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INFLUENCES OF FIELD APPLICATIONS OF VERMICOMPOSTS ON SOIL MICROBIOLOGICAL, CHEMICAL AND PHYSICAL PROPERTIES AND THE GROWTH AND YIELD OF STRAWBERRIES, PEPPERS AND TOMATOES

DISSERTATION

Presented in Partial Fulfillment of the Requirements for the

Degree of Doctor of Philosophy in the

Graduate School of the Ohio State University

By

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ABSTRACT

Vermicomposts are stabilized organic matter produced through the biological degradation of organic wastes by interactions between earthworms and microorganisms. Vermicomposts commercially-produced from food waste and paper wastes and vermicomposts produced by us at OARDC were applied at the rate of 10 and 5 t/ha to soil plots planted to strawberries var. Chandler at two different sites – OSU, Piketon Research Center and OARDC Vegetable Branch, Fremont, Ohio in 1999. Food waste, paper waste and cow manure vermicomposts were applied to the pepper and tomato plots at the rates of 20 t/ha and 10 t/ha in 1999 and at rates of 10 t/ha and 5 t/ha in 2000. Control plots were treated with inorganic fertilizers only and all of the vermicompost-treated plots were supplemented with inorganic fertilizers to equalize the available N levels in all plots on the transplanting date.

Leaf areas, numbers of strawberry suckers, numbers of flowers, shoot weights, and marketable fruit yields increased significantly in plants that received vermicompost treatments compared to those from strawberries that received inorganic fertilizers only. Food waste vermicomposts had greater effects on the growth and yields of strawberries than paper waste vermicomposts. The total extractable N, microbial biomass N and dissolved organic N were statistically similar in all treatments at end of the growth cycle of strawberries. There were more orthophosphates in soils that received vermicompost treatments than the inorganic control plots. There were more fungivorous and bacterivorous nematodes in soils that were treated with vermicomposts than in the inorganic control plots and there were more plant-parasitic nematodes in soils that received inorganic fertilizers only than in the vermicompost-treated soils. *Verticillium wilt* disease was suppressed significantly in soils treated with vermicomposts.

There were significant increases in pepper shoot weights, leaf areas and marketable fruit yields in plants from plots that were treated with vermicomposts (with inorganic supplements) compared to those from the inorganic control plots. There was more microbial biomass N and orthophosphates in soils that were treated with vermicomposts than in the inorganic controls. Paper waste and cow waste vermicompost applications produced significantly greater pepper fruit yields than those of food waste vermicomposts with no significant differences in yields between the rates of 10 t/ha and 5 t/ha. Soils growing peppers that were treated with vermicomposts conatined more fungivorous and bacterivorous nematodes compared to soils that received inorganic fertilizers only. There were more plant-parasitic nematode populations in soils from the inorganic control plots compared to those treated with vermicomposts.

The tomato fruit yields in the vermicompost treated plots were usually greater but not statistically different from the yields in the inorganic treated plots. The amounts of total extractable N, orthophosphates, dehydrogenase enzyme activity, and microbial biomass were greater in the soils from vermicompost plots but only on certain sampling dates. The numbers of bacterivorous nematodes were significantly greater in the soils from vermicompost-treated tomato plots than in inorganic controls. The numbers of plant-parasitic nematodes were greater in soils that received only inorganic fertilizers than in those treated with vermicomposts.

The improvements in plant growth and increases in yields could not be explained by the availability of macronutrients because all vermicompost treatments were supplemented with inorganic fertilizers to equalize macronutrient availability at transplanting time. Changes in the amounts of microbial biomass, dehydrogenase activity and nematode trophic compositions could possibly be linked to the increases in the growth and yield of strawberries, peppers and tomatoes. Additionally, increases in growth and yields could have been due to availability of growth regulators or to the effects of humates in the vermicomposts since these can produce growth effects independent of nutrients.

Dedicated to Mama

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Major Field: Environmental Science

TABLE OF CONTENTS

Chapters:

LIST OF TABLES

LIST OF FIGURES

Figure ....Page

Figure Page

CHAPTER I

INTRODUCTION

In 1798, Thomas Malthus' controversial essay on the principle of human populations if population growth increased exponentially eventually suggested that worldwide famine was inevitable. This prediction was made after considering that the arithmetical growth in food production was much lower than the exponential rate of population growth. Although the phenomenon was localized in some parts of the world until recent years, famine never occurred worldwide. In fact, food production was able to sustain the ever-growing population until about 1980 although there has been localized malnutrition and there are suggestions that there were several reasons why Malthus' prediction did not fully materialize. Some of the factors that Malthus disregarded that accounted for the boost in food supply were increased areas for arable cropping, more land reclamation, and more importantly the advances in technologies especially the use of fertilizers and pesticides that were responsible in the increase of production per unit area and the minimization of losses in post-harvest production. However, some of these means of increasing food supply have become less attractive because they have posed many negative environmental consequences. Clearing more lands means meant decreasing the area of our forested lands. This practice has been blamed partially for upsetting the balance of CO_2 that indirectly affects the highly debated phenomenon on global warming and erosion caused by both wind and water. It has also decreased and disrupted the habitats for wildlife thereby endangering them in the process. Reclaiming land such as arid regions or areas with extreme climatic conditions became economically restrictive because this entailed utilization of tremendous amounts of energy to create suitable conditions condition and provide irrigation which favors plant growth. The evolution of chemical and engineering technologies have remained the most significant steps in increasing food production which responded in pace of population growth.

Technologies in crop production that have helped to increase food production per unit area have ranged from the creation of better seed varieties to the use of synthetic soil amendments to increase fertility. Products used since Second World War have included inorganic fertilizers and synthetic pesticides that have boosted plant growth and yield dramatically. However, these two technologies have both been shown to be hazardous to the environment in the long term. In affirmation, the influential environmental publication of Rachel Carlson's Silent Spring in 1972, prompted people around the globe to consider possible negative impacts brought about by pesticides. Many other publications have also demonstrated negative environmental impacts of pesticides and initiated steps in generating alternative ways to increase crop production without jeopardizing the capacity of the environment to maintain productivity in the future. Such discussions have paved the way for scientists and leaders around the world to initiate movements that address environmental issues. In 1984, a world summit was held in Rio de Janiero where the concept of sustainable agriculture was adopted globally in response to the growing need to preserve the environment. The concept sought to generate new technologies and confirm existing ones that fitted into the criteria of sustainability:

environmentally sound, economically viable, appropriate, culturally sensitive, promote social equity and justice, based on holistic science and promote total human development among others.

Among the technologies that were considered to be appropriate to sustainability criteria was the greater and more efficient use of soil organic amendments. Their use has long been recognized in traditional agriculture as beneficial for plant growth and yield and the maintenance of soil fertility. The new approaches to the use of organic amendments in farming have proved to be effective means of improving soil structure, enhancing soil fertility and increasing crop yields. Follet (1981) outlined the important functions of organic matter in soils, such as: 1) serving as the principal storehouse for anions essential for plant growth such as nitrates, phosphates, sulfates, borates, molybdates, and chlorides; 2) increasing the cation exchange capacity of soils by a factor of 5 to 10 times that of clay which is true with humified organic matter (humus); 3) buffering the soil against rapid changes due to acidity, alkalinity, salinity, pesticides, and toxic heavy metals. Pascual et. al. (1997) reported that the addition of organic materials to the soil increased values of biomass C, basal respiration, biomass C:total organic C ratio, and metabolic quotient (qCO_2), indicating the activation of soil microorganism. Other workers have reported enhanced microbial populations (Barakan et al 1995) and increases in microbial activity after the addition of organic matter (Zink and Allen 1998). Many crop yields have increased with the corresponding improvements in soil quality from organic matter. Significant yield increases using mulches from coffee husks (Bwamiki, 1998) and increases in productivity using animal manures and hay residues (Johnston et al. 1995) have been reported. Their important roles in the soil and their potentially positive effect on crop yields have made organic amendments a valuable component of farm fertilization and management programs in alternative agriculture. Forms of organic matter used include crop residues as mulches, animal manures, human waste, sewage effluents, sewage sludges and composts among others.

Traditional composting of organic matter wastes has been known for many years but new methods of thermophilic composting have become much more popular in organic waste treatment recently since they eliminate some of the detrimental effects of organic wastes in the soil. Composting has been recognized as a low cost and environmentally sound process for treatment of many organic wastes (Hoitink, 1993). Furthermore, the rapid decomposition and raised temperatures during composting produce a relatively homogeneous, odor-free, pathogen-free and easy-to-handle product. Tester (1990) reported that composting significantly reduced soil bulk density, increased soil water content, and modified pH to greater depths, and increased soil surface area linearly. Bevacqua and Mellano (1993) reported that compost-treated soils had lower pHs and increased levels of organic matter, primary nutrients, and soluble salts. In crop studies, Bryan and Lance (1991) found that tomatoes grown in compost-amended soils yielded more. Maynard (1993) also reported increases in fruit yield of compost-amended plants compared with those growing in soil alone. Other benefits from the use of compost include the possible reduction of hazards from nitrate leaching into groundwater compared to those from inorganically fertilized controls (Maynard, 1989). Furthermore, composting and composts have been reported to suppress plant pathogens. Hoitink and Fahy (1986) reported that composts were suppressive to soilborne plant diseases such as *Pythium* damping-off and *Rhizoctonia* damping-off. Population development of

Helicotylenchus spp. (Hunt, et al, 1973) and *Pratelynchus dianthus* (D'Errico and Di Maio, 1980) were suppressed by composts made from municipal refuse. Composts have also been reported to enhance population development of beneficial nematodes such as *cephaloids* and *rhabditids* (saprophagous nematodes).

A process related to composting which can improve the beneficial utilization of organic wastes is vermicomposting. It is a non-thermophilic process by which organic materials are converted by earthworms and microorganisms into rich soil amendments with greatly increased microbial activity and nutrient availability.

The Role of Earthworms

Earthworms have long been shown to play a major role in the maintenance of soil fertility (Darwin, 1881; Edwards and Bohlen, 1996). Their activities in soil have been associated mostly with the presence of organic matter such as plant and animal debris. Earthworms increase the rates of decomposition of organic matter and enhance soil microbial activity, in their sphere of influence lining the earthworm burrows (the "drilosphere") and thereby increase mineralization rates of nitrogen and phosphorus. These nutrients may be taken up in greater quantities by plants and increase plant biomass production. Traditional farming sustained soil fertility by incorporating waste organic materials which in turn enhanced natural nutrient cycling to provide nutrients for crops. However, earthworm populations in agricultural land have presently decreased due to intensive farming methods and the importance of returning organic matter to the soil has been neglected in the recent years (Edwards and Lofty, 1982; St Remy and Daynard, 1982).

The many contributions of earthworms to soil fertility and plant growth have been documented widely. Controlled introductions of several different earthworm species to sites that were otherwise earthworm-free have improved both the structure and fertility of mineral soils (Nielsen, 1951; Larymaid, 1964; Stockdill, 1982; Springett, 1984, 1987; Curry, 1988). The introduced earthworm species usually improved the rates at which organic residues were incorporated, degraded (Hoogerkamp, Rogaar, and Eijsakers, 1983) and increased soil mixing and the formation of water-stable aggregates (van Rhee, 1977). Other field experiments involved adding tropical endogeic poly-humic earthworms (*Pontoscolex corethrusus)* to soil around trees also enhanced plant growth significantly (Pashanasi et al, 1992). Schen and Parkinson (1994) reported increases in shoot:root ratios of wheat grass (*Agropyron trachycaulum*) after the introduction of some earthworm species. Increases in basal respiration, specific respiration, inorganic nitrogen in the soil and plant nitrogen concentration have also been reported (Devliegher and Verstraete, 1995, 1996).

Clearly, earthworms play a major role in affecting soil and field crop productivity positively. I believe that these potentials could be increased significantly through vermicomposting. Earthworms have been used to process many kinds of organic wastes, including: sewage sludges and solids from waste waters, brewery wastes, processed potato waste, waste from paper industries, waste from supermarkets and restaurants, animal wastes from poultry, pigs, cattle, sheep, goats, horses, and rabbits, horticultural residues from dead plants, yard wastes, and wastes from the mushroom industry (Edwards, 1998).

There are several reasons why vermicomposts, the product derived from the biological degradation of organic wastes by earthworms and microorganisms have greater potential to become a major soil additive for use in the horticultural industry and soil ecology.

Definition of Vermicomposts

Vermicomposts are products derived from the accelerated biological degradation of organic wastes by earthworms and microorganisms. Earthworms consume and fragment the organic wastes into finer particles by passing through a grinding gizzard and derive their nourishment from microorganisms that grow upon them. The process accelerates the rates of decomposition of the organic matter, alter the physical and chemical properties of the material, leading to a humification effect in which the unstable organic matter is fully oxidized and stabilized (Albanell et al., 1988; Orozco et al., 1996). The end product, commonly referred to as vermicompost is greatly humified through the fragmentation of the parent organic materials by earthworm and further decomposition by microorganisms.

The Physico-chemical Properties of Vermicomposts

Vermicomposts are finely divided peat-like materials with high porosity, aeration, drainage, water-holding capacity (Edwards and Burrows, 1988). They have greatly increased surface areas, providing more microsites for microbial decomposing organisms, and strong adsorption and retention of nutrients (Shi-wei and Fu-zhen, 1991). Albanell et al. (1988) reported that vermicomposts tended to have pH values near neutrality which may be due to the production of CO_2 and organic acids produced during microbial metabolism. They also reported that their moisture content was reduced progressively during vermicomposting giving final moisture contents between 45% and 60%, the ideal moisture contents for land-applied composts (Edwards 1983).

Humates are highly complex stable organic compounds that remain after soil organisms have broken down the original dead plant and animal material. They are important in binding soil aggregates, and improving the water and nutrient-holding capacity of the soil (Ingham 1999). Vermicomposts have been described by several authors as humus-like materials and their degree of humification has been investigated fairly thoroughly by many authors. The humifying capacity of earthworms, in the production of vermicomposts, was reported by Businelli et al. (1983) after *Lumbricus rubellus* processed the following mixtures: cow and rabbit dungs, cattle and horse dungs, horse dung, cow and sheep dungs and municipal waste compost. All earthworm casts had E_4/E_6 values of humic and fulvic acids that were higher relative to the original wastes that were processed by earthworms. This was confirmed by Elvira et al (1996) who reported that humification rates were increased significantly in paper-pulp mill sludge worked by *Eisenia andrei*. The transformation into the humic compounds by passage through the earthworm gut revealed that the rates of humification of ingested organic matter are intensified during earthworm gut transit (Kretzschmar, 1984). Kretzschmar presented that the ratio of fulvic acid and humic acid deceased from 0.86 to 0.63 after transit through earthworm guts which indicated an elimination of more labile elements. Orlov and Biryukova (1996) reported that vermicomposts contained 17-36% of humic acid and 13-30% fulvic acid of the concentrations of these compounds in organic matter. The humic and fulvic acid concentration ratio was found to be 1.0 – 2.7 with the total content of organic carbon 5.4 – 10.2%. Senesi et al. (1992) compared the quality of humic acids present in vermicomposts, with those found in natural soils, using spectroscopic analysis procedures. They demonstrated that the metal-humic acid-like substances containing appreciable amounts of iron and copper, present in materials processed by earthworms, are similar to the humic acids common in soils and other sources irrespective of the nature of the parent material. This indicated that vermicomposting can produce adequate amounts of humic acid and as far as their metal complexation properties and behavior are concerned.

Among their superior chemical attributes, Edwards and Burrows (1988) reported that vermicomposts usually contained more mineral elements than commercial plant growth media, and many of these elements were changed to forms more readily taken up by the plants, such as nitrates, exchangeable phosphorus, and soluble potassium, calcium, and magnesium. Orozco et al. (1994) reported that coffee pulp, increased the availability of similar nutrients such as phosphorus, calcium and magnesium, after processing by *Eisenia fetida*. Phosphorus was 64% higher in vermicomposts than in the original material which was suggested to be due to increased phosphatase activity from the direct action of gut enzymes and indirectly by the stimulation of microorganisms. In vermicompost analyses by Werner and Cuevas (1996), vermicomposts contained adequate amounts of macronutrients and trace elements of various kinds depending on the sources of the earthworm feedstock. Similar results were reported by Businelli et al (1984) who reported differences in chemical compositions of the vermicopost based on the substrate used. In his experiments, the highest elemental values were recorded in vermicomposts from cattle and horse manure mixture with 38.75% organic carbon, 2.72% total N and 1080 mg/kg NO_3-N. Lowest elemental concentrations were recorded in the municipal waste compost with only 9.48% organic carbon, 1.04% total N and 503 mg/kg NO_3-N. Edwards (1988) also reported large amounts of minerals in earthworm-processed animal wastes compared with those in a commercial compost. The wastes they investigated were separated cattle solids, separated pig solids, cattle solids on straw, pig solids on straw, duck solids on straw, and chicken solids on shavings. These materials contained mineral contents (% dry weight) ranging from 2.20–3.00 N, 0.40-2.90 P, 1.70-2.50 K, and 1.20-9.50 Ca compared to those of the commercial composts (Levington Compost) which only had 1.80, 0.21, 0.48 and 0.94 for N, P, K, K and Ca, respectively.

The quantity and quality of the nutrients in vermicomposts can be explained by accelerated mineralization of organic matter, breakdown of polysaccharides and a higher rate of humification achieved during vermicomposting (Elvira et al., 1996; Albanell et al., 1988). In investigations into earthworms the bioconversion of solid paper-pulp mill sludge, it was reported that total carbohydrate content decreased while total extractable carbon, non-humified fraction and humification rates increased by the end of the experiment.

Microbial Qualities and Effects of Vermicomposts

Vermicomposts have many outstanding biological properties. They are rich in bacteria, actinomycetes, fungi (Edwards, 1983; Tomati et al., 1987; Werner and Cuevas, 1996) and cellulose-degrading bacteria (Werner and Cuevas, 1996). In addition, Tomati et al. (1983) reported earthworm castings, obtained after sludge digestion, were rich in microorganisms, especially bacteria. Nair et al (1997) compared the microflora associated with vermicomposts with those in conventional compost. The vermicomposts had larger populations of bacteria (5.7×10^7), fungi (22.7×10^4) and actinomycetes (17.7×10^6) compared with those in conventional composts. It was reported by Matsumoto (1990) that there were large populations of bacteria and actinomycetes in the earthworm casts. The presence of the large number of microorganisms has been associated closely with the high quality of nutrients that are mineralized from vermicomposts and more emphasis has been placed on its association with the ability of vermicompost to suppress plant diseases as well as human pathogens.

The associations between microbial activity and nutrient availability of vermicomposts have been reported by Carlile and Wilson (1993). They measured the microbial activity in a media containing earthworm-worked duck wastes by quantifying CO_2-C liberation. They reported that amounts of CO_2-C liberated from the media used, sphagnum and sedge, increased proportionally with the amount of earthworm-worked duck waste substituted into the mixture. There was also more CO_2-C liberated from earthworm-worked duck waste – amended media than from peat media which contained only nutrients. The increases in microbial activity have been reported to be associated positively with high nutrient availability and mineralization in vermicomposts. In a ferti-irrigation experiment conducted by Masciandaro et al (1996), a more pronounced relationship between microbial activity and nutrient mineralization, after addition of vermicompost, was reported using vermicomposts in a solid form and an extracted humic acids from vermicomposts. It was speculated that available nutrients and labile carbon from vermicomposts sustained high microbial activities although effects of humic acids on microbial activity was not fully understood. Significant correlations were found among growth indices, chemical and biochemical parameters considered. In particular dehydrogenase activity, which is a measure of microbial activity, was correlated highly with the availability of the chemical nutrients. This conclusion was validated by an investigation by Marinari et al (2000) which not only correlated nutrient mineralization, microbial activity and plant growth positively but also correlated these parameters to soil porosity. Porosites which ranged from 100-500 µm, the ideal size for microbial activity, were in soils with vermicompost added. Dehydrogenase, acid phosphatase and protease activities were correlated highly with the overall porosity of the vermicompost – applied soils. This could possibly explain results obtained by Venkatesh et al (1997) who reported vermicompost applications, coupled with the addition of chemical fertilizers, resulted in greater availability of micronutrients in soil and to plants (except for copper) compared to applications of chemical fertilizer alone. Mba (1987) reported that nitrogen fixation was achieved after the substrate, *Paspalum dilitum* (Dallis grass diet) was processed by *Eudrilus eugeniae* and that the significant increases in total N relative to the Dallis grass diet could be correlated with increases in nitrogenase enzyme activities as determined by acetylene reduction. When microbial counts were made, they revealed significant numbers of N-fixing bacteria and their numbers increased relative to the amount of Dallis grass feedstock added. The enrichment of available nutrients and microorganisms in vermicomposts may be explained further in the work by Gorres et al. (1997) who investigated the dynamics of carbon and nitrogen mineralization, microbial biomass, and nematode abundance within and outside the burrow walls of the anecic earthworms *Lumbricus terrestris L.* This aimed at determining whether carbon and/or nitrogen mineralization increased in earthworm burrows. They showed that, although microbial biomass decreased during the period of 11 weeks, there was an increasing build up of nematode populations in the drilosphere. The grazing activities of the nematodes on the microorganisms caused the mineral N to convert to NH_4 and NO_3. However, because the trophic structures of the nematode populations were not investigated, only speculations on the mineralization of C and N could be made. Grazing on microorganisms and the resulting mineralization of C and N could also be due to the build up of microbivorous microbes such as protozoa. Perhaps, this could explain to some extent the ability of vermicomposts to suppress diseases. A similar experiment that assessed the microorganisms and physio-chemical conditions in the drilosphere of *Lumbricus terrestris* L. was by Devliegher and Verstraete (1997) who showed that there were more microorganisms in the drilosphere but most of those that were counted were composed of siderophore-producing fluorescent pseudomonads. They also confirmed that higher concentrations of NO_3-N occurred in the drilosphere. In another experiment, using paddy rice, Kale (1992) reported increases in mycorrhizal colonization in the plant system after the addition of vermicompost at planting time. Mycorrhizae are known to have mutualistic relationships with plants as they form a network of hyphae in the rhizosphere to increase plant efficiency in the uptake of water and nutrients while plants excrete metabolites to maintain their existence.

Plant-Growth-Regulators and Vermicomposts

The ability of vermicomposts to enhance growth and increase yield has been attributed not only the quantity, availability and quality of minerals and large numbers of microorganisms but it has also been linked with the production of growth-regulating substances. The presence of such biological factors has been consistently underestimated in their potential role to influence plant growth positively. According to Tomati et al.

(1983), vermicomposts contain large amounts of plant hormones such as gibberellins, auxins, and cytokinins. The nature of these biologically active substances was first suggested by Tomati et al. (1983, 1987) and Grappeli et al. (1987) who tested vermicomposts as media for growing ornamental plants and mushrooms. The growth of *Petunias*, *Begonias* and *Coleus* in soil treated with vermicompost extracts were compared to plants that received auxins, gibberellins, and cytokinins. Growth changes that were observed in the plants included stimulation of rooting, dwarfing, time of flowering, and lengthening of internodes. Tomati et al. (1988) stated that the promotion of growth in plants was not influenced merely by the nutrients released by earthworms. They concluded that the plant growth increases that occurred were too large to be explained purely on the basis of the nutrient content of vermicompost, but could more likely be caused by organic compounds such as plant growth hormones found in the medium produced by microorganisms as metabolites. The production of these metabolites was made possible by microbial activity producing the humus-like characteristics of vermicomposts produced by earthworm fragmentation, digestion and mixing processes. Krishnamoorthy and Vajrabhaiah (1986) showed that seven species of earthworms could promote the production of cytokinins and auxins in organic wastes.

