following a structural analysis, which enhanced root elongation, lateral root emergence and plasma membrane H^+-ATPase activity of maize roots.

References

Atiyeh, R.M., Arancon, N.Q., Edwards, C.A., Metzger, J.D., 2002a. Incorporation of earthworm-processed organic wastes into greenhouse container media for production of marigolds. Bioresource Technology 81, 103–108.

Atiyeh, R.M., Lee, S.S., Edwards, C.A., Arancon, N.Q., Metzger, J., 2002b. The influence of humic acid derived from earthworm-processed organic wastes on plant growth. Bioresource Technology 84, 7–14.

Atiyeh, R.M., Edwards, C.A., Subler, S., Metzger, J.D., 2001. Pig manure as a component of a horticultural bedding plant medium: effects on physiochemical properties and plant growth. Bioresource Technology 78, 11–20.

Atiyeh, R.M., Arancon, N., Edwards, C.A., Metzger, J.D., 2000a. Influence of earthworm-processed pig manure on the growth and yield of greenhouse tomatoes. Bioresource Technology 75 (3), 175–180.

Atiyeh, R.M., Edwards, C.A., Subler, S., Metzger, J., 2000b. Earthworm-processed organic wastes as components of horticultural potting media for growing marigold and vegetable seedlings. Compost Science and Utilization 8 (3), 215–223.

Barakan, F.N., Salem, S.H., Heggo, A.M., Bin-Shiha, M.A., 1995. Activities of rhizosphere microorganisms as affected by application of organic amendments in a calcareous loamy soil. 2. Nitrogen transformation. Arid Soil Research and Rehabilitation 9 (4), 467–480.

Brookes, P.C., Landman, A., Pruden, G., Jenkinson, D.S., 1985. Chloroform fumigation and the release of soil nitrogen: a rapid direct extraction method to measure microbial biomass nitrogen in soil. Soil Biology and Biochemistry 17, 387–842.

Brown, G.G., 1995. How do earthworms affect microfloral and faunal community diversity? Plant and Soil 170, 209–231.

Canellas, P.L., Olivares, F.L., Okorokova, A.L., Facanha, A.R., 2000. Humic acid isolated from earthworm compost enhance root elongation, lateral emergence, and plasma membrane H^+-ATPase activity in maize roots. Plant Physiology 130, 1951–1957.

Casida Jr., L.E., 1977. Microbial metabolic activity as measured by dehydrogenase determinations. Applied and Environmental Microbiology 34, 630–636.

Edwards, C.A., Burrows, I., 1988. The potential of earthworm composts as plant growth media. In: Edwards, C.A., Neuhauser, (Eds.), Earthworms in Environmental and Waste Management. SPB Academic Publ. b.v., The Netherlands, pp. 211–220.

Edwards, C.A., 1998. The use of earthworms in the breakdown and management of organic wastes. In: Earthworm Ecology. CRC Press LLC, Boca Raton, Fl, pp. 327–354.

Follet, R., Donahue, R., Murphy, L., 1981. Soil and Soil Amendments. Prentice-Hall, Inc., New Jersey.

Frankenberger Jr., W.T., Arshad, M., 1995. Phytohormones in Soils: Microbial Production and Function. Marcel and Deckker, New York. p. 503.

Goenadi, D.H., Sudharama, I.M., 1995. Shoot initiation by humic acids of selected tropical crops grown in tissue culture. Plant Cell Reports 15, 59–62.

Grappelli, A., Galli, E., Tomati, U., 1987. Earthworm casting effect on *Agaricus bisporus* fructification. Agrochimica 21, 457–462.

Hoitink, H.A., Fahy, P., 1986. Basis for the control of soilborne plant pathogens with composts. Annual Review Phytopathology 24, 93–114.

Johnston, A.M., Janzen, H.H, Smith, E.G., 1995. Long-term spring wheat response to summer fallow frequency and organic amendment in southern Alberta. Canadian Journal of Plant Science 75 (2), 347–354.