Humic matter extracted from vermicomposts produced auxin-like cell growth and nitrate metabolism of *Daucus carota* (Muscolo et al., 1999). They showed that humic substances obtained from the faeces of earthworms *Nicrodrilus caliginosus* and *Allolophora rosea,* at a concentration of 200 $\mu g\ C\ l^{-1}$, caused increases in carrot cell growth, determined by packed cell volumes, similar to those produced by 2,4-D, and morphological changes were similar to those from IAA. Specific physiological processes that were stimulated to various extents by the humic extracts were the production of glutamate dedyhrogenase (GDH), glutamine synthetase (GS), and malic dehydrogenase (MDH). From the previous section, Masciandaro (1997) reported positive growth responses of plants after addition of humic extracts from vermicomposts. These humic substances were contained in high levels in animal manures, sewage sludges or paper-mill sludges. Several other studies on humic substance applications reported plant growth enhancement even under conditions of completely adequate mineral nutrition (Lee and Barlett, 1976; Albuzio et al., 1994; Mylonas and Mccants, 1980; Tan and Tantiwiramanond, 1983; Valdighi et al., 1996; Goenadi and Sudharama, 1995). In an experiment conducted by Atiyeh et al. (2000, unpublished data), evidences of the positive effects of humic acids from pig manure and food waste vermicomposts were shown. Results of these experiments showed increases in shoot and root dry weights at very low concentrations of addition of humic acid extracts.

Disease Suppression by Vermicompost

Vermicomposts have suppressed disease-causing pathogens in plants. The mechanism of this disease suppression is not well understood. It has been speculated that the suppression of disease-causing pathogens is due to various organic substances present in organic amendments of composts and vermicompost. However, this property decreases with time as these organic materials decompose. Another speculation was based on the rich composition of beneficial microorganism present in the vermicompost that could have caused changes in the microbial populations in the planting medium after vermicompost addition and antagonism. Nevertheless, although a few experiments have demonstrated suppression of some pathogens in plants they made no attempts to explain its mechanism. Szczech et al (1993) reported the suppression by vermicomposts of *Phytophthora nicotianae* var. *nicotianae* and *Fusarium oxysporum* f.sp. *lycopersici* in tomatoes and *Plasmodiophora brassicae* in cabbage. The suppression increased with increasing amounts of vermicompost applied to the planting. In an investigation by Szczech (1998), it was reported that the mineral composition of vermicomposts had little to do with their ability to suppress disease. This was confirmed when fungal growth was still observed after addition of sterilized vermicompost extract to the growth media. Furthermore, the numbers of microorganisms and populations of antagonistic bacteria and fungi were significantly higher in vermicomposts than in the control peat substrate. Recently, several other experiments reported similar disease suppression abilities of vermicomposts. The applications of vermicompost to lettuce controlled *Meloidgyne javanica* (Ribiero, 1998). The incidence of *Heterosphylla cubana* was reduced after the addition of progressively increasing amounts of vermicompost in a tropical leguminous tree commonly called Ipil-ipil, *Leucaena leucocephala* (Biradar, 1998). More recently, in investigations by Brickner and Chaoui (2000, unpublished data) at the Ohio State University, vermicomposts from cattle manure and pig manure suppressed *Pythium* and *Rhizoctonia* diseases in cucumber and radish seedlings, respectively.

Toyota et al. (1995) suggested two mechanisms of microbial. General suppression may be based on a competition for nutrients and energy and involves the total microflora and this is considered to be the major source of widespread fungistasis in soil. More specific suppression refers to particular antagonistic microorganisms. It was suggested that both mechanisms could occur after vermicompost applications.

Utilization of Vermicomposts in the Greenhouse and Field

Greenhouse and field experiments have demonstrated that vermicomposts have positive effects on plant growth, development and yield. In greenhouse experiments, using ornamentals, Edwards and Burrows (1988) reported that vermicomposts positively favored seedling emergence over the that in the control commercial medium, using a wide range of test plants such as pea, lettuce, wheat, cabbage, tomato and radish. In the same work, the growth of ornamental shrubs such as *Eleagnus pungens, Cotoneaster conspicua, Pyracantha, Viburnum bodnantense, Chaemaecyparis lawsonia, Cupressocyparis leylandii and Juniperus communis* grew as well or better in a vermicompost than in the commercial plant growth medium when transplanted into larger pots or grown outdoors. They also reported that at an early stage of plant growth some ornamental plants such as chrysanthemums, salvias and petunias flowered earlier compared to those grown in a commercial peat/s and planting media. There was promotion of growth in plants even at 5% substitution of a 50:50 mixture of pig and cattle manure vermicomposts diluted into a range of levels of commercial plant growth medium. Similar results were obtained by Atiyeh (1998) demonstrating that vermicomposts enhanced vegetable and ornamental seedling growth, even at low concentrations, with all needed nutrients available. Atiyeh (1998) reported that larger proportions of vermicomposts substituted into the commercial growth media did not always improve plant growth and they demonstrated further, that even 5% of vermicompost in the mixture was sometimes enough to produce dramatic growth responses of the test crops. More recently, Atiyeh et al (2000) reported increases in tomato growth planted in 10% vermicompost and 90% commercial medium from pig waste compared to plants grown in 100% commercial potting media, Metro-Mix 360, a peat/perlite mixture or a coir/perlite mixture. Substitution of this commercial medium with 10%, 20%, and 50% vermicompost all stimulated plant growth independent of nutrient supply, resulting in significant increases in plant height and root and shoot biomass. Plant growth was also enhanced significantly when 10% and 20% vermicompost was substituted with either peat/perlite or coir/perlite mixtures. In another experiment, Atiyeh et al (2000) reported that the substitution of Metro-Mix 360 with 10% or 50% pig manure vermicompost increased the dry weight of tomato seedlings significantly compared to those grown in the 100% Metro-Mix 360 controls. The largest marketable fruit yields were in the substitution of 80% Metro-Mix 360 and 20% vermicompost. Furthermore, lower concentrations of vermicomposts (less than 50%) in the potting mixture usually produced greater growth effects: 20% vermicompost substitution resulted in 12.4% more fruit weight and 10%, 20% and 40% vermicompost substitution reduced the proportions of non-marketable fruits and produced more larger size tomato fruits. The positive responses of tomatoes to vermicomposts were attributed to the high mineral N concentration of pig manure vermicomposts. However, I speculated that other growth factors were involved.

In a pot trial by Buckerfield et al (1999), using 0% to 100% mixtures of vermicompost and sand, similar trends were reported. The germination of radishes decreased from 95% to less than 50% with increasing vermicompost added concentrations. However, the radish harvest weights were directly proportional to the application rates of vermicomposts, with the yields of plants in 100% vermicompost being up to ten times greater than those in 10% vermicompost. In a separate experiment, using water extracts (vermiliquid) from vermicomposts, Buckerfield (1999) showed similar responses. At first applications inhibited germination but subsequent weekly applications of the diluted vermiliquid improved plant growth and increased radish yields significantly up to 20%. The growth of tomatoes, lettuce, and peppers were reported at optimum substitution 8-10%, 8%, and 6%, respectively, using duck waste vermicompost and peat mixture (Wilson and Carlile, 1989). It was shown further that plant nutrient uptake was correlated with the rate of plant growth and development. At higher vermicompost concentrations, the inhibition of growth was reported to be due to higher conductivity and nutrient levels. Subler et al (1998) reported increases in plant growth in vermicompost mixtures with Metro-Mix in comparison with two commercial composts – biosolids and yardwaste using common bedding plants, tomatoes and marigolds as test plants. In their experiments, differences in chlorophyll contents were observed at the early stages of marigold growth. At the end of the trial, differences in leaf area and significant increases in the total plant weights were reported in 10% vermicompost and MetroMix 360 combinations compared with the control 100% MM360. Significant increases in tomato seedling weights at substitution of 10 % and 20% MM360 were also reported. Raspberries grown in pots and commercial media substituted with 20% pig manure vermicompost produced the largest shoot dry weights comparable ton that of plants in pots that received complete inorganic fertilizer. Furthermore, those pots amended with pig manure vermicomposts deterred the toxic effects of chicken manure over the raspberry plants. In an investigation by Scott (1988) using hardy nursery stocks, 20-50% vermicompost from cattle manure, pig manure, and duck waste substitution with full application of nutrients gave better growth over the control pots using only peat:sand mix as control. In the second year of the same experiment, there was a variability of responses among the test crops used. Using *Juniperus sabina tamariscifolia* 25% of all three types of animal waste with the addition of a controlled release fertilizer, Osmocote (18:11:10), produced similar growth results to the control. However, the best growth was obtained from the pots with no Osmocote.

The effects of a wide variety of vermicomposts produced from cow manure, sheep manure, poultry manure, goat manure (mixed with carpet underfelt, lawn clippings, cardboard, and domestic waste), kitchen scraps, cardboard (mixed with wheat, maize, meat, lucerne and linseed meals, rice pollard and oat hulls), and pig wastes on plant growth were investigated by Handreck using *Pinus radiata* bark and quartz sand into the mixtures. Thirty percent of each of the vermicomposts was added to the mixtures. It was reported that all the mixes increased the dry weights of *Mathiola incana* over that in the control after adding small amounts of nitrogen. Addition of trace elements and potassium were found to be unnecessary in most of the vermicompost mixtures. The same trend was found in the germination of tomatoes and peppers grown in vermicompost mixed with a commercial peat/sand planting medium. Chan and Griffiths (1988) reported stimulating effects of pig manure vermicomposts on the growth of *Glycine max* (soybean) particularly in terms of increased root lengths, lateral root numbers, shoot lengths, and internode lengths of seedling plants. Another rooting experiment using vermicomposts showed that the establishment of *Vanilla planifolia* cuttings was better than in other planting media used such as coir pith and sand (Siddagangaiah et al., 1996). Similar responses were observed from clove (*Syzygium aromaticum*) and black pepper (*Piper nigrum*) sown in 1:1 vermicompost and soil media (Thankamani et al, 1996). Black pepper cuttings raised in vermicomposts were significantly taller and had more leaves than those grown in commercial potting mixtures. Plant height, number of branches, and longest taproots occurred on cloves planted into the vermicompost mixture. *Cardamom* was investigated for its response to vermicomposts produced from forest litter. Vadiraj et al (1993) showed enhanced growth and dry matter yield of cardamom seedlings indicating the superiority of vermicomposted forest litter over other growth media tested such as soilrite, sand, coir dust and spagnum moss. Vermicompost produced from coir dust also increased the yield of onions, *Allium cepa* (Thanunathan, 1997). In pot cultures with rice, treatment with 1/3 of N from vermicomposts from animal manure, significant increased numbers of effective panicles, plant height, and grain yield was observed (Rani and Srivastava, 1997).

In contrast with the experiments done in the greenhouse, investigations into effects of vermicompost applications in the field are few. However, most of the available field experiments provided positive effects of vermicompost that confirmed findings in the greenhouse. When cabbage which was usually grown in compressed blocks made from a commercial medium was grown in blocks from pig waste vermicompost, they were larger and more mature at harvest compared to those grown in commercial blocking material (Edwards and Burrows, 1988). In a field experiment applying cassava peel mixed with guava leaves and vermicomposts from poultry droppings, Mba (1983) reported greater shoot biomass and seed yield of cowpea. Masciandro et al (1997), investigated the effects of the direct applications of vermicompost from sewage sludge into the soil as well ferti-irrigation of humic extracts from vermicomposts. Using *Lepidium sativum* to test the capacity of these treatments to stimulate germination, he reported that the growth index was higher than in the control treatments with direct vermicompost applications showing the highest growth index. Soil analyses after vermicompost applications showed marked improvements in the physical and biochemical properties of the soil. A surface application of vermicompost derived from grape marc, spread undervine and covered with a straw and paper mulch increased yield of a grape variety Pinot Noir by 55%, (Buckerfield and Webster, 1998). The increases in yields were constituted by large increases in both bunch-weights and bunch numbers. In the same experiment at a second site, vermicompost applications from animal manures, under a straw mulch, increased Chardonnay grape yields up to 35%. In his experiment, vermicompost applications tended to have more pronounced effects when applied with mulch that those that were applied directly to the surface of the plantation. A similar trend was reported by Venkatesh et al (1999) where yields of Thompson Seedless grapes were significantly greater when the vermicomposts was applied compared to all other treatments. In another experiment by Vadiraj et al (1998), vermicomposts were applied at rates of 5 T/ha up to 25 T/ha with 5 T/ha increments. Three coriander varieties were grown – Rcr-41, Bulgarian, and Sakalespur Local. The extent of responses to vermicompost applications differed with all three varieties tested. However, he reported RCr-41 have the highest herbage yields among the three. Maximum herbage yields in all three varieties were obtained 60 days after sowing. RCr-41, Bulgarian, and Sakalespur Local reached maximum yields at 15T/ha, 10-25T/ha, and 20T/ha vermicompost applications, respectively.

The overall effects of vermicomposts on soil and crops reported to date overwhelmingly favor their use in crop production on a large scale. However, their acceptance as a soil amendment or organic fertilizer has received a considerable degree of skepticism because vermicompost applications have not been studied extensively under large-scale field conditions and in a wide variety of soil types and climatic conditions. My projects were aimed to investigate the effects of vermicomposts produced from cattle manure, paper waste and food waste in promoting the growth and increasing yields of bell pepper, tomatoes and strawberries. They also aim to validate the earlier trials of vermicomposts in the greenhouse and investigate their performance on crops in the field. It will also investigate the appropriate application methods and rates with which crop growth and yield can be optimized. The study also further investigates the correlations of vermicomposts' effect with soil fertility and crop productivity. Many excellent chemical, biological and physical properties of vermicomposts have been reported and the main goal of this project to investigate if crop growth and yields are increased independently or synergistically by these qualities and possibly others such as disease suppression and plant-growth-regulators.

Positive results of this research will go a long way to reinforcing movement towards minimizing the use and avoid the negative consequences of the application of fossil fuel-based inorganic fertilizers, possibly cut down crop production cost and promote vermicomposting as a major way of recycling of organic wastes.

CHAPTER 2

INFLUENCES OF VERMICOMPOST APPLICATIONS ON THE GROWTH AND YIELD OF HIGH-TUNNEL STRAWBERRIES

2.1 INRODUCTION

The use of organic amendments, such as traditional composts, in farming practices has long been recognized as an effective means of improving soil structure, enhancing soil fertility (Follet 1981), increasing microbial populations (Barakan et al, 1995) and activity (Zink and Allen 1998; Pascual 1997), and improving the moisture-holding capacity of the soil. These effects have been associated with the capability of composts to suppress soil-borne plant diseases (Hoitink and Fahy 1986; D'Errico and Di Maio, 1980) and thereby increase crop yields (Bwamiki 1998; Johnston et al 1995; Maynard 1993). The use of vermicomposts has emerged in recent years as another form of organic amendments that have considerable potential in crop production.

Vermicomposts are finely divided peat-like materials with high porosity, aeration, drainage, and water-holding capacity, stabilized by the interactions between earthworms and microorganisms (Edwards and Burrows, 1988). Vermicomposts contain nutrients in forms such as nitrates, exchangeable calcium, phosphorus, and soluble potassium that are readily taken up by plants (Orozco et al., 1996). Vermicomposts have large surface areas that provide many microsites for microbial decomposing organisms and for the strong retention of nutrients (Shi-wei and Fuzhen, 1991). Additionally, vermicomposts have been reported to have outstanding biological properties. They are rich in fungi, bacteria and actinomycetes (Edwards, 1983; Tomati et al., 1987; Werner and Cuevas, 1996). Populations and diversity of these microorganisms in vermicomposts are significantly greater compared with those in conventional thermophilic composts (Nair et al., 1997). The considerable improvements in plant growth recorded after amending soils with vermicomposts have always been attributed to their physio-chemical and biological properties. However, there is now a considerable degree of evidence that other biological factors are involved which cause plants to germinate and grow better. For instance, substitution of soil-less potting mixtures with equal amounts of vermicomposts, to grow bedding plants, tomatoes and peppers in greenhouse trials, has resulted in increases of growth of these plants even at low substitution rates, when of all necessary nutrients are supplied (Atiyeh et al, 2000). Vermicomposts have been shown to contain plant growth-influencing substances such as phytohormones (Tomati et al., 1988, 1990; Grappelli et al., 1987). Krishnamoorthy and Vajranabhaiah (1986) also reported the production of plant growth regulators such as cytokinins and auxins in organic wastes that were processed by earthworms. Vermicomposts have also been found to contain large amounts of humic substances (Albanell et al., Senesi et al., 1992; Masciandaro et al., 1997) and the effects of these substances on plant growth have been shown to be very similar to the effects of soil-applied growth hormones (Musculo et al., 1999; Dell' Agnola and Nardi, 1987). Furthermore, increases in microbial populations can stimulate two mechanisms of disease suppression – fungistasis and competition (Toyota et al., 1995). Applications of vermicomposts have been reported to suppress *Phytophthora, Fusarium, Plasmodiophora* in tomatoes and cabbage (Szczech et al., 1993), Meloidgyne in lettuce (Ribiero, 1998), *Pythium* and *Rhizoctonia* in cucumber and radish (Brickner and Chaoui, 2000).

Kale et al. (1992) reported enhancement of *mycorrhizal* colonization in rice paddies after the application of farmyard manure-based vermicomposts. Masciandaro *et al.* (1997) reported a higher plant growth index and improved soil properties after the application of humic extracts and vermicomposts from sewage sludge. In grape growth trials, vermicomposts produced from animal wastes, applied to plots and mulched with straw, increased grape yields by up to 56% (Buckerfield and Webster, 1998). Venkatesh *et al.* (1998) reported a similar trend using grapes as test crop. Most of research on use of vermicomposts has been in the greenhouse, but although a few field trials such as those quoted earlier have reported positive results, we decided to explore the full potentials of vermicomposts as soil amendments in terms of application methods and rates for field-grown fruit and vegetables crops such as strawberries.

The main objectives of the work reported in this Chapter are to assess the effects of the application of different rates and placements of vermicomposts on the growth and yields of strawberries grown in the field and to determine their effects on the soil chemical and biological changes that occur throughout the growth cycle of the strawberries.

2.2 MATERIALS AND METHODS

The field research was located at two sites: Site A was located at the Piketon Research and Extension Center, Piketon, Ohio and Site B at the Ohio Agricultural Research and Development Council (OARDC) Fruit and Vegetable Research Center in

Fremont, Ohio. Brief descriptions of the experimental sites from the soil survey of each county by the USDA-Soil Conservation Service and local weather stations of the Sites follow:

Site A : Piketon, Ohio.

Piketon belongs to Pike County which is located in south-central part of Ohio, latitude: 39° 04' N, longitude: 83° 00' W and elevation: 176 meters. Pike County is cold in winter and quite hot in summer. In winter the average temperature is 0 ^{0}C, and the average daily minimum temperature is –5 ^{0}C. In summer the average temperature is 22 ^{0}C and the average daily maximum temperature is 28 ^{0}C.

The bedrock of Pike County is on a deeply dissected part of the old Appalachian Plateau. The bedrock is sedimentary rock where the exposed strata consist of rocks of four geologic systems: Silurian, Denovian, Mississippi, and Pennsylvanian Systems. The experimental soil has been designated in the soil survey as DoA – Doles silt loam, 0 to 3 percent slopes. It is a deep, nearly level and somewhat poorly drained soil. Typically, the soil surface is brown, friable silt loam about 8 inches. The subsoil is about 18.5 m thick.

Site B: OARDC Vegetable Research Branch at Fremont, Ohio.

The OARDC Vegetable Research Branch is located in Fremont, Sandusky County in north-central part of Ohio: latitude: 41° 21' N, longitude: 83° 07' W and elevation: 193.9 meters. Sandusky is cold and snowy in winter and warm in summer. Precipitation is well distributed during the year and generally adequate for most crops. In winter the average temperature is -2 ^{0}C and the average daily minimum temperature is -7 ^{0}C. In summer the average temperature is 21 ^{0}C and the average daily maximum temperature is

27 ^{0}C. During the experiment, the average upper temperature was 13 ^{0}C and the average lower temperature was 0.2 ^{0}C. The total average annual precipitation is 6.2 meters.

Sandusky County is mainly in the broad plain section of the Central Lowlands Province. The soils formed mainly in glacial till or lacustrine sediments. They commonly have a clayey subsoil. The experimental site is a Hoytville silty clay loam soil. It is characterized as nearly level, very poorly drained, moderately fine textured, high organic matter content, moderate available water capacity and slow or ponded runoff.

Field lay-out and design

Raised soil beds were constructed, measuring 1.5 x 3 m (4.5 sq.m. per plot). Commercially produced food waste and paper waste 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 at two dosage rates: equivalent to 5 t/ha and 10 t/ha. All vermicompost-treated plots were supplemented with appropriate amounts of inorganic fertilizer to equalize the total recommended full rate of nitrogen, phosphorus, and potassium (NPK) at 85-155-125 kg/ha. Vermicomposts and inorganic fertilizers were applied and incorporated into the top 10 cm of the whole bed.

Plastic mulch and drip irrigation systems were set-up over the raised beds after vermicompost and fertilizer applications. Mini-sprinklers were used in addition to cotton mesh row covers for frost protection. On September 10, 1999, six-week old strawberry seedlings var. ‘Chandler’ were transplanted. 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 tunnel hoop house structures measuring 9.14 x 14.6 x 3.6 m. They were unheated and ventilated by rolling up the sides on bright sunny days.

Data Collected

Plant samples

Three whole plant samples, selected randomly, were harvested for assessment of leaf area, number of floral buds, number of suckers and fresh and dry shoot weights 110 days after transplanting in Sites A and 150 days after transplanting in Site B. A second set of samples were taken at the end of fruit harvesting – 220 and 200 DAT (days after transplanting) from Sites A and B, respectively. All leaves were taken off the plants and passed through LI300 leaf area measuring machine. Leaves and stems were weighed for shoot fresh weights, placed in paper bags and dried at 60 °C for 92 hours and weighed for shoot dry weights. All ripe fruits were harvested, graded and weighed into marketable and non-marketable yields. Fruits were classified non-marketable when signs of decay and malformations were present on the surface. The proportions of non-marketable fruits were determined by calculating their percentage from the total fruits harvested. Non-marketable fruits were not assessed for diseases.

Soil samples

Eight 2.5 cm diameter x 20 cm deep soil samples were taken at random from the rhizospheres in each plot. Four sets of samples were taken from Site A: at transplanting, 110 days, 160 days and 220 after transplanting/end of harvesting) and three times in Site B: at transplanting, 150 days 200 days after transplanting/end of harvesting.

Extractable nitrogen (NO3-N and NH_4-N) was determined using a modified indophenol blue technique (Sims et al., 1995). Soluble phosphorus was assessed using NH_4-HCl reagent. Color in the sample filtrates was developed with stannous chloride and ammonium paramolybdate and absorbance was measured using Bio-Tek EL211sx automated microplate reader. A more complete nutrient analysis was done on vermicompost samples 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 by in vermicomposts by dry combustion using Carlo-Erba apparatus.

Microbial biomass 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 EL211sx automated microplate reader. 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.

Disease and nematode sampling

Nematodes were extracted from 20-gram soil samples in sieves held in water in glass Baermann filters/funnel for 48 hours (MacSorley and Welter, 1991). Nematodes were identified to trophic levels (bacterivores, fungivores, plant-parasites and omnivores/carnivores) under a stereo microscope (Edwards and Bohlen, 1991). Diseases were monitored by scouting plots and the severity of infection was rated in terms the proportion of the number of seedlings that showed leaf symptoms to the total seedlings planted.

The means of parameters were grouped for comparisons and differences were separated by orthogonal contrasts using SAS (SAS Ins., 1990).

2.3 RESULTS AND DISCUSSIONS

The results and discussions are divided into following subsections to:

2.3.1 Growth and yield effects of vermicompost applications

2.3.2 Changes in soil nitrogen chemical and biological properties after vermicompost applications

2.3.3 Nematode populations and disease suppression after vermicompost applications

2.3.1 RESULTS

Effects of vermicompost applications of growth and yield

Table 2.1 is a summary of the chemical composition of food waste and paper waste vermicomposts. Food waste vermicompost had larger amounts of C, N, Ca, Fe, K, Mn, P and S whereas paper waste vermicompost had greater amounts of B, Mg, Na and Zn than food waste.

Growth parameters

On Site A (Piketon, Ohio), the shoot weights in vermicompost-treated plots did not differ significantly from those in the inorganically-fertilized plots (control) 110 days after transplanting (Fig. 2.1). The means of the dry shoot weights in the food waste vermicompost- treated plots were significantly higher than those in the controls. All plants in the vermicompost–treated plots developed significantly more suckers and flowers than in the controls. Moreover, plants in food waste vermicompost-treated plots had significantly more flowers than those in the inorganic control plots. Two hundred twenty days after transplanting, the mean fresh shoot weights of strawberry plants in vermicompost-applied plots at harvest did not differ significantly from those in the control plots (Fig 2.2a). However, the food waste vermicomposts produced plants with significantly greater fresh shoot weights than those in control plots ($P < 0.05$) and paper waste vermicompost-treated plots ($P < 0.01$, Table 2). Dry shoot weights did not differ between plants in the control and vermicomposts-applied plots (Fig. 2.2b). Application of 10 t/ha of food waste vermicompost produced plants with significantly greater dry weights than the lower application rate of 5 t/ha (Table 2.2). Mean leaf areas of plants in the vermicompost-treated plots did not differ from those in the control plots (Fig. 2.2c). Plants in food waste-treated plots had significantly greater leaf areas than those in plots treated with paper waste vermicompost. The numbers of suckers in the vermicomposts-treated plots did not differ from those in the control plots (Fig. 2.2d). The higher application rates of food waste vermicomposts (10 t/ha) produced plants with more suckers than those treated with 5 t/ha. Overall, the higher rate of vermicompost applications (10t/ha) produced plants with more suckers to the lower rate (5 t/ha) of vermicompost applications.

On Site B (Fremont, Ohio), all growth parameters – i.e. fresh shoot weights, dry shoot weights, leaf areas and number of flowers were significantly greater in plants in the vermicompost-applied plots than those in the control plots, 120 days after transplanting (Fig. 2.4). Food waste, applied at 5 t/ha, produced greater fresh shoot weights than 10 t/ha. At harvesting, a similar trend was observed in all growth parameters measured, except for the leaf areas where no significant difference was recorded between plants in the vermicompost-treated plots than the inorganic control plots (Fig. 2.5). Plants treated with both rates of food wastes did not differ statistically in all growth parameters. Greater dry shoot weights recorded in response to food waste vermicompost applications than in paper waste vermicompost treatments (Table 3).

Yields

On Site A, the marketable yields of strawberries did not differ significantly between the vermicompost-treated plots and the inorganic control plots (Fig. 2.3a). However, the food waste vermicompost produced larger marketable yields compared to either in the inorganic control only treatment ($P < 0.05$) or the paper waste vermicompost treatments ($P < 0.05$ in Table 2.2). Similar trends occurred in relation to the numbers of fruits (Fig. 2.3b). Food waste vermicomposts additions produced more fruits than either the inorganic control fertilizer treatment ($P < 0.05$) and paper waste vermicompost ($P < 0.01$). More fruits were produced by amendments with 10 t/ha and 5 t/ha of vermicomposts than the inorganic fertilizer control treatments. No differences occurred between the weights of the largest fruit among the treatments (Fig 2.3c).

On Site B, greater yields of marketable fruits and higher weights of the largest fruit occurred in fruits from the vermicompost-treated plots than the inorganic fertilizer control plots (Fig. 2.6). No significant differences in yields occurred between the two different vermicompost application rates (Table 2.3) although the food waste vermicompost-treated plots produced higher yield than paper waste vermicompost-treated plots.

	C %	N %	B ug/g	Ca ug/g	Fe ug/g	K ug/g
Food Waste	19.51	1.30	23.30	18,613.81	23,263.58	9,203.18
Paper Waste	17.23	1.00	31.44	9,214.24	17,811.01	6,252.73

	Mg ug/g	Mn ug/g	Na ug/g	P ug/g	S ug/g	Zn ug/g
Food Waste	4,363.99	609.75	842.46	2,748.63	2,586.86	279.02
Paper Waste	4,510.89	605.43	986.23	2,700.72	83.94	2,219.36

Table 2.1: Summary of nutrient composition of food and paper waste vermicomposts.

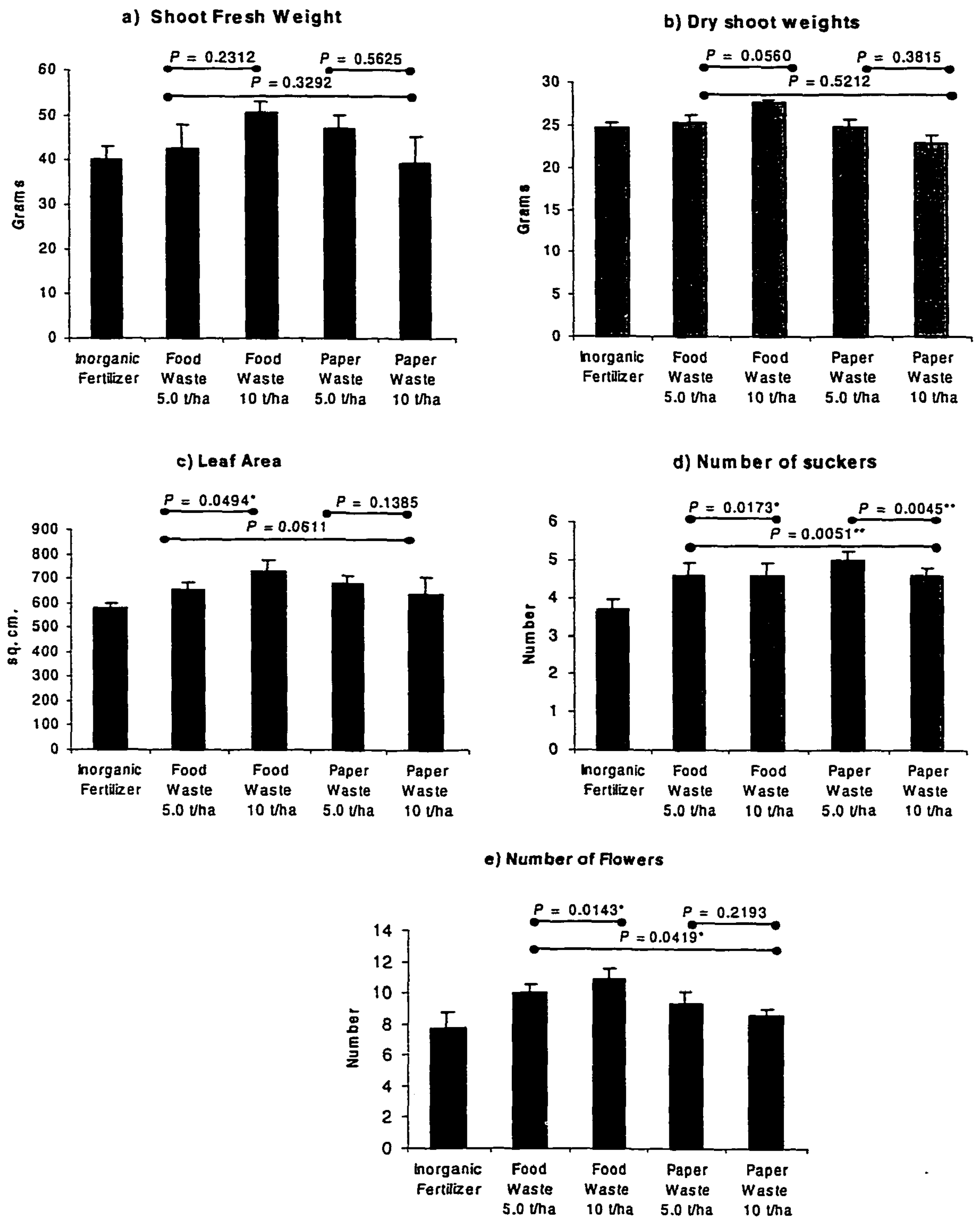


Figure 2.1: Growth parameters of strawberries at 110 days after transplanting in Site A: Piketon, OH. All *P* values refer to orthogonal contrasts between the grouped means of vermicompost treatments and inorganic fertilizer treatment.

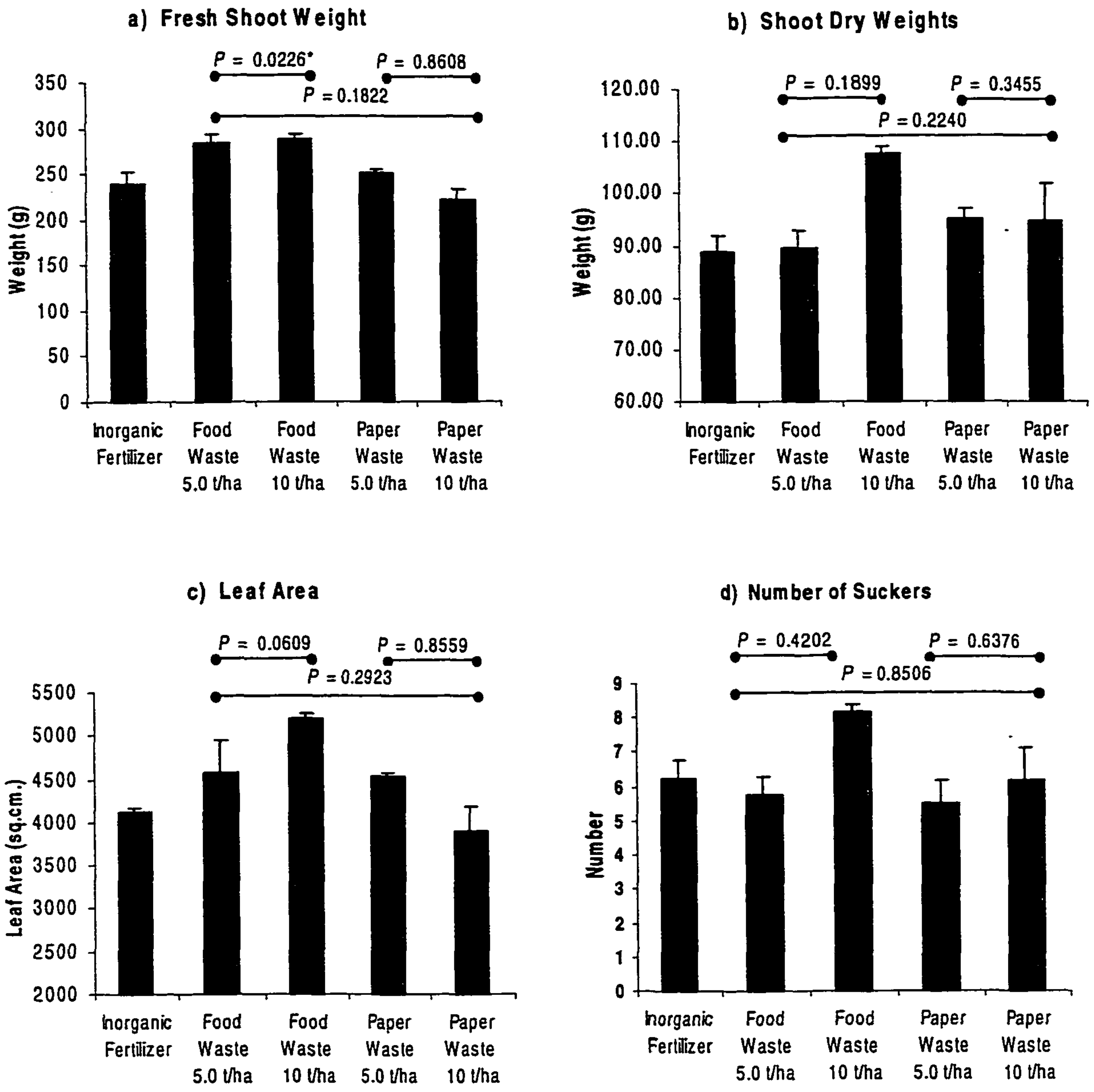


Figure 2.2: Growth parameters of strawberries at harvest (220 days after transplanting) in Site A: Piketon, OH. All *P* values refer to orthogonal contrasts between the grouped means of vermicompost treatments and inorganic fertilizer treatment.

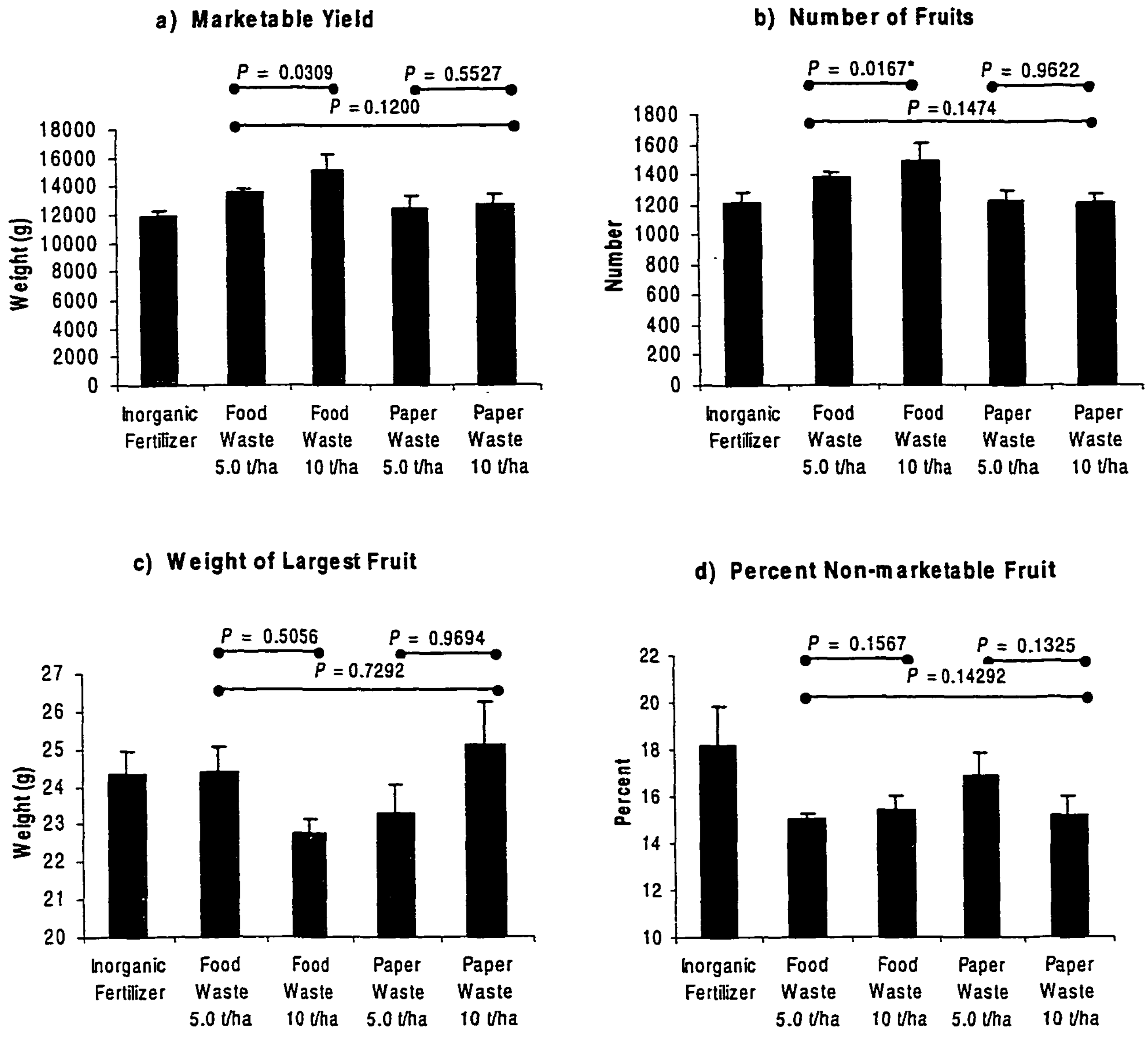


Figure 2.3: Yield and yield attributes of strawberries in Site A: Piketon, OH. All *P* values refer to orthogonal contrasts between the grouped means of vermicompost treatments and inorganic fertilizer treatment.

	P values under corresponding paired treatments			
	Food Waste v. Paper Waste	Food Waste (5 v 10 t/ha)	Paper Waste (5 v 10 t/ha)	5 t/ha v. 10 t/ha
110 DAT				
Dry shoot weight	0.0030 **	0.0433 *	0.0926	0.7655
Fresh shoot weight	0.4309	0.2125	0.2258	0.0856
Leaf Area	0.4781	0.2543	0.4930	0.7348
Number of Suckers	0.3903	1.0000	0.2814	0.4407
Number of Flowers	0.0792	0.4539	0.4989	0.9576
220 DAT				
Dry shoot weight	0.6379	0.0316 *	0.9820	0.0925
Fresh shoot weight	0.0053 **	0.8745	0.1658	0.3305
Leaf Area	0.0166 *	0.0742	0.0758	0.9228
Number of Suckers	0.1325	0.0300 *	0.5065	0.0461 *
Yield	0.0443 *	0.1827	0.8211	0.0499 *
Fruit Number	0.0058 **	0.2551	0.8676	0.0101 *
Largest Fruit Wt.	0.3918	0.0761	0.6794	0.3044
Number of Culls	0.5600	0.7915	0.1644	0.4087
Weight of Culls	0.4863	0.2855	0.4849	0.7836

Table 2.2: *P* values are from comparisons of growth parameters among vermicompost treatments of strawberries in Site A: Piketon, OH taken 110 and 220 days after transplanting (DAT). All *P* values refer to orthogonal contrasts between paired treatment means .

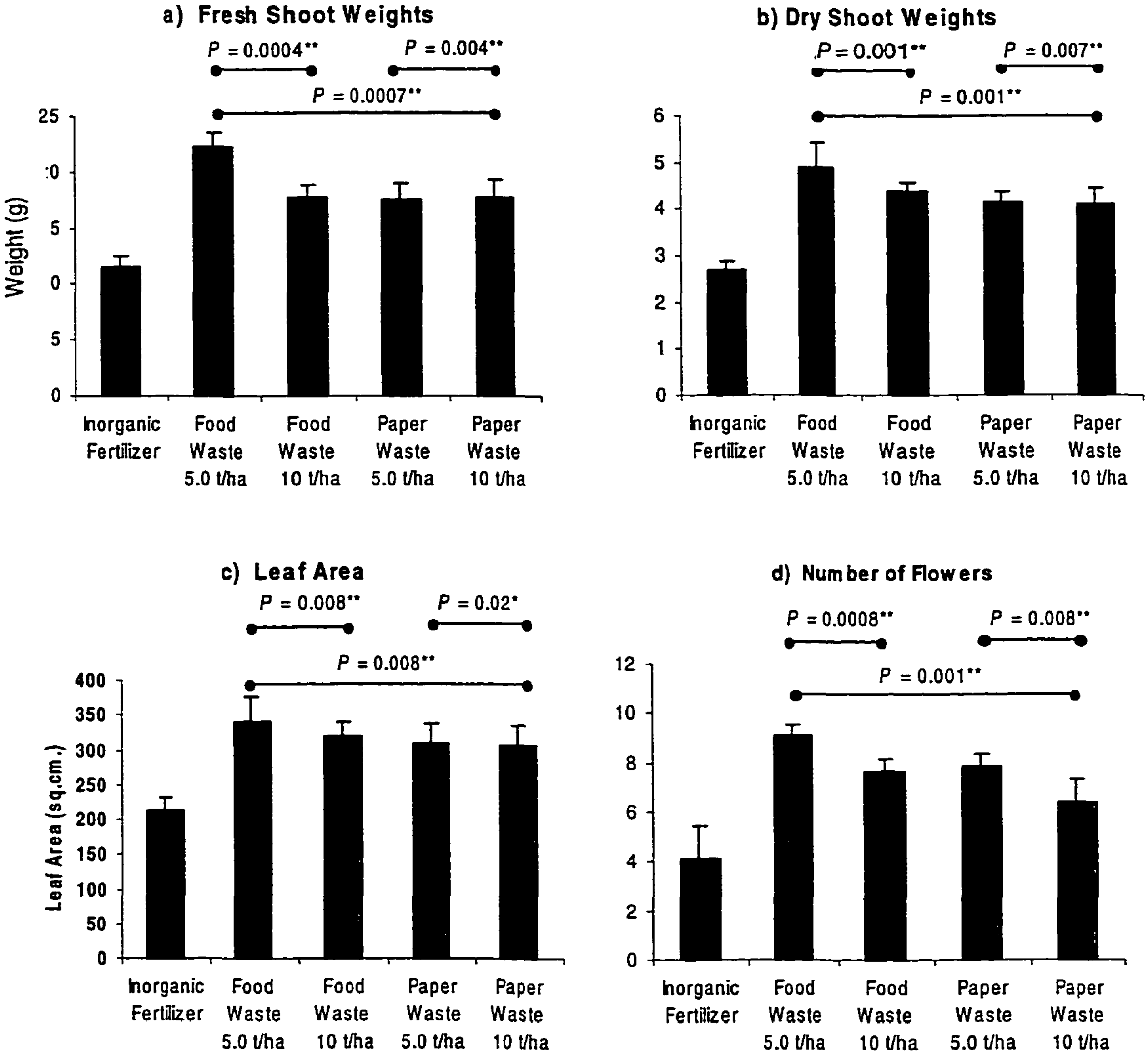


Figure 2.4: Growth parameters of strawberries 150 days after transplanting in Site B: Fremont, OH. All *P* values refer to orthogonal contrasts from grouped means of vermicompost treatments against inorganic fertilizer treatment.