Krishnamoorthy, R.V., Vajrabhiah, S.N., 1986. Biological activity of earthworm casts: an assessment of plant growth promoter levels in casts. Proceedings of the Indian Academy of Sciences (Animal Science) 95, 341–351.

Masciandaro, G., Ceccanti, B., Garcia, C., 1997. Soil agro-ecological management: fertirrigation and vermicompost treatments. Bioresource Technology 59, 199–206.

Munter, R.C., Grande, R.A., 1981. Plant tissue and soil extract analysis by ICP-atomic emission spectroscopy. In: Barnes, R.M. (Ed.), Developments in Atomic Plasma Spectral Analysis. Heyden, London, pp. 653–672.

Muscolo, A., Bovalo, F., Gionfriddo, F., Nardi, F., 1999. Earthworm humic matter produces auxin-like effects on *Daucus carota* cell growth and nitrate metabolism. Soil Biology and Biochemistry 31, 1303–1311.

Orozco, F.H., Cegarra, J., Trujillo, L.M., Roig, A., 1996. Vermicomposting of coffee pulp using the earthworm *Eisenia fetida*: effects on C and N contents and the availability of nutrients. Biology and Fertility of Soils 22, 162–166.

Senesi, N., Saiz-Jimenez, C., Miano, T.M., 1992. Spectroscopic characterization of metal-humic acid-like complexes of earthworm-composted organic wastes. The Science of the Total Environment 117/118, 111–120.

Shi-wei, Z., Fu-zhen, H., 1991. The nitrogen uptake efficiency from ^{15}N labelled chemical fertilizer in the presence of earthworm manure (cast). In: Veeresh, G.K., Rajagopal, D., Viraktamath, C.A. (Eds.), Advances in Management and Conservation of Soil Fauna. Oxford and IBH publishing Co, New Delhi, Bombay, pp. 539–542.

Sims, G.K., Ellsworth, T.R., Mulvaney, R.L., 1995. Microscale determination of inorganic nitrogen in water and soil extracts. Communications in Soil Science and Plant Analysis 26, 303–316.

Singer, M.J., Hanson, L., 1969. Lead accumulation in soils near highways in the Twin Cities metro area. Proceedings of Soil Science Society of America 33, 152–153.

Tomati, U., Grappelli, A., Galli, E., 1988. The hormone-like effect of earthworm casts on plant growth. Biology and Fertility of Soils 5, 288–294.

Tomati, U., Grappelli, A., Galli, E., 1987. The presence of growth regulators in earthworm-worked wastes. In: Bonvicini Paglioi, A.M., Omodeo, P. (Eds.), On Earthworms. Proceedings of International Symposium on Earthworms, Selected Symposia and Monographs, Unione Zoologica Italiana, 2. Mucchi, Modena, pp. 423–435.

Tomati, U., Galli, E., Grapppelli, A., Dihena G, 1990. Effect of earthworm casts on protein synthesis in radish (*Raphanus sativum*) and lettuce (*Lactuca sativa*) seedlings. Biology and Fertility of Soils 9, 288–289.

Tomati, U., Grappelli, A., Galli, E., 1983. Fertility factors in earthworm humus. In: Proceedings of the International Symposium on Agricultural Environment. Prospects in Earthworm Farming. Publication Ministero della Ricerca Scientifica e Technologia, Rome, pp. 49–56.

Valdrighi, M.M., Pera, A., Agnolucci, M., Frassinetti, S., Lunardi, D., Vallini, G., 1996. Effects of compost-derived humic acids on vegetable biomass production and microbial growth within a plant (*Cichorium intybus*)-soil system: a comparative study. Agriculture, Ecosystems and Environment 58, 133–144.

Zink, T.A., Allen, M.F., 1998. The effects of organic amendments on the restoration of a disturbed coastal sage scrub habitat. Restoration-Ecology 6 (1), 52–58.