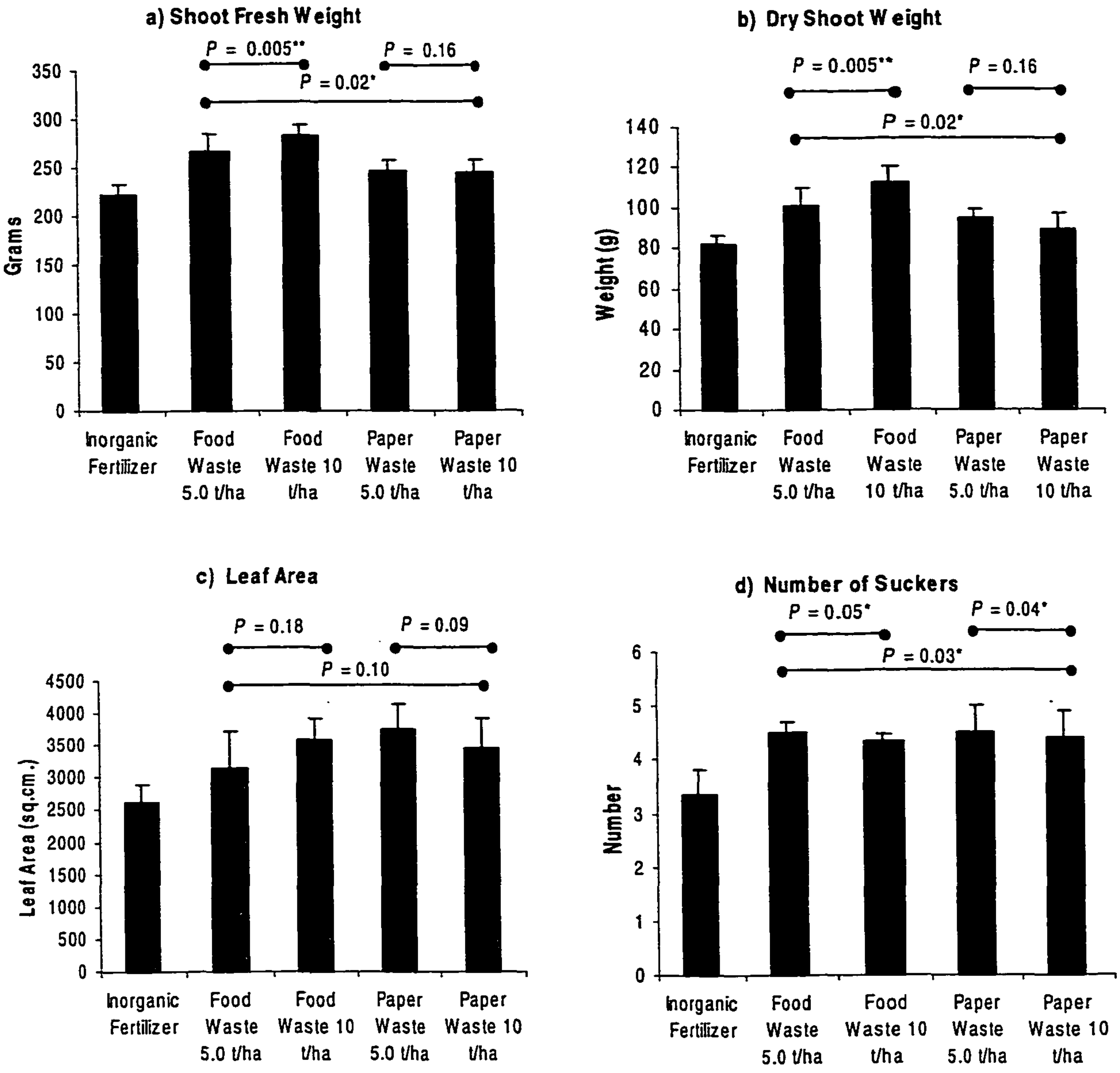


Figure 2.5: Growth parameters of strawberry 200 DAT (days after transplanting) in Site B: Fremont, Ohio. All *P* values refer to orthogonal contrasts from grouped means of vermicompost treatments against inorganic fertilizer treatment

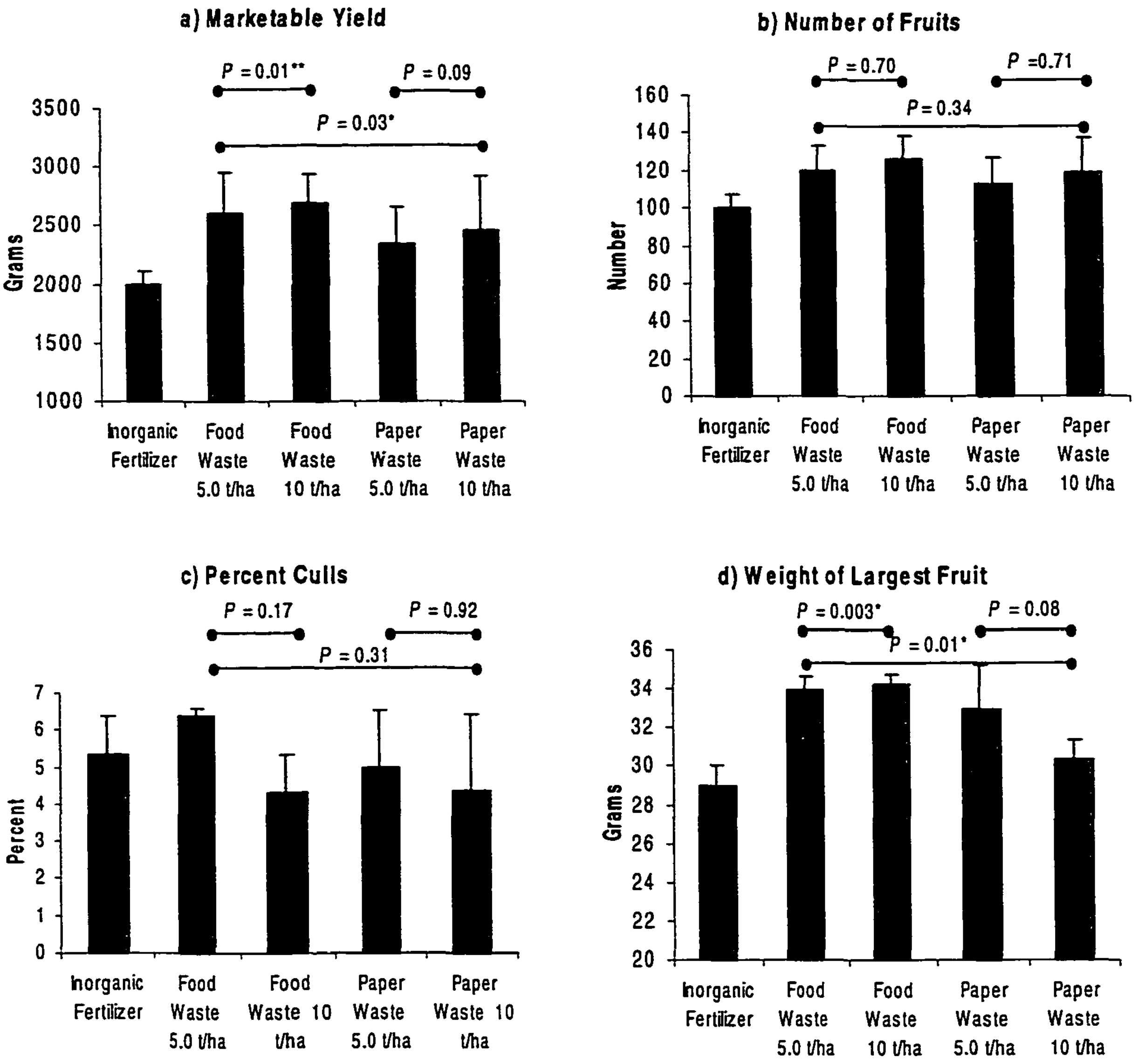


Figure 2.6: Yield and yield attributes of strawberry in Site B (Fremont, OH). All P values refer to orthogonal contrasts from grouped means of vermicompost treatments against inorganic fertilizer treatment

	***P* values of orthogonal contrast of paired treatments**			
	Food Waste v. Paper Waste	Food Waste (5 v 10 t/ha)	Paper Waste (5 v 10 t/ha)	5 t/ha v. 10 t/ha
150 DAT				
Fresh shoot weights	0.1191	0.0403 *	0.9681	0.1364
Dry shoot weights	0.1795	0.3112	0.9460	0.4412
Leaf Area	0.4690	0.6648	0.9697	0.7386
Number of flowers	0.1325	0.1952	0.1952	0.0762
200 DAT				
Fresh Shoot Weight	0.0363	0.3928	0.8767	0.6161
Dry Shoot Weight	0.0362 *	0.2289	0.5718	0.6360
Leaf Area	0.6195	0.5005	0.6218	0.8963
Number of suckers	0.9187	0.7765	0.8887	0.7645
YIELD				
Marketable fruits	0.2339	0.7791	0.7793	0.9822
Largest Fruit Weight	0.06535	0.8462	0.1375	0.3440
Total Fruit Number	0.5765	0.7073	0.7176	0.6032
Percent Culls (by wt.)	0.3545	0.1715	0.9252	0.3558

Table 2.3: *P* values from comparisons of growth parameters and yield among vermicompost treatments in strawberries. All values refer to orthogonal contrast between paired treatment means.

2.4.1 DISCUSSION

Effects of vermicompost applications on growth and yield

Increases in rates of strawberry growth in Site A were evident early in the strawberry growth cycle (110 days after transplanting) in the vermicompost-treated plots compared with inorganic controls. These growth increases carried over until harvesting (220 days after transplanting). There were significant differences in leaf areas, numbers of suckers and numbers of flowers between plants in vermicompost-treated plots and inorganic control plots. Generally, the food waste vermicompost influenced overall growth significantly more than the inorganic fertilizer control and the paper waste vermicompost treatments. In Site B, pronounced increases in vegetative growth, over the inorganic controls, in response to vermicompost treatments became evident at the earlier strawberry growth stages. Increases in fresh and dry shoot weights, leaf areas and number of flowers were all significantly greater in both of the vermicomposts-treated plots than in the inorganic controls. These growth increases carried over to the end of the strawberry reproductive growth pattern. Increases in growth during the earlier part of the growth cycle in response to vermicomposts allowed the strawberries to develop better vegetative growth that provided more support to the reproductive growth stage of the strawberries. It has been reported that vermicompost applications favored seedling emergence in pea, lettuce, cabbage, wheat, tomato and radish in the greenhouse (Edwards and Burrows, 1988). Similar effects on seedling growth were reported in ornamentals (Atiyeh, 2000; Scott, 1988; Buckerfield et al, 1999) and tree seedlings in nurseries (Handreck, 1997). Increases in growth in response to vermicomposts in the greehouse have been associated with increased root lengths, lateral root numbers, shoot lengths and distance between nodes of seedlings of soybeans (Chan and Griffiths, 1988) and better rooting in vanilla cuttings (Siddagangaiah et al, 1996). Increases in the growth of field crops have also been reported after vermicompost applications in terms of greater shoot biomass and seed yields of cowpea (Mba, 1983), increased berry yields in grapes (Buckerfield and Webster, 1998) and increased herbage yield of coriander (Venkatesh et al, 1999). The reported increases in strawberry yields were correlated positively with the number of crowns per unit area and early initiation of flowers.

A number of growth parameters have been correlated closely with strawberry yields, such as number of flowers, leaf areas, shoot biomass and number of suckers (Hancock, 1999; Goulart, 1984). The decreased strawberry plant growth in the inorganic controls could have been due to macronutrient deficiencies. Boron deficiency in strawberries has been reported to decrease viable pollen production, pollen germination and receptacle expansion (Guttridge and Turnbull, 1975). Zinc deficiency could result to strawberries having smaller leaves, fruits and reduced yields (Ulrich et al, 1980) and iron deficiencies could lead to reduced vigor and chlorotic leaves (Hancock, 1999). Any of these deficiencies could have caused the strawberry plants in the inorganic control plots to have decreased leaf areas and shoot biomass. In terms of yield parameters, the numbers of fruits and the weight of largest fruit were correlated positively with the marketable fruit yields. An inverse correlation was established between non-marketable and marketable fruit yields in both experiments. Yield reductions of strawberries in the inorganic control plots could have also been due to a combination of micronutrient deficiencies. Several researches have reported that vermicomposts contain more macro and micronutrients than are necessary for plant growth (Edwards and Burrows, 1988;

Orozco et al, 1996; Werner and Cuevas, 1997; and Businelli et al, 1984). Vermicompost applications could have provided better nutrition over that in the inorganic controls because of their micronutrient availability. Greater amounts of Ca, Fe, S, and Mn in the food waste vermicompost could have produced larger increases in growth and yields, than the paper waste vermicompost, even though paper waste vermicomposts contained greater amounts of B, Mg, Na and Zn. Nitrogen is one of the more critical nutrients for strawberries and at the later part of the reproductive growth excess N could cause the production of soft berries, excessive runner productions and lowers yields (Stadelbacker, 1963; Voth et al., 1967; May and Pritts, 1990). However, the availability of nitrogen and phosphorus in the vermicompost-treated plots, throughout the growth cycle of the strawberries, seemed to be maintained in adequate levels because strawberries did not exhibit any signs of excess symptoms.

It is likely that the high microbial populations in vermicompost may have influenced plant growth. Microorganisms have been shown to improve soil aggregation and thereby influence the root environment and plant growth indirectly. Polysaccharides have an important role in soil aggregate formation and stability and such polysaccharides can be microbial in origin (Chesire, 1977). It has been shown that microorganisms added to soil promote aggregate formation, and much of the improvement in soil texture in pastures, has been attributed to the binding effects of mychorrhizal hyphae (Oades, 1978). Microorganisms are also known to produce materials that can affect plant growth in other ways. One of the possible mechanisms is the production of substances acting as hormone analogues (Brown, 1972). According to Tomati et al. (1983), vermicomposts contain large amounts of plant hormones such as gibberellins, auxins, and cytokinins and research in our laboratory has supported this. Such biologically active substances were first reported by Tomati et al. (1983, 1987) and Indian worker Grappeli et al. (1987) tested vermicomposts as media for growing ornamental plants and mushrooms. They showed that the growth of Petunias, Begonias and Coleus treated with vermicompost extracts compared with that of plants treated with auxins, gibberellins, and cytokinins. The growth changes observed included stimulation of rooting, dwarfing, time of flowering, and lengthening of internodes. Tomati et al (1988) concluded that the promotion plant growth by vermicomposts was not merely due to nutrient transformations by earthworms. They concluded that the plant growth increases that occurred were too large to be explained purely on the basis of the nutrient content of vermicompost, but more likely were caused by organic compounds similar to plant growth hormones produced by microorganisms as metabolites during the vermicomposting process. The production of such substances could be made possible by the humus-like characteristics of vermicomposts produced by earthworm during shredding, digestion and mixing processes that enhanced microbial growth. Krishnamoorthy and Vajrabhaiah (1986) showed that seven field species of earthworms could promote the production of cytokinins and auxins in organic wastes. Hence, the growth differences due to vermicomposts used in my experiments could have due to production of hormone analogues from microorganism activity promoted by earthworms.

It was reported by Muscolo et al (1999) that humic materials extracted from vermicompost produced auxin-like cell growth and nitrate metabolism of *Daucus carota*. Their work showed that such humic substances could be obtained from the faeces of earthworms *Nicrodrilus caliginosus* and *Allolophora rosea* caused increases in carrot cell growth, determined by packed cell volumes, similar to those produced by 2,4-D, and the morphological changes that occurred were similar to those of IAA. In their experiments, the specific physiological processes that were stimulated to various extents by the humic extracts were glutamate dedyhrogenase (GDH), glutamine synthetase (GS), and malic dehydrogenase (MDH). Masciandaro (1997) reported positive growth response of plants to addition of humic material extracted from vermicomposts. These humic substances occur in large amounts in mature animal manure, sewage sludges or paper-mill sludges and are increased by vermicomposting. Several other studies on the growth effects of humic substance reported significant plant growth enhancements in response to their even under conditions of adequate nutrition (Lee and Barlett, 1976; Albuzio et al., 1994; Mylonas and Mccants, 1980; Tan and Tantiwiramanond, 1983; Valdighi et al., 1996; Goenadi and Sudharama, 1995). In an experiment in our laboratory by Atiyeh et al. (2000), definitive evidence of the positive effects of humic acids extracted from pig manure and food waste vermicomposts were shown. In their experiments, extracted from pig manure vermicompost humic acids applied to vegetable seedlings grown in a soil-less media increased the growth of tomato and cucumber plants significantly, and that the growth increases were correlated directly with the concentration of humic acids incorporated in the container medium, but growth decreased when concentrations exceeded 500-1000 mg/kg. They concluded that growth responses were due either to the ability of humic acids to produce hormone-like activities or because they have plant growth regulators adsorbed onto them and it is these that influence growth. Based on this, it seems likely that humic acids produced in the vermicomposts used in the experiment could also have increased the growth and yield of strawberries. However, it is still not clear whether the growth responses were due directly to humates or to plant growth-regulators adsorbed onto them.

2.3.2 RESULTS

The biochemical changes of the soil in response to vermicompost applications

On Site A, the amounts of extractable nitrogen (Fig. 2.7), ammonium-nitrogen (Fig. 2.8), and nitrate-nitrogen (Fig. 2.9) between vermicomposts-treated plots and the inorganic controls did not differ significantly on all sampling dates. However, there was a trend for increasing amounts of total extractable nitrogen to occur in soil from the food waste vermicompost-treated plots than in the paper waste vermicompost-treated plots and in the inorganic controls. A high variability in the amounts of ammonium-nitrate occurred 160 and 220 days after transplanting. Soils from plots treated with paper waste vermicompost at a rate of 5 t/ha contained most ammonium-nitrate after 160 days and food waste vermicompost applied at 5 t/ha had the highest ammonium-nitrate 220 days after transplanting.

Soil from the food waste vermicompost-treated plots (10 t/ha) had significantly more dissolved organic nitrogen at transplanting and 100 days after transplanting than those in the inorganic control (Fig. 2.10). However, there were no significant differences in amounts of dissolved organic nitrogen in the soils 160 and 220 days after transplanting although soils from the paper waste vermicompost-treated plots (5 t/ha) contained more dissolved organic nitrogen than the rest of the plots.

Soils from the vermicompost-treated plots contained significantly more orthophosphates than those from the inorganic control plots at transplanting, 110 and 220 days after transplanting (Fig. 2.11). Both types of vermicomposts applied at a higher rate (10 t/ha) had resulted in significantly more soil orthophosphates than in those applied with 5 t/ha at the later growth stage of strawberries (220 days after transplanting).

Dehydrogenase enzyme activity did not differ significantly in soils from any plots at transplanting. Soils from the food waste vermicompost-treated plots had significantly more dehydrogenase activity, 110 days after transplanting than the inorganic control (Fig. 2.12). This higher dehydrogenase activity was maintained in soils from the food waste vermicompost-treated plots for 160 and 220 days after transplanting. However, there were no significant differences between those sampling dates.

Amounts of microbial biomass-N in soils from vermicompost-treated plots were significantly higher at transplanting for both types of vermicomposts. Higher applications rate (10 t/ha) produced significantly greater soil microbial biomass than the lower rate (5 t/ha) (Fig. 2.13). No significant differences occurred in soil microbial biomass between treatments 110 and 160 days after transplanting. Soils from the food waste vermicompost-treated plots had significantly more microbial biomass-N than that from the inorganic controls 220 days after transplanting.

In Site B, there were no significant differences in amounts of total extractable soil nitrogen (Fig. 2.14), ammonium-nitrogen (Fig. 2.15), nitrate-nitrogen (Fig. 2.17) and dissolved organic nitrogen (Fig. 2.19) between either of the vermicompost-treated plots and the inorganic controls on all sampling dates.

Concentrations of orthophosphates were significantly greater in the vermicompost-treated plots than in the that from control plots only after 220 days from transplanting (Fig. 2.18).

Soils from the inorganic controls had significantly more dehydrogenase activity than the vermicompost-treated plots at transplanting (Fig. 2.19). No significant differences in soil dehydrogenase activity in any treatment occurred 150 and 200 days after transplanting although soils from inorganic controls had less dehydrogenase activity than the vermicompost-treated plots.

No significant differences in soil microbial biomass-N were recorded among plots on sampling dates (Fig 2.20). However, soils from the inorganic control plots had less microbial biomass than either of the vermicompost-treated plots 200 days after transplanting.

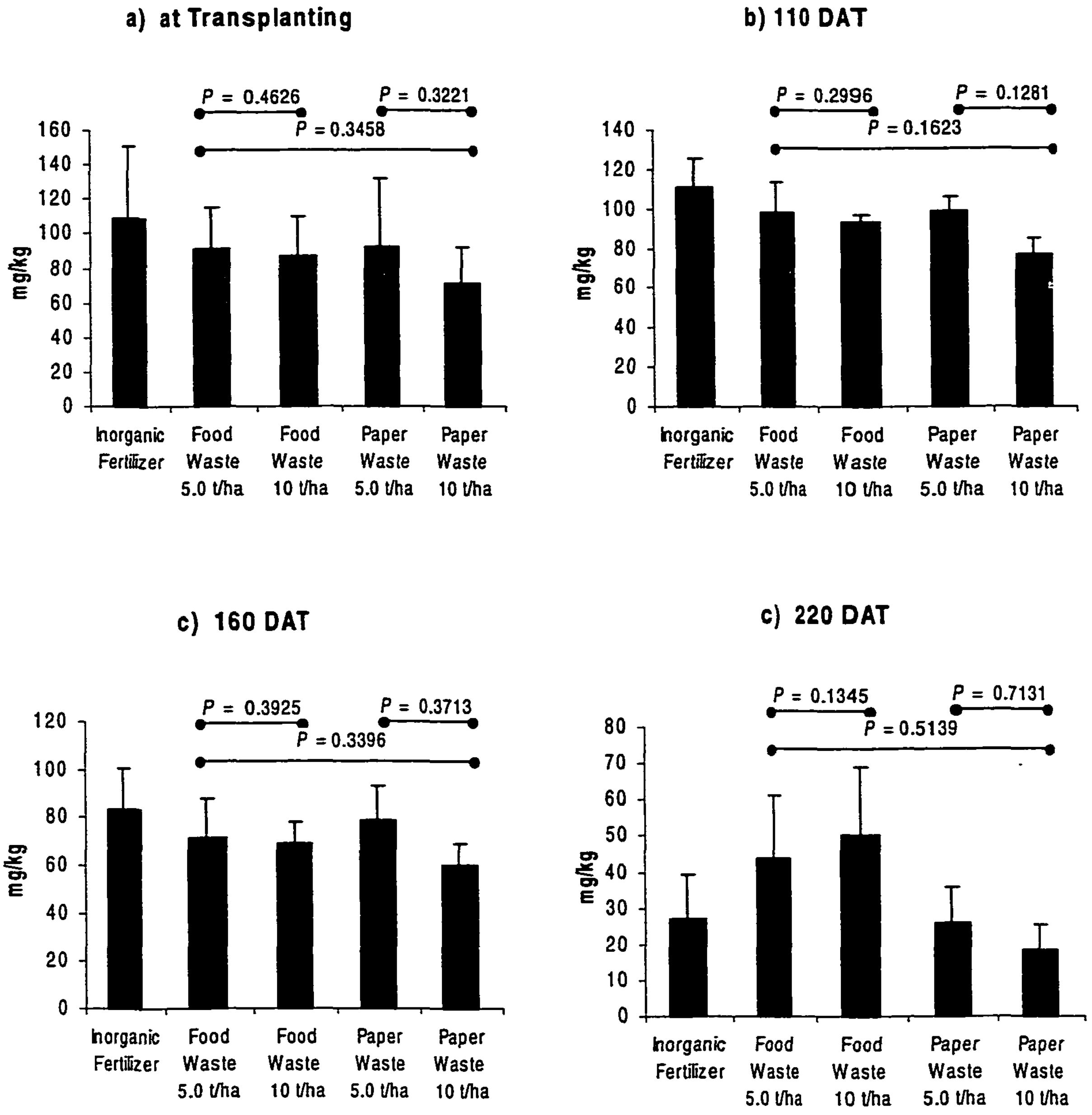


Figure 2.7: Total extractable nitrogen in strawberry plots in Site A (Piketon, OH) at four sampling dates: at transplanting, 110, 160 and 220 DAT (days after transplanting). Al *P* values refer to orthogonal contrasts from grouped means of vermicompost treatments against inorganic fertilizer treatment.

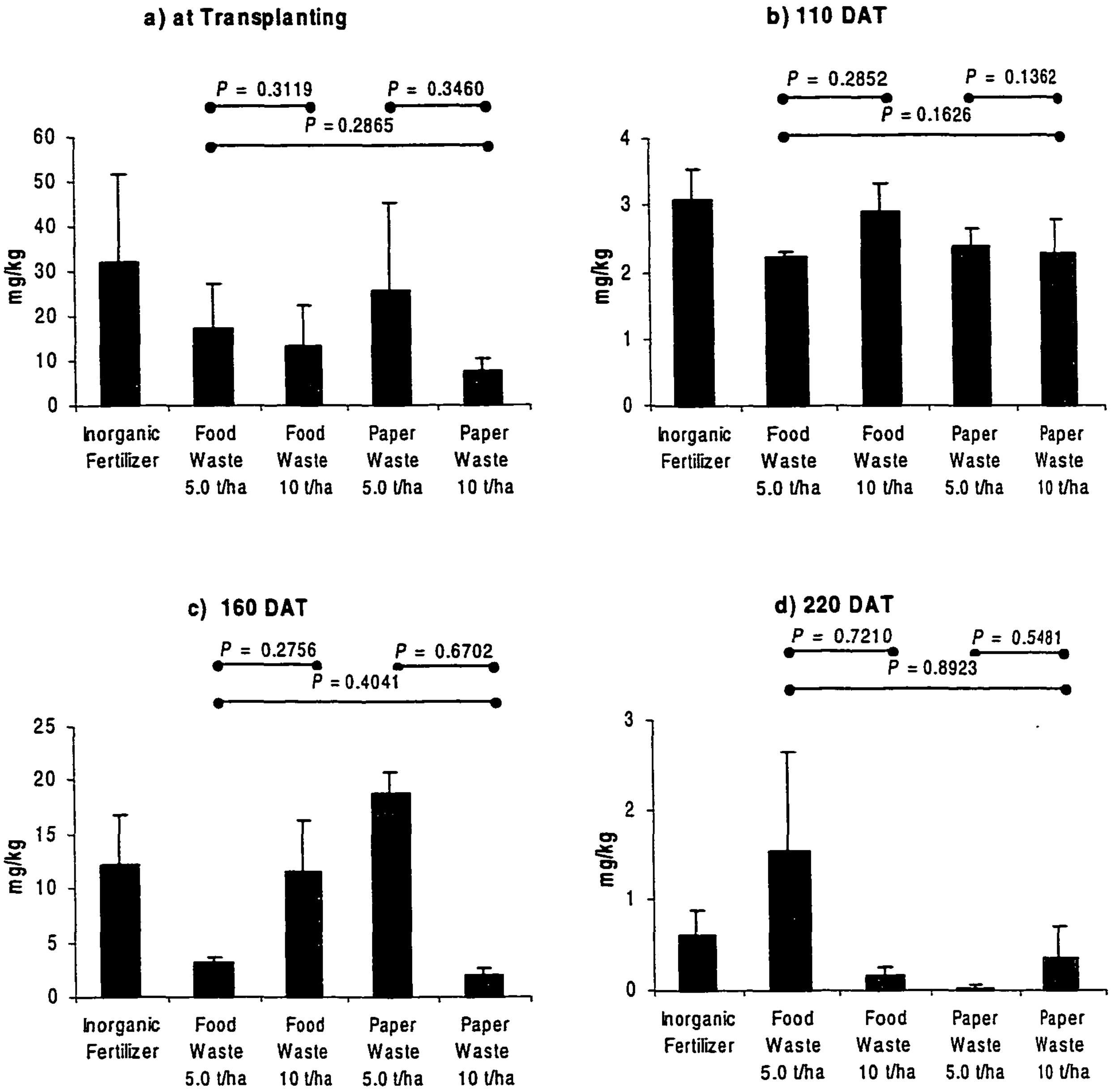
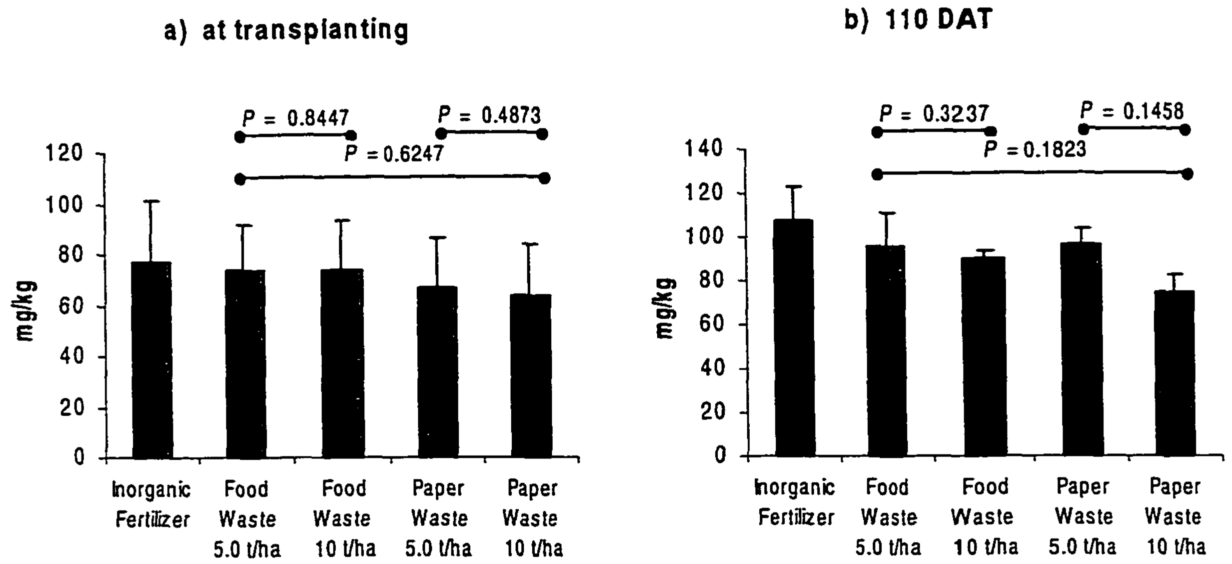
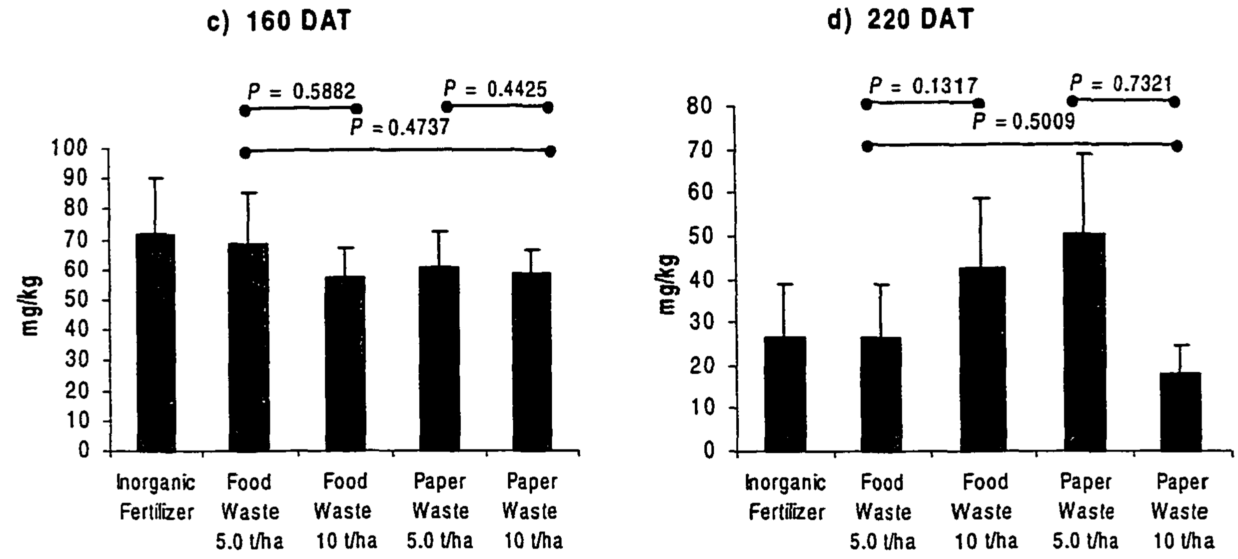


Figure 2.8: Ammonium-nitrogen (NH_4-N) in strawberry plots in Site A (Piketon, OH) at four sampling times: at transplanting, 110, 160, and 220 days after transplanting (DAT). All *P* values refer to orthogonal contrasts from grouped means of vermicompost treatments against inorganic fertilizer treatment.


a) at transplanting

b) 110 DAT


c) 160 DAT

d) 220 DAT

Figure 2.9: Nitrate-nitrogen (NO_3-N) in strawberry plots in Site A (Piketon, OH) at four sampling times: at transplanting, 110, 160, and 220 days after transplanting (DAT). All *P* values refer to orthogonal contrasts from grouped means of vermicompost treatments against inorganic fertilizer treatment.

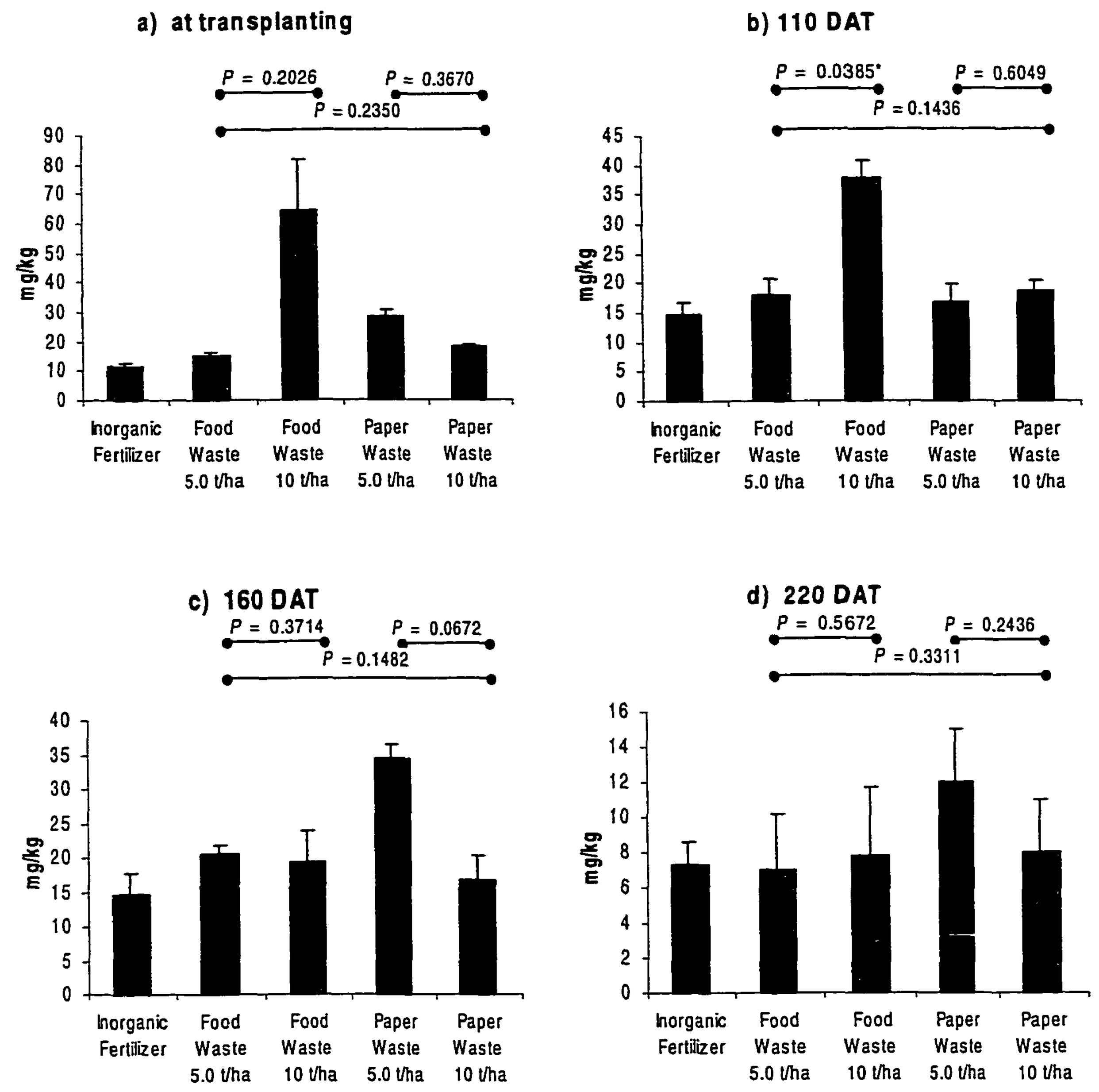


Figure 2.10: Dissolved organic nitrogen (DON) in strawberry plots in Site A (Piketon, OH) at four sampling dates: at transplanting, 110, 160 and 220 DAT (days after transplanting). All *P* values refer to orthogonal contrasts from grouped means of vermicompost treatments against inorganic fertilizer treatment.

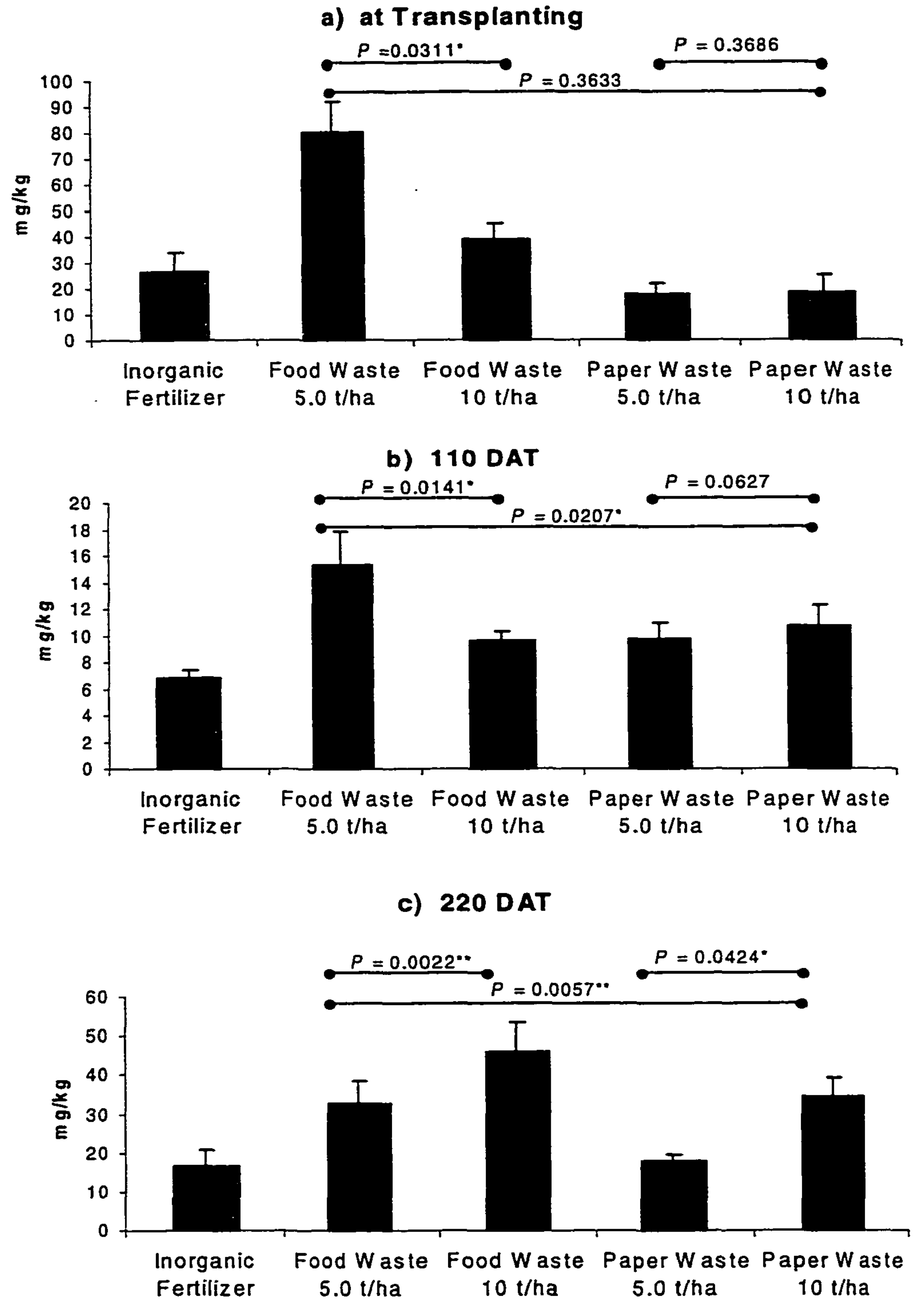


Figure 2.11: Orthophosphate in strawberry plots in Site A (Piketon, OH) at three sampling dates: at transplanting, 110 and 220 days after transplanting DAT (days after transplanting). All *P* values refer to orthogonal contrasts from grouped means of vermicompost treatments against inorganic fertilizer treatment.

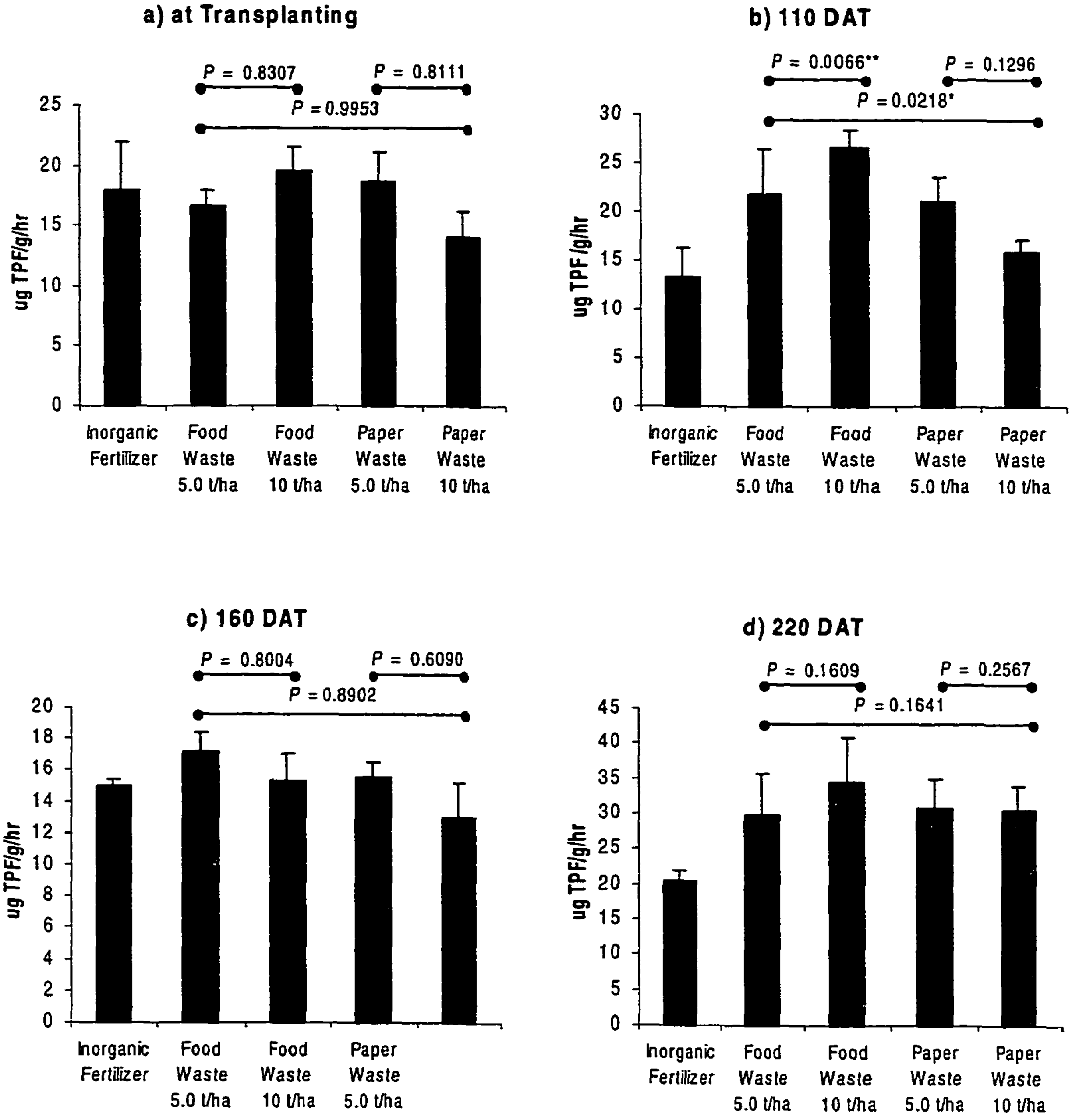


Figure 2.12: Dehydrogenase enzyme activity (DHA) in strawberry plots in Site A (Piketon, OH) at four sampling times: at transplanting, 110, 160, and 220 DAT (days after transplanting). All *P* values refer to orthogonal contrasts from grouped means of vermicompost treatments against inorganic fertilizer treatment.

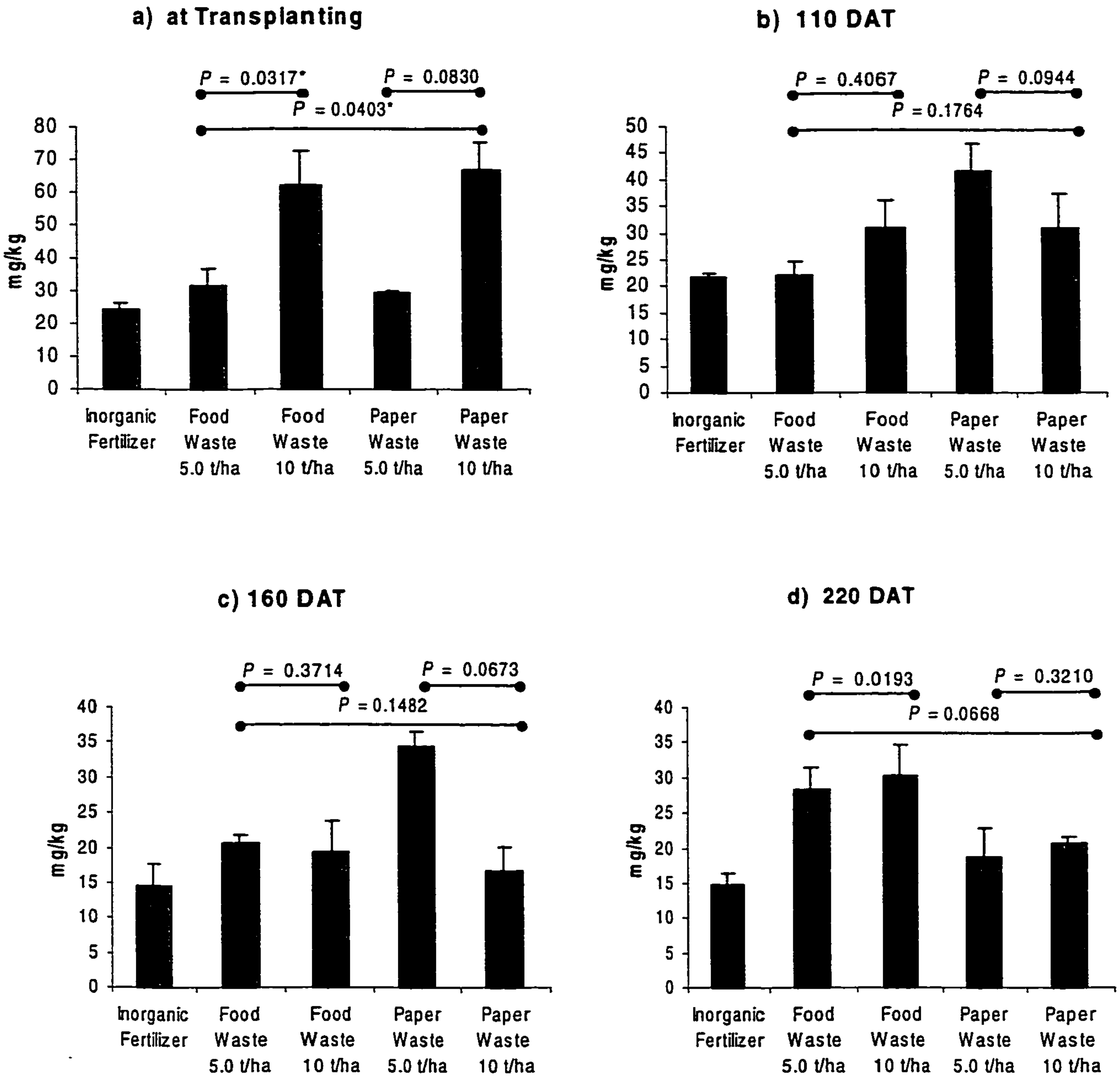


Figure 2.13: Microbial biomass-nitrogen in strawberry plots in Site A (Piketon, OH) at four sampling dates: at transplanting, 110, 160 and 220 DAT (days after transplanting). All *P* values refer to orthogonal contrasts from grouped means of vermicompost treatments against inorganic fertilizer treatment.

	***P* values of orthogonal contrast of paired treatments**			
	Food Waste v. Paper Waste	Food Waste (5 v 10 t/ha)	Paper Waste (5 v 10 t/ha)	5 t/ha v. 10 t/ha
Total Extractable N				
At Transplanting	0.7430	0.9102	0.5043	0.5804
110 DAT	0.5130	0.7893	0.1836	0.2566
160 DAT	0.9601	0.8827	0.3034	0.6272
220 DAT	0.0319 *	0.6656	0.6090	0.9546
NH4-Nitrogen				
At Transplanting	0.9284	0.8359	0.3449	0.4147
110 DAT	0.5685	0.2606	0.8255	0.5122
160 DAT	0.4043	0.1143	0.0052 **	0.0754
220 DAT	0.2515	0.0997	0.6811	0.8062
NO3-Nitrogen				
At Transplanting	0.5389	0.9833	0.8786	0.9257
110 DAT	0.5315	0.7622	0.1921	0.2546
160 DAT	0.7758	0.5445	0.9156	0.9596
220 DAT	0.0329 *	0.5927	0.5864	0.0433 *
Dissolved Organic N				
At Transplanting	0.5246	0.0219 *	0.4182	0.1039
110 DAT	0.0309 *	0.0103 *	0.6407	0.0187 *
160 DAT	0.0939	0.7763	0.0021 **	0.0108
220 DAT	0.1047	0.8144	0.9126	0.9386
Biomass N				
At Transplanting	0.3821	0.0356	0.5978	0.1000
110 DAT	0.1513	0.1877	0.2460	0.8551
160 DAT	0.5601	0.1285	0.3900	0.4426
220 DAT	0.0684	0.6897	0.5941	0.5085
Orthophosphate				
At Transplanting	0.0018 **	0.0271 *	0.0019 **	0.0670
160 DAT	0.2344	0.0590	0.0550	0.2726
220 DAT	0.0261 *	0.0491 *	0.0900	0.0096**
DHA				
At transplanting	0.5528	0.4797	0.2720	0.7794
110 DAT	0.0381 *	0.1919	0.1612	0.9385
150 DAT	0.2430	0.5369	0.2750	0.2408
220 DAT	0.7159	0.5262	0.8977	0.6217

Table 2.3: *P* values are from comparisons of soil nutrient parameters and DHA among vermicompost treatments in strawberries in Site A (Piketon, OH) at three sampling times: at transplanting, 110, 160 and 220 DAT (days after transplanting). All *P* values refer to orthogonal contrasts between paired treatment means.

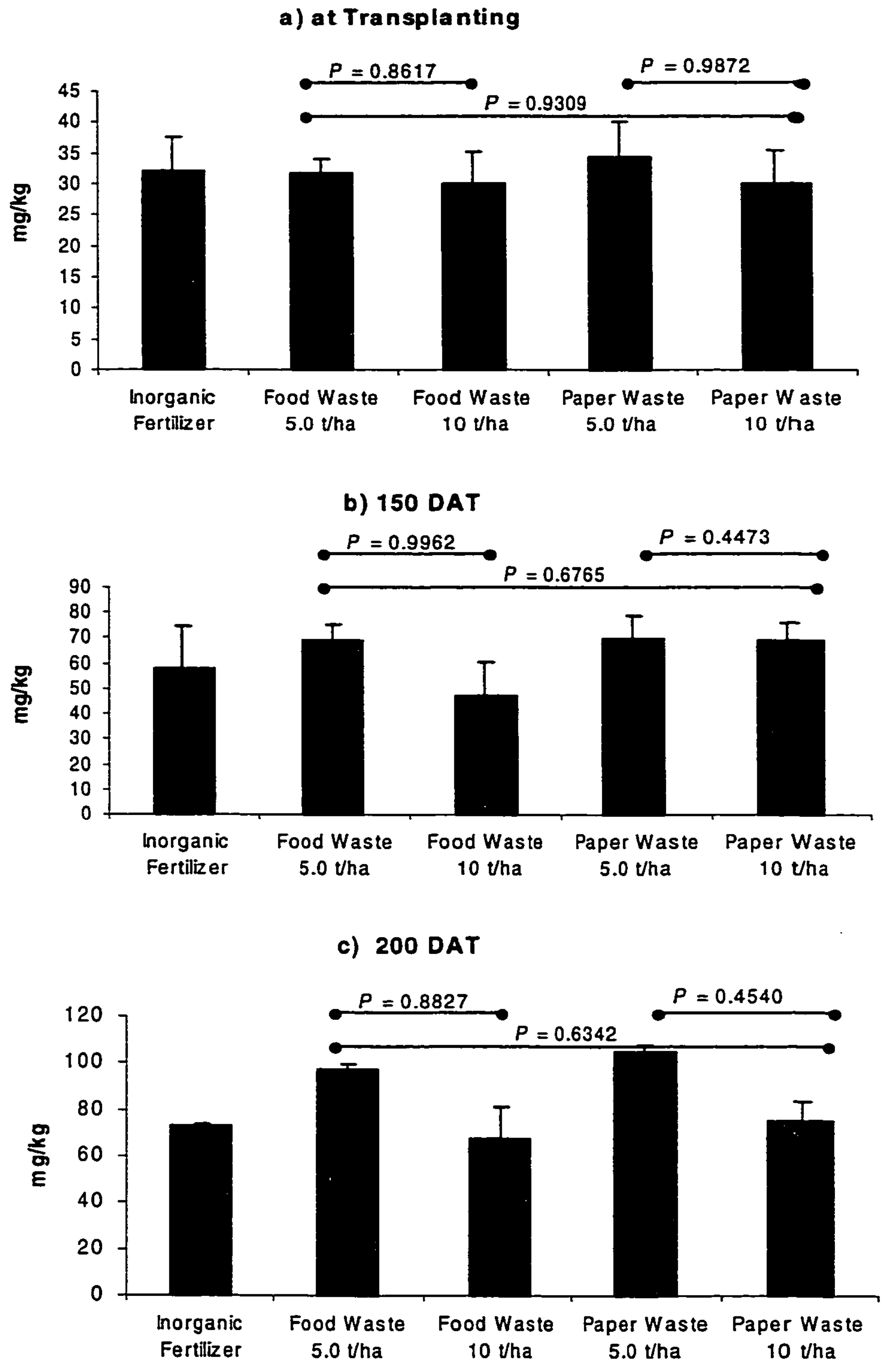
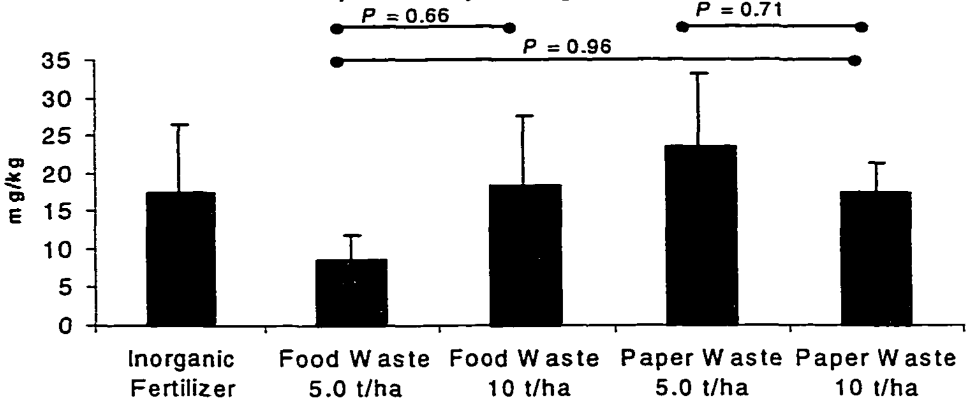
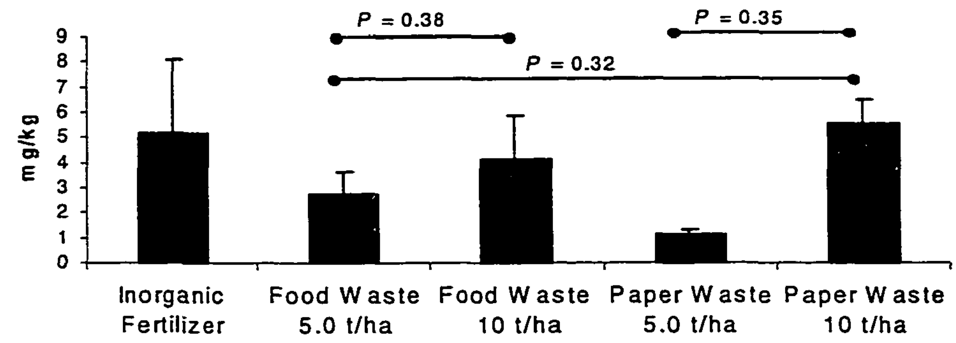


Figure 2.14: Total extractable nitrogen in strawberry plots at three sampling times: at transplanting 150 and 200 DAT (days after transplanting) in Site B (Fremont, OH). All *P* values refer to orthogonal contrasts from grouped means of vermicompost treatments against inorganic fertilizer treatment.

a) at Transplanting



b) 150 DAT



c) 200 DAT

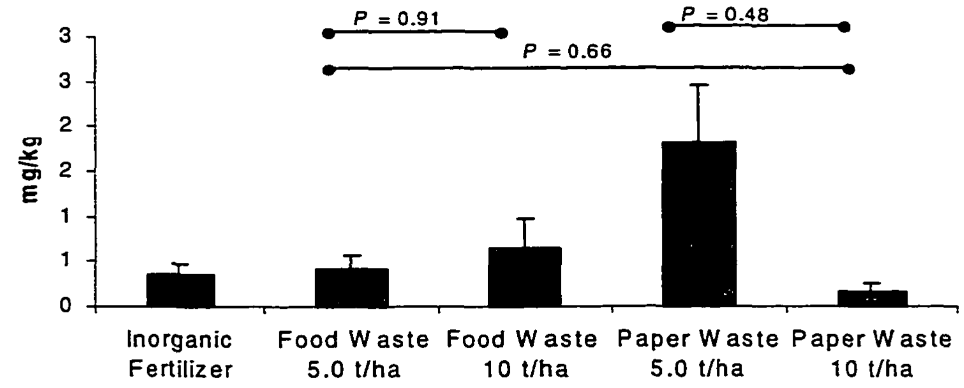


Figure 2.15: NH4-N in strawberry plots at transplanting, 150 and 200 DAT (days after transplanting) in Site B (Fremont, OH). All *P* values refer to orthogonal contrasts from grouped means of vermicompost treatments against inorganic fertilizer treatment.

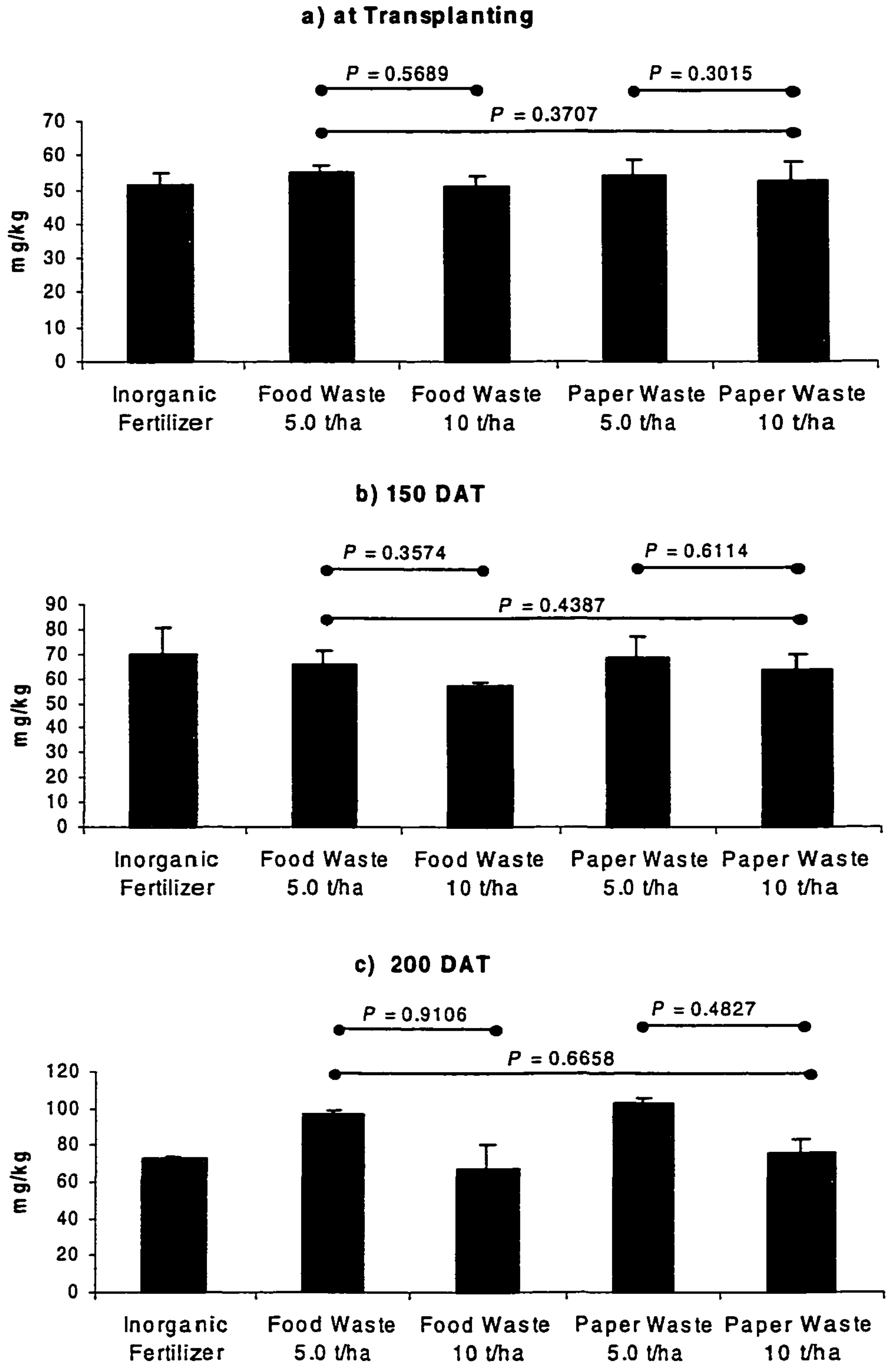
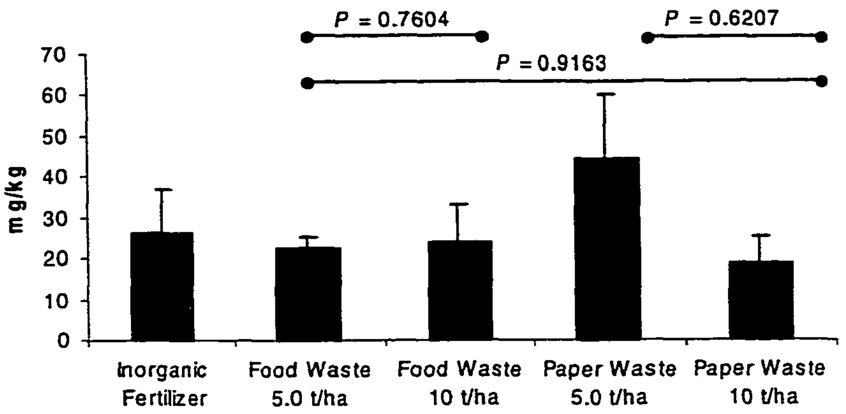
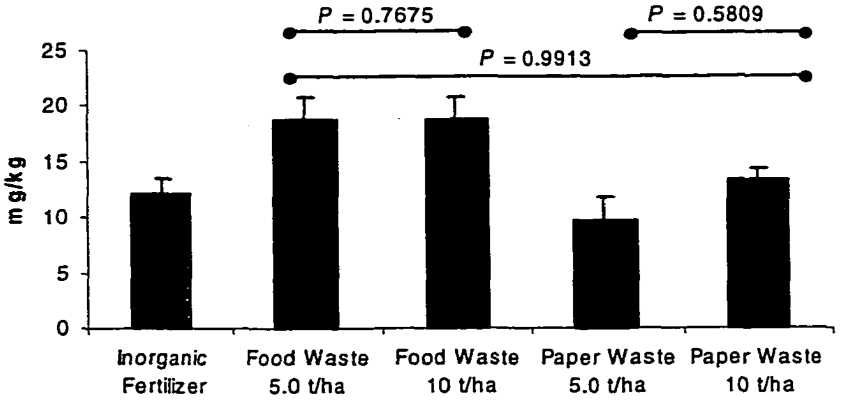


Figure 2.16: NO3-N in strawberry plots at transplanting, 150 and 200 DAT (days after transplanting) in Site B (Fremont, OH). All *P* values refer to orthogonal contrasts from grouped means of vermicompost treatments against inorganic fertilizer treatment.

a) at Transplanting



b) 150 DAT



c) 200 DAT

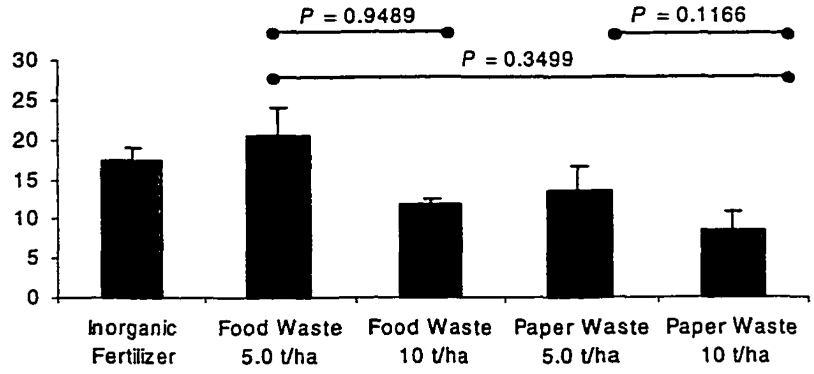


Figure 2.17: Dissolved organic nitrogen (DON) in strawberry at transplanting, 150 and 200 DAT (days after transplanting). All *P* values refer to orthogonal contrasts from grouped means of vermicompost treatments against inorganic fertilizer treatment.

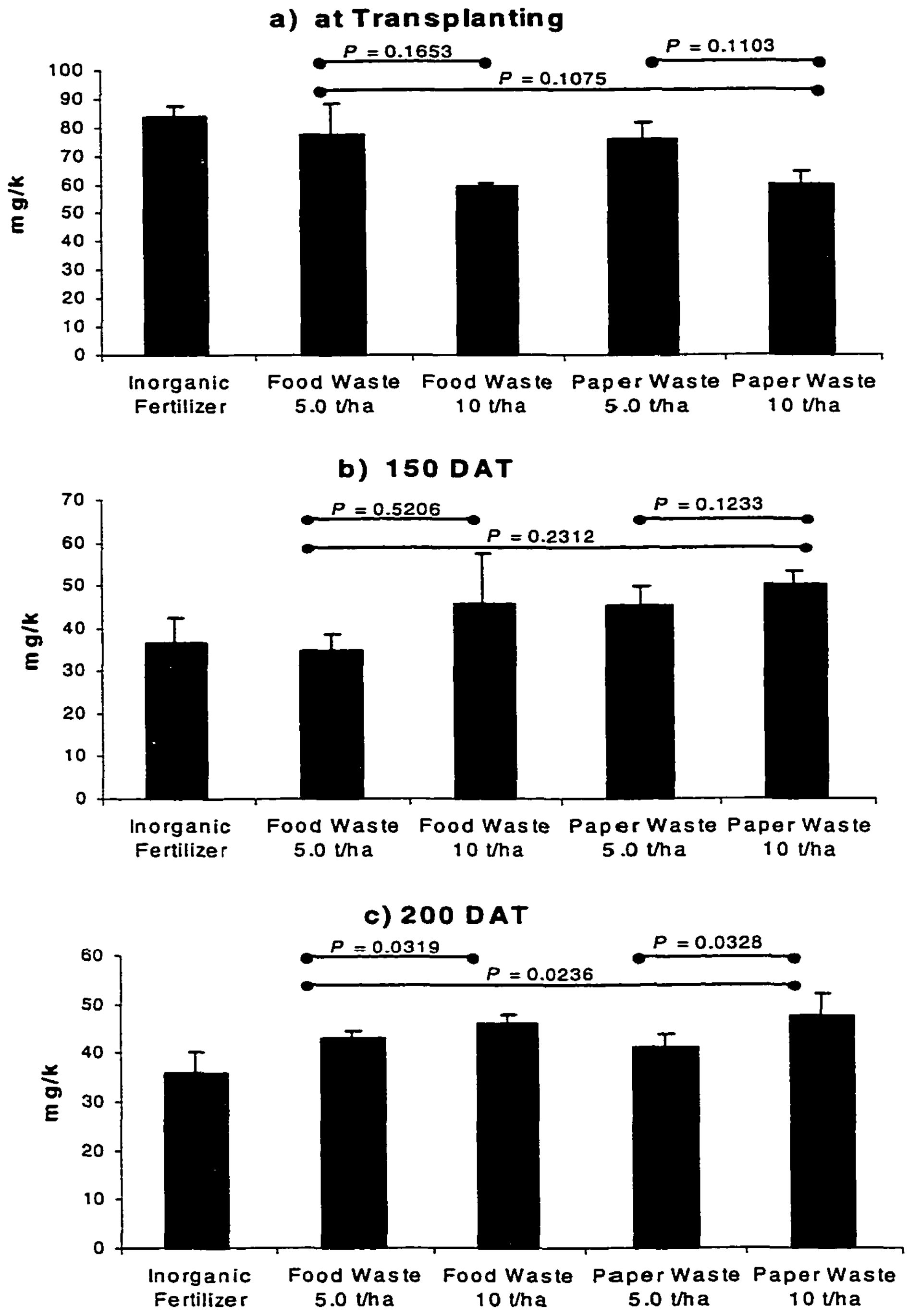


Figure 2.18: Orthophosphate in strawberry plots at transplanting, 150 and 200 DAT (days after transplanting) in Site B: Fremont, Ohio All *P* values refer to orthogonal contrasts from grouped means of vermicompost treatments against inorganic fertilizer treatment.

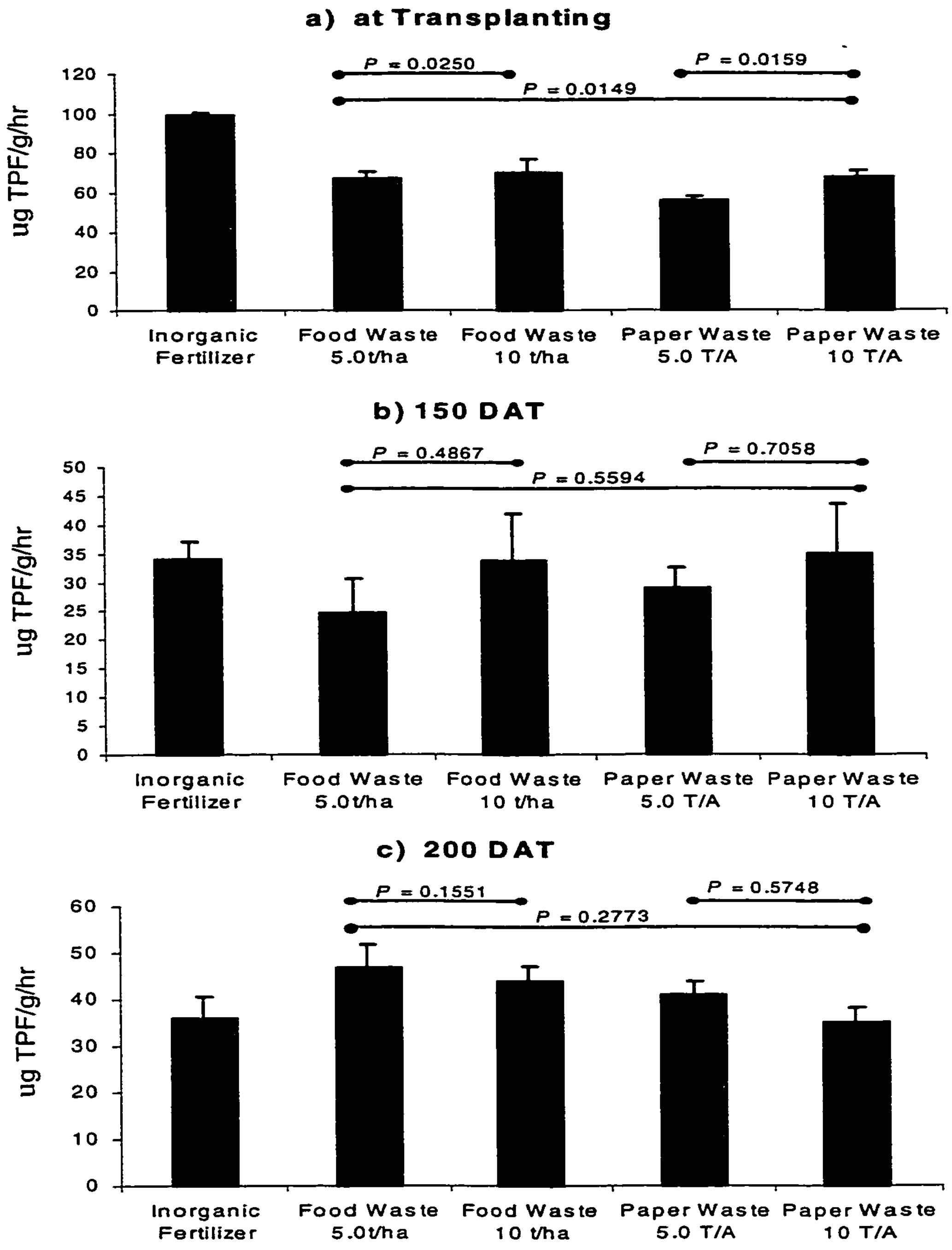


Figure 2.19: Dehydrogenase enzyme activity (DHA) in strawberry plots from three sampling dates: at transplanting, 150 and 200 DAT (days after transplanting) in Site B (Fremont, OH). All *P* values refer to orthogonal contrasts from grouped means of vermicompost treatments against inorganic fertilizer treatment.

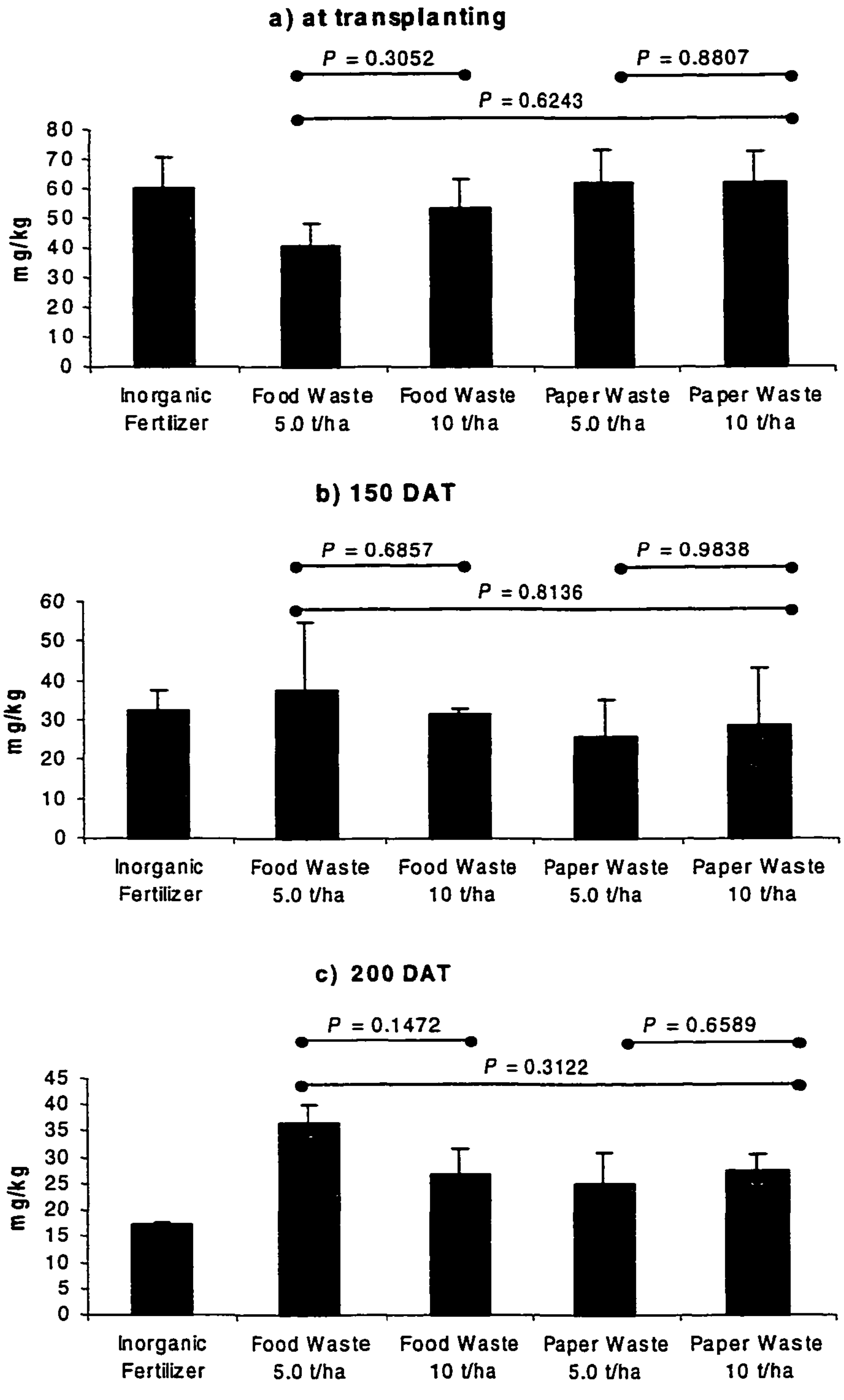


Figure 2.20: Microbial biomass-nitrogen in strawberry plots at transplanting, 150 and 200 DAT (days after transplanting) in Site B (Fremont, OH). All *P* values refer to orthogonal contrasts from grouped means of vermicompost treatments against inorganic fertilizer treatment.

	***P* values of orthogonal contrast of paired treatments**			
	Food Waste v. Paper Waste	Food Waste (5 v 10 t/ha)	Paper Waste (5 v 10 t/ha)	5 t/ha v. 10 t/ha
Total Extractable N				
At Transplanting	0.8159	0.8131	0.5785	0.5761
150 DAT	0.3521	0.2210	0.9532	0.3583
200 DAT	0.3548	0.0281 *	0.0389 *	0.0087 **
NH4-Nitrogen				
At Transplanting	0.3365	0.3467	0.5457	0.8046
150 DAT	0.9388	0.5555	0.0755	0.0962
200 DAT	0.1934	0.6527	0.0049 **	0.0572
NO3-Nitrogen				
At Transplanting	0.5636	0.2220	0.4236	0.1555
150 DAT	0.5453	0.4257	0.6374	0.3687
200 DAT	0.3651	0.0235 *	0.0426 *	0.0083 **
Dissolved Organic N				
At Transplanting	0.3351	0.9129	0.0518 *	0.1734
150 DAT	0.5532	0.0109 **	0.8101	0.0465 *
200 DAT	0.0683	0.0314 *	0.3432	0.0377*
Biomass N				
At Transplanting	0.1595	0.3704	0.9992	0.5234
150 DAT	0.6369	0.5873	0.6471	0.8883
200 DAT	0.1294	0.0888	0.8966	0.24150
DHA				
At Transplanting	0.5890	0.8155	0.4325	0.6433
150 DAT	0.6704	0.5189	0.8316	0.5689
200 DAT	0.2632	0.5535	0.3772	0.3003

Table 2.4: *P* values are from comparisons of soil nutrient parameters and DHA among vermicompost treatments in strawberries at three sampling times at transplanting, 150 and 200 DAT (days after transplanting). All *P* values refer to orthogonal contrasts between paired treatment means

2.3.2 DISCUSSION

The biochemical changes of the soil in response to vermicompost applications

The amounts of total extractable nitrogen in soil from the vermicompost-treated plots did not differ significantly from those of the inorganic controls. This was probably due to the inorganic fertilizer supplements applied to the vermicompost-treated plots aimed at equalizing available nutrient contents in soil with those in the inorganic control in terms of NPK. The amounts of total extractable soil nitrogen were constituted mainly by nitrate-nitrogen rather than ammonium nitrogen. The marked decreases in extractable soil nitrogen in the inorganic controls and in the paper waste vermicompost-treated plots relative to those in the food waste vermicompost-treated plots, may have been due to more total carbon and nitrogen in the food waste vermicompost that could have provided a greater pool of nitrogen for eventual mineralization. Hence, the food waste vermicompost could have produced more residual nitrogen than the inorganic fertilizer or the application of materials with a low source of total nitrogen content such as paper waste vermicompost. There have been several reports of increases of nitrogen in soil after vermicompost additions (Nenthra et al., 1999).

A similar trend was obtained for soil orthophosphates since the vermicompost-treated plots had significantly more orthophosphates at harvest, although all plots received equal amounts of phosphorus at transplanting. This also implies that continuous additions of orthophosphates to the soil in the plots were accomplished by the slow release from the vermicomposts. Both types of vermicomposts contained almost similar amounts of total phosphorus which may explain comparable amounts of soluble phosphorus in the vermicompost-treated plots at harvest. A trend for decreasing amounts of dissolved organic nitrogen in the vermicompost-treated plots, may be linked to the mineralization of nutrients from nitrogen pools since those water-soluble compounds that may be found in the organic fraction of vermicomposts are easily degraded by microorganisms (Cook and Allan, 1992). In my experiment, increases in amounts of orthophosphates in the vermicompost-treated plots could be explained by the significant correlation that occurred between the microbial biomass and the concentration of orthophosphates. Marinari et al (2000) reported similar increases in phosphates from the application of organic fertilizers.

The fate of individual nutrients in the soil could have been determined by interactions of several factors. Uptake by plants would have been an influencing factor together with leaching and the activity of colonizing microorganisms (Carlile and Wilson, 1989). Hence, differences in the residual nitrogen and phosphorus may have been due to differences in rates of plant absorption, rates of leaching of these nutrients or microbial immobilization. Differences in the rates of plant uptake could not be verified in my experiment because no plant tissue analyses were done. Rates of leaching may have differed among the plots with the inorganic controls having the fastest rate of leaching because their soils contained less organic matter than the vermicompost plots. For instance, decreased nitrate leaching has reported in compost-treated soils (Maynard, 1989). Leaching of nutrients could also be slowed down by microbial nutrient immobilization. Since there were more microorganisms in soil treated with vermicomposts, they probably used the available nutrients in their metabolic activities. Immobilization of nutrients may be explained further by the increases in microbial biomass in the soil from plots treated with vermicomposts and such increases in microbial biomass were greater in those plots with higher rates of application (10 t/ha).

As well as chemical soil parameters, microbial biomass has been used to measure soil quality in long-term experiments (Albaldejo and Diaz, 1990) and may be an early and sensitive indicator of soil ecological stress or need fro restoration in long-term experiments (Jankinson and Ladd, 1981;Paul, 1984). In an experiment using municipal sewage compost applications to soil, Pascual et al (1999) reported significant increases in microbial biomass C which reached values near those in the natural soils in the areas far from anthropogenic effects. The addition of vermicomposts into the soil increased microbial biomass nitrogen significantly especially in response to food waste vermicompost-treated plots. The increases in soil microbial biomass apparently did not affect the supply of nutrients to the strawberry plants by immobilization, since there was even more residual nitrogen and phosphorus in soils from the vermicompost-treated plots than in the inorganic control soil.

The ecological significance of microorganisms may not be evaluated simply by assessing populations. It is more important to obtain information on overall microbial activity (Alexander, 1977). We measured the dehygrogenase enzyme activity since these enzymes are often considered to be a good index of total microbial activity (Nannipieri et al., 1990). In my field experiment, the dehydrogenase activity increased in soils treated with vermicomposts and those from the food waste vermicompost-treated plots contained most. Furthermore, it was positively correlated significantly with soil microbial biomass towards the later growth stages of the strawberry plants. Many authors have reported that organic fertilization causes an increase in soil microbiological activity (Bolton et al., 1986, Fraser, et al., 1988; Kirkner et al., 1993; Marinari et al. 2000). Many enzymatic activities have been reported to be correlated with the total organic C in the soil (Frankenberger and Tabatabai 1981). Serra-Wittling et al (995) reported increases in dehydrogenase activity in compost-soil incubation trials with the highest level of dehydrogenase activity coinciding with the flush of mineralization. These increases were attributed to the intense activity of the soil microorganisms in degrading easily-metabolizable compounds with consequent decreases in activity attributed to the decreases in easily biodegradable substances. Pascual et al (1999) reported significant increases in dehydrogenase activity after 8 years of amending soil with composts compared with unamended soils. Masciandaro et al (1997) reported increases in soil dehydrogenase activity following vermicompost applications at 90 t/ha. In my experiment, soil dehydrogenase activity was correlated negatively with microbial biomass at transplanting. This could have been due to the direct applications of the supplemental inorganic fertilizers to balance nutrients in the vermicomposts to the levels of inorganic controls which might have been inhibitory to microbial activities. Increases in the soil dehydrogenase activity at the later stage, 110 days after transplanting were probably due to mineralization of nitrogen and phosphorus because there were 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 it was higher in the inorganic controls than in soil from vermicompost treatments but eventually fell at the later stages of strawberry growth. This was probably because the soil in site B was rich in organic matter, as demonstrated by the similar amounts of dissolved organic nitrogen compared to those in vermicompost-treated plots and may have contained a considerable amounts of microbial biomass initially, so that the vermicompost applications did not affect either microbial biomass or dehydrogenase activity. A significantly lower soil dehydrogenase activity at transplanting may have been due to an inhibitory effect resulting from the introduction of 'foreign' soil microorganisms from the vermicomposts to the exotic microflora. However, this was overcome at the later stages of strawberry growth especially at harvest.

2.3.3 RESULTS

Nematode populations and disease suppression after vermicompost applications

The incidence of *Verticillium wilt* disease damage was greater in the plants in inorganically-fertilized control plots than those in vermicompost-treated plots (Fig. 2.21).

Populations of *bacterivorous* and *fungivorous* nematodes were significantly greater in the vermicompost-treated plots whereas significantly larger populations of *plant parasitic* nematodes occurred in the inorganic control plots (Fig. 2.22). There were no significant differences in the number of carnivorous/omnivorous nematodes between the treatments.

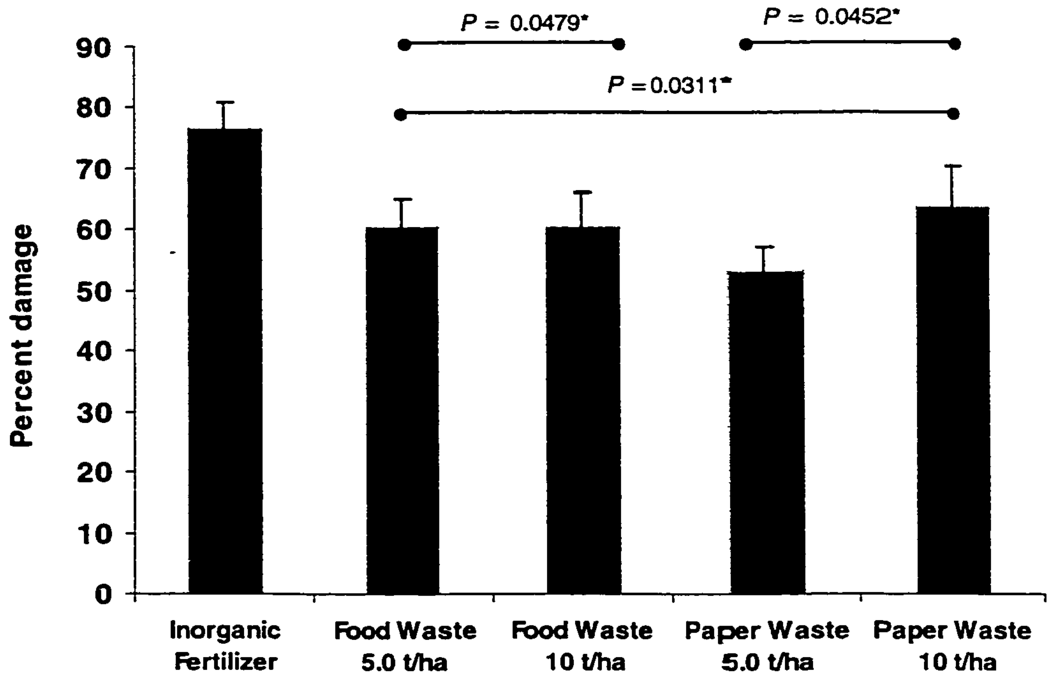


Figure 2.21: *Verticillium wilt* disease damage rating in strawberry plants in Site A: Piketon, Ohio.

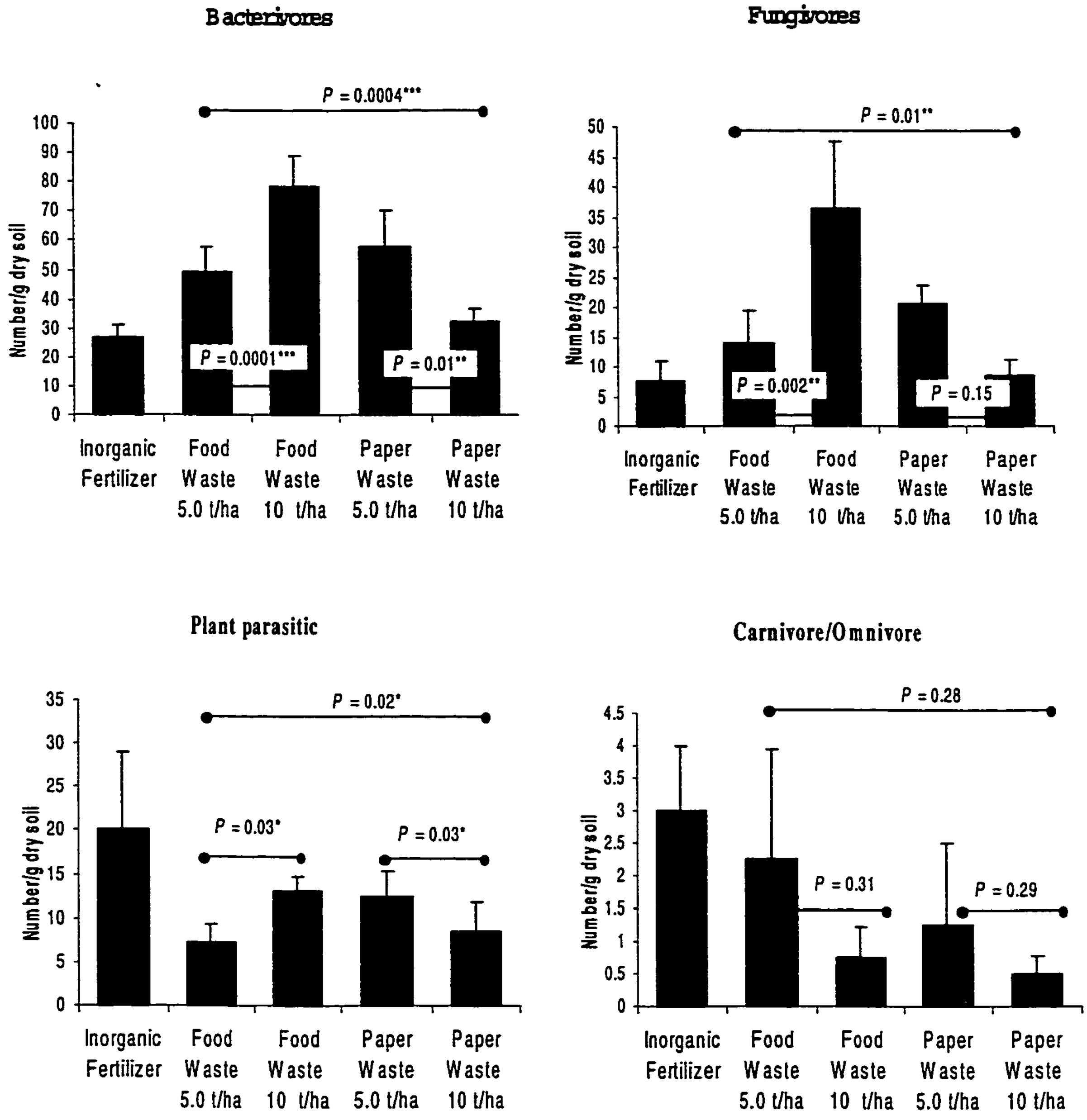


Figure 2.22: Number of nematodes in strawberry plots 110 days after transplanting.

2.3.3 DISCUSSION

Nematode populations and disease suppression after vermicompost applications

The ability of traditional composts to suppress disease has been reported widely. Craft and Nelson (1996) reported suppression of *Pythium graminicola* root rot in bentgrass after application of composts prepared from various feedstocks. Applications of increasing rates of municipal solid waste composts progressively increased the suppressiveness of soil to *Fusarium wilt* (Serra-Wittling et al., 1996). Several other works have confirmed the suppressiveness of composts to diseases induced by soilborne plant pathogens and their application to soil or container media has been proposed as a way to control diseases (Hoitink et al., 1993). The suppressiveness of composts to several species of microorganisms have been described as biotic in nature since this property is lost when composts are heated. Furthermore, suppressiveness to diseases has been suggested as due to microbial interactions and two mechanisms have been suggested. General suppression (Cook and Baker, 1983), based on competition for energy, involves the total microflora (Lemanceau et al., 1988). Specific suppression is linked to a specific group of antagonistic microorganisms, such as non-pathogenic *Fusarium* (Larkin et al., 1993) or fluorescent *Pseudomonas* (Ingham , 1999), interacting with the pathogen.

Vermicomposts are much newer materials than the traditional thermophilic composts, but also seem to provide similar disease suppressive properties. A few reports on disease suppression by vermicomposts exist. Container media supplemented with vermicompost were suppressive to root rot of tomato caused by *Phytophthora nicotiane* var. *nicotianae* (Szczech and Brzeski, 1994; Szczech et al., 1995). Dipping cabbage roots in mixtures of clay and vermicomposts decreased the incidence of infection by *Plasmodiophora brassicae* (Szczech et al., 1993). Potato plants grown in soil amended with vermicomposts were less susceptible to *Phythophthora infestans* and post-harvest diseases of tubers decreased compared with untreated controls (Kostecka et al., 1996). Weltzian (1989) described the control of powdery mildew in barley treated with water extracts from vermicompost. Preliminary experiments have also shown protective properties of vermicomposts against *Fusarium* wilt of tomato (Szczech et al., 1993). In our laboratory, we have demonstrated suppression of *Rhizoctonia* and *Pythium* by vermicomposts. In my field experiment, vermicompost from food waste and paper waste reduced the incidence of *Verticillium wilt* damage in the strawberry plants. *Verticillium wilt*, *Verticillium albo-atrum* Reinke & Berth. And *V. dahlia* Kleb., is a disease of hundreds of crop plants including strawberry.

The suppression of *Verticillium* in strawberries might be explained by a general suppression and/or antagonism between of the microbial populations in the vermicomposts and the soil. A number of reports have suggested that vermicomposts contain more and more diverse microorganisms than traditional thermophilic composts (Nair, 1997; Edwards, 1983, Werner and Cuevas, 1996). The large microbial populations commonly reported in vermicomposts may have stimulated increases in beneficial microorganisms and consequently competed or antagonized the disease-causing fungus and thereby reduced or eradicated them.

The vermicompost applications caused changes in the trophic populations of nematodes favoring larger populations of fungivores and bacteriovores and lower numbers of plant parasites. Grazings by fungivores may have decreased the populations of diseases -causing fungi on strawberries such as *Verticillium*. The dominance of fungal -feeding nematodes in the vermicompost-treated plots was probably due to inoculations of these organisms from vermicomposts. Although the populations of microbially feeding nematodes and other microorganisms could have been directly influenced by vermicompost applications, other factors may also have contributed. Yardim and Edwards (1998) reported increases in numbers of plant parasitic nematodes in tomato plantings that were treated with a full spectrum fungicide and pesticide suggesting that nematode populations may be influenced by the cultural management of crops. Although reports several reports have indicated that agrochemicals can increase numbers of plant-parasitic nematodes (Bohlen and Edwards, 1994; Parmelee et al., 1993), there have been no published reports on the direct influence of application of inorganic fertilizers on nematode populations. However, various other reports have indicated that agrochemicals can cause increase in plant-parasitic nematode populations. For instances, pesticides could alter the larval growth and hatching patterns of plant-parasitic nematodes. It has been reported that direct and residual effects of a pesticide such as tetraphon applied to jute had stimulatory effects on populations of the plant parasitic nematode *Hoplolaimus indicus*, *Heliocotylenchus digonychus* and *Tylenchorynchus* sp. (Biswas and Mishra, 1987). Increased populations of *H. glycines* resulted after applications of alachlor herbicides (Schmitt and Corbin, 1981). They considered that alachlor stimulated egg-hatch and thereby *increased H. glycines* populations. Similar hatch-stimulating reactions in response to cycloate *on H. schachtii* in sugar beet have been reported (Abivardi and Altman, 1978). Riggs and Oliver (1982) reported increases in *H. glycine* populations in response to the applications of trifluralin. Significant increases in plan-parasitic nematodes in soils treated with pesticides carbaryl compared to that in pesticide-free plots were so reported by Yardim and Edwards (1998). Although several workers have indicated that agrochemicals can increase plant-parasitic nematodes populations (Bohlen and Edwards, 1994; Parmelee et al., 1993), I have identified no reports on the direct influence of the application of inorganic fertilizers on nematode populations. In the work by Neher and Olson (1999), it was reported that trophic diversity was greatest in a farming system that was treated with mineral fertilizer, herbicides and insecticides and least in those farming systems that was treated with manures only. My experiments on strawberries showed that inorganic fertilizer may have provided a soil microenvironment that favored increases in populations of plant-parasitic nematodes. Alternatively, decreases in populations of other trophic species may have provided a greater ecological niche for plant-parasitic nematodes..

The trophic composition of nematodes could be a factor in regulating their populations. According to Small (1978), predatory nematodes can play a role in regulating plant-parasitic nematodes. A decrease in predatory nematode populations could lead to significant increases in plant-parasitic nematode populations. However, this relationship apparently did not exist in the strawberry plots applied with inorganic fertilizers because there were no significant correlations between omnivorous/carnivorous nematodes in the strawberry plots. There were more of carnivorous/omnivorous nematodes and plant parasites in the soil from inorganic controls compared to those in the soil from vermicompost-treated plots although their numbers were not statistically significant.

My experiment showed that inorganic fertilization may have provided a microenvironment that favored increases in populations of plant-parasitic nematodes at the expense of other trophic levels

CHAPTER 3

INFLUENCES OF VERMICOMPOST APPLICATIONS ON THE GROWTH AND YIELD OF PEPPERS

3.1 INTRODUCTION

Peppers, which belong to the *Solanaceae* family, are known for their versatility as a vegetable crop. Peppers are consumed primarily as fresh vegetables or dehydrated for spices. Both pungent and non-pungent red pepper products represent one of the most important spice commodities in the world by volume. They add spice flavoring and color to foods while providing essential vitamins and minerals. In many households, peppers provide the only variety needed to enhance diets. The range of food products that contain pepper or its chemical constituents is broad. They include ethnic foods, meats, salad dressings, mayonnaise, dairy products, beverages, candies, baked goods, snack food, breading and batters, salsas and sauces. Pepper extracts are also used in pharmaceutical and cosmetic products (Bosland and Vostava, 2000). World production of peppers has increased 21% since 1994 (FAO, 1997). The FAO has also reported that world production of peppers for 1996 was 14,068,000 metric tons. It is also estimated that more than 3 million hectares are grown annually in the world. In most years, China leads world production of peppers with more than 300,000 hectares harvested annually. In the United States, New Mexico is the leading state in pungent pepper production with more than 12,000 hectares under cultivation. California produces the most bell peppers with approximately 10,000 hectares grown annually.

As with other vegetable crops, peppers are still commonly grown using conventional methods using inorganic fertilizers and pesticides. Inorganic fertilizers are still the major source of nutrients in most fertilization programs and whether crops are grown in the greenhouse or in the field and yields are usually dependent on these inputs.

There is a growing awareness of economic and environmental problems related to the use of fertilizers. In developed countries, high fertilizer inputs have led to overproduction of certain crops that led to the fall of commodity price and farm income (Edwards, 1990). Moreover, high fertilizer inputs are inefficient in terms of energy. For every calorie of food currently produced in the United States, three calories are needed in production and seven in processing, distribution and preparation (Papendick, 1987). Furthermore, the intensive use of fertilizers has created not only economic problems but also environmental and ecological problems. Nutrient loading from inorganic fertilizers has been a major cause of water pollution (Clark et al, 1985) with potentially devastating effects on lakes, rivers, and bays in some areas. Increased nutrient levels in aquatic systems, particularly phosphorus and nitrogen, stimulates algal growth which can accelerate eutrophication (Laegreid, 1999). Increased use of nitrogen over the past few years has raised the potential for ground water contamination. A survey by the U.S. Geological Survey of 1,663 counties showed 474 counties in which 25 percent of the wells tested had nitrate-nitrogen levels in excess of 3 milligrams/liter (Committee on

Role of Alternative Farming, 1989). In developing countries, nutrient loading has favored the growth of phytoplankton resulting in red tides and often lowered fish populations.

There has been a growing movement to find ways of reducing inorganic fertilizer use. These include the development of new crop varieties that use soil nutrients more efficiently and more use of organic matter. The use of organic amendments like traditional composts has been long recognized as an effective means of improving soil and increasing plant growth and yield. A number of reports on their beneficial effects on plants and soils have been detailed in Chapter 2.

Recently, vermicomposts have received attention by agricultural practitioners as other organic amendments that have great potential in improving soils properties and plant growth and yield. Various reports on their benefits to soils plants are also discussed in Chapter 2.

Positive results from the beneficial applications of vermicomposts to greenhouse vegetables have led me to explore further the influences of vermicomposts on field crops such as peppers that are grown commercially. As a hypothesis, I expected obtaining positive responses of growth and yield of peppers that could be associated with positive changes in soil properties. This would enable me to reinforce earlier conclusions that vermicomposts are ideal soil amendments in the field.

Objectives

The main aims of the work reported in this chapter are:

1. To assess the effects of different application rates of vermicomposts on the growth and yields of peppers grown in the field.

2. To determine their effects on the soil chemical and biological changes that occur throughout the growth cycle of the peppers.

3. To determine the effects of vermicompost applications on disease suppression.

3.2 MATERIALS AND METHODS

Two field experiments were conducted at the Ohio State University Research Center at Piketon in 1999 and 2000. Brief descriptions of the experimental site from the soil survey by the USDA-Natural Resource Conservation Service and local weather stations has been described in the previous chapter:

Plot layout and design

Raised soil beds were set-out measuring 1.5 x 5.5 m (8.25 sq.m. per plot). Vermicomposts were applied at two dosage rates: equivalent to 10 t/ha and 20 t/ha in 1999. Lower rates at 5 t/ha and 10 t/ha were applied in 2000. Vermicompost-treated plots were supplemented with amounts of inorganic fertilizer to equalize with total recommended full rate of nitrogen and potassium (NK). Soil tests showed that available phosphorus was adequate for optimum yields of pepper, so no P fertilizer was applied in either year. The full fertilizer rates applied to the inorganic fertilizer control were 95 kg/ha actual N (as ammonium nitrate) and 95 kg/ha actual K (as potassium chloride). Another application of 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 actual 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. Full inorganic fertilization rate was applied in the inorganic control plots in both years. Vermicomposts and inorganic fertilizers were applied by manual spreading into each whole bed. They were mixed into the top 10 cm of each bed using a rotavator before transplanting. Paper waste, cow manure and food waste vermicomposts were used in the trials. Paper waste vermicompost were provided by American Resource Recovery, Stockton (CA), food waste vermicomposts were provided by Oregon Soil Corporation, Portland, (OR). Cow manure vermicomposts were provided by Soil Ecology Lab, Columbus (OH). Yard waste compost from Kurtz Bros from Columbus, (OH) was used in the first year and Com-Til, a composted biosolids (sewage sludge), was used in the second year. The following were the treatments:

T1: Inorganic Fertilizer (Control)

T2: Paper Waste Vermicompost (10 t/ha in 1999 and 5 t/ha in 2000)

T3: Paper Waste Vermicompost (20 t/ha in 1999 and 10 t/ha in 2000)

T4: Cattle Manure Vermicompost (10 t/ha in 1999 and 5 t/ha in 2000)

T5: Cattle Manure Vermicompost (20 t/ha in 1999 and 10 t/ha in 2000)

T6: Food Waste Vermicompost (10 t/ha in 1999 and 5 t/ha in 2000)

T7: Food Waste Vermicompost (20 t/ha in 1999 and 10 t/ha in 2000)

T8: Compost (20 t/ha Biosolids in 1999 and 10 t/ha Yard waste in 2000)

Plastic mulch and drip irrigation systems were used over the raised beds after vermicompost and fertilizer applications. Four-week old pepper seedlings var. 'King Arthur' were used in the trial. Twenty-four plants were transplanted into two rows in each raised bed. Seedlings were planted in a staggered fashion relative to plants in the other row and spaced 38 cm. between plants and 38 cm between rows. Treatments were replicated four times in a randomized complete block design

Data Collected

Plant sampling

Four whole designated plant samples were harvested for assessment of leaf area, and fresh and dry shoot weights 90 and 155 days after transplanting in 1999 and 56 and 128 days after transplanting in 2000.

All fresh leaves from plant samples were removed from the stems and passed through a portable LI 3100 leaf area measuring machine for assessment of leaf area. Leaves and stems of each plant were weighed for shoot fresh weights, placed into paper bags, oven-dried at 60 ^{0}C for 92 hours and weighed for shoot dry weights.

Mature green fruits were harvested manually, graded, and weighed into marketable and non-marketable yields. Fruits were classified as non-marketable when signs of rots, insect feedings, and malformations were present on the surface. These indices of non-marketability were recorded as percentage of the total non-marketable fruits. The proportions of non-marketable fruits were determined by calculating their percentage from the total fruits harvested.

Soil sampling and analysis

Eight 2.5 cm diameter x 20 cm deep soil samples were taken from the root zone in each plot. Five sets of soil samples were taken during 1999: at transplanting, 30, 65, 90, 120 and 155 days after transplanting and four sets 2000: at transplanting, 56, 85 and 128 days after transplanting. Moist soil samples were passed through a 2mm-sieve and stored in the cold room at 4 ^{0}C until chemical analyses.

Extractable nitrogen (NO3-N and NH_4-N) levels were determined using a modified indophenol blue technique (Sims et al., 1995). Five-gram soil subsamples were extracted with 0.5M K_2SO_4 for 1 hour and filtered through Whatman no. 42 filter paper. Filtrates were collected and stored in scintillation vials. NO_3-N and NH_4-N levels were determined by color development by adding citrate, salicylate and hypochlorite reagents into the samples. Absorbance was measured using Bio-Tek EL211sx automated microplate reader. Soluble phosphorus was assessed using NH_4-HCl reagent. Three-gram soil samples were extracted with Bray no.1 extracting reagent. Color in the sample filtrates was developed with stannous chloride and ammonium paramolybdate and absorbance was measured using Bio-Tek EL211sx automated microplate reader. A more complete nutrient analysis was done on vermicompost and compost samples after nitric acid/perchloric acid digestion (Singer and Hanson, 1969). Extracts were analyzed for P, K, Ca, Mg, B, Cu, Fe, Mn, S and Zn by inductively coupled plasma-atomic emission spectroscopy (ICP-AES) (Munter and Grande, 1981). Total carbon and nitrogen were measured in vermicomposts and composts by dry combustion using Carlo-Erba apparatus.

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 EL211sx automated microplate reader. 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.

Nematode and fruit disease sampling

Nematodes were extracted from 20-gram unseived soil subsamples stood in water in glass Baermann filters/funnel for 48 hours (MacSorley and Weltter, 1991). Nematodes were identified to trophic levels under a stereomicroscope (Edwards et al., 1991). Non-marketable fruits were inspected for surface damages due to fruit rotts, malformations, sun scalding, blossom-end-rots, and insect feedings.

Statistical analysis

Means of parameters were grouped for comparisons and differences were separated by orthogonal contrasts using SAS (SAS Inc., 1990). Contrasts were made between grouped means to determine differences in the following: 1) among vermicomposts, inorganic fertilizers and composts 2) among the three kinds of vermicomposts and 3) among the rates of vermicompost applications on pepper growth, yield and changes in the soil properties.

3.3 RESULTS AND DISCUSSIONS

The results and discussions are addressed in the following subsections to cover:

3.3.1 Effects of vermicompost applications on pepper growth and yield

3.3.2 The biochemical changes of the soil after vermicompost applications

3.3.3 Nematode populations after vermicompost applications

3.3.1 RESULTS

Effects of vermicompost applications on pepper growth and yield

The chemical analyses of the vermicomposts and compost used in the experiment are summarized in Table 3.1. The food waste vermicompost contained most iron and manganese. The cow manure vermicompost contained most total nitrogen, boron, potassium, sodium and the second greatest amounts of iron, phosphorus, sulfur and zinc. Paper waste vermicompost contained most calcium and the second largest amounts of iron, magnesium, and manganese. Composted biosolids had most phosphorus, sulfur and zinc and second largest amounts of sodium. Yard waste compost contained most magnesium and the second largest amounts of boron and calcium.

The average nitrogen content of the soil after applications of soil amendments to pepper plots are given in Table 3.2. The soil contained relatively average amounts of ammonium-nitrate (3.07 mg/kg), nitrate-nitrogen (10.17 mg/kg), and 21 mg/kg and 52.8 mg/kg of dissolved organic nitrogen and microbial biomass nitrogen, respectively.

In 1999, pepper shoot fresh weights and dry weights did not differ significantly among the treatments 90 days after transplanting (Fig. 3.1a and 3.1b). However, 20 t/ha of vermicompost produced the greatest pepper fresh and dry shoot weights. Among the vermicompost treatments, food waste produced larger pepper dry shoot weights than peppers grown in the paper waste plots, $P < 0.05$.

The plants grown in plots treated with vermicomposts and compost had significantly larger leaf areas than plants grown in the inorganic control plots, $P < 0.01$. The combined means of leaf areas in all plants in vermicompost plots were significantly greater compared to those grown in the inorganic control, $P < 0.01$ (Fig. 3.1c). Both paper waste and cow manure vermicomposts produced significantly greater pepper leaf areas $P < 0.05$ and $P < 0.01$, respectively, compared to peppers grown in the inorganic control plots. Twenty t/ha of vermicompost produced the greatest leaf areas, $P < 0.01$ (Table 3.3;) compared to peppers grown in 10 t/ha and those grown in the inorganic control.

Pepper fresh and dry shoot weights 155 days after transplanting were significantly larger in all organic plots compared with peppers in inorganic plots (Fig. 3.2a and 3.2b; $P < 0.01$). Cow manure vermicompost produced plants with significantly greater shoot fresh weights ($P < 0.05$) and dry weights ($P < 0.001$) than peppers grown in paper waste vermicompost treated plots (Table 3.3). Cow manure vermicompost-treated plots also produced plants with significantly greater shoot fresh weights than peppers grown in the food waste treated vermicompost plots, $P < 0.01$ (Table 3.3). Peppers treated with composts did not show any significant difference in shoot weights and leaf areas compared with those plants that were treated with vermicomposts.

Plants grown in the paper wastes and cow manure-treated plots produced more marketable fruits than peppers grown in the inorganic control plots ($P < 0.01$; Fig. 3.3a). The means of marketable yields of peppers grown in the vermicomposts and organic-treated plots were significantly greater than those grown in the inorganic control plots (Fig. 3.3a). Paper waste vermicomposts produced significantly greater marketable yields ($P < 0.01$) than the food waste-treated plots, whereas the cow manure treated plots produced significantly greater in marketable yields compared to those in food waste-treated plots, $P < 0.001$ (Table 3.3). The 10 t/ha application rate of paper and food waste vermicompost produced significantly more marketable fruits than those in 20 t/ha of the same type of vermicomposts.

All of the plants in the vermicompost and compost-treated plots produced fewer non-marketable fruits than those in the inorganic control (Fig 3.3b). Cow waste vermicompost-treated plots produced the lowest percentage of non-marketable pepper yield compared to that in the paper waste vermicompost-treated, plots, $P < 0.01$, and food waste vermicompost-treated plots, $P < 0.001$ (Table 3.3). There were no significant differences between the number of fruits in the different treatments in 1999.

In 2000, there were no significant differences in the fresh and dry shoot weights and leaf areas of peppers among the treatments 56 days after transplanting (Fig. 3.4). Plants grown in the cow waste vermicompost-treated plots had significantly more fresh shoot weights ($P < 0.01$) and dry shoot weights ($P < 0.05$) than those grown in the inorganic control plots 128 days after transplanting (Fig. 3.4). The vermicompost application rates of 10t/ha produced significantly more pepper fresh and dry shoot weights than those grown in 5 t/ha vermicompost128 days after transplanting.

Plots treated with cow manure and food waste vermicomposts both produced significantly greater marketable yields than the inorganic-treated control plots, $P < 0.01$ (Fig. 3.6). There were no significant differences between pepper yields in vermicompost and compost plots. Plants grown in cow manure vermicompost-treated plots had significantly less non-marketable yields than those in the inorganic control plots, ($P <$ 0.01; Fig 3.6b). The vermicompost application rate of 10 t/ha produced a significantly fewer non-marketable fruits ($P < 0.05$; Table 3.4).

No significant differences occurred in the total number of fruits among the various treatments in 2000.

	N %	B ug/g	Ca ug/g	Fe ug/g	K ug/g
Food Waste	1.30	23.30	18613.81	23263.58	9203.18
Cow Manure	1.90	57.71	23244.74	3454.04	14011.10
Paper Waste	1.00	31.447	9214.24	17811.00	6252.73
Biosolids Compost		33.17	27965.44	7714.36	6445.15
Yard Waste Compost	0.50	50.03	89206.62	9031.18	6683.56

	Mg ug/g	Mn ug/g	Na ug/g	P ug/g	S ug/g	Zn ug/g
Food Waste	4363.99	609.75	842.46	2748.63	2586.86	279.02
Cow Manure	5801.53	159.96	3359.90	4778.18	5524.53	515.90
Paper Waste	7660.94	446.56	612.77	1402.40	1929.13	126.58
Biosolids Compost	7185.37	363.95	929.97	18352.36	6291.00	1280.49
Yard Waste Compost	21228.65	323.95	120.84	1791.68	2859.82	120.07

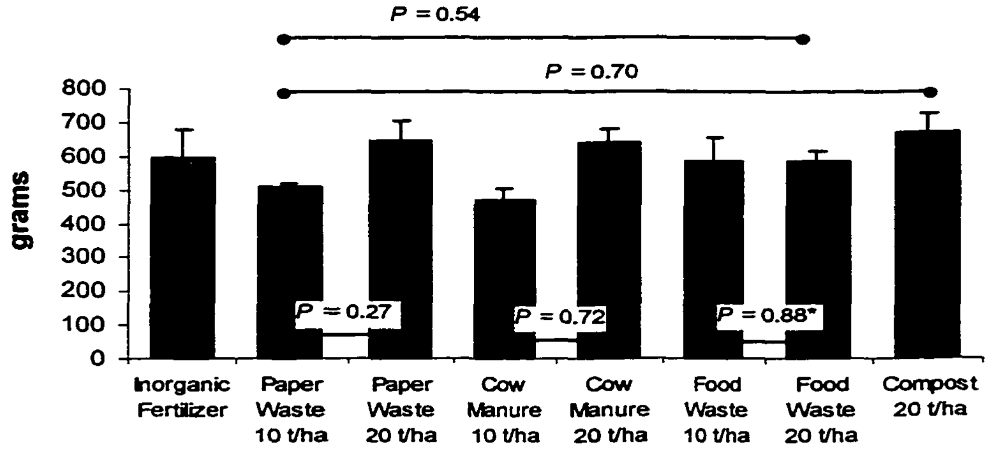
Table 3.1. Chemical composition of vermicomposts and composts.

NH_4-N	(mg/kg)	3.07
NO_3-N	(mg/kg)	10.17
DON	(mg/kg)	21.43
Bio-N	(mg/kg)	52.84

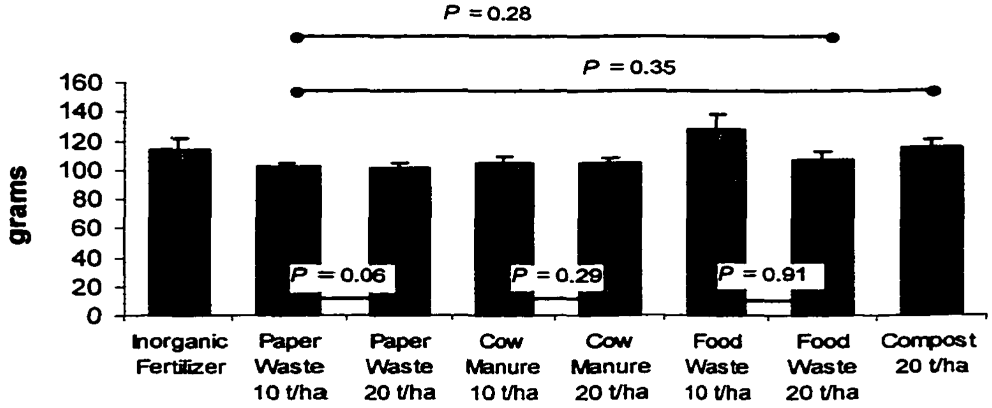
Table 3.2. Nitrogen content of pepper plots in 1999.

Figure 3.1: Fresh shoot weights, dry shoot weights, and leaf areas of peppers 90 days after transplanting in 1999. Bars designated by a line (●—●) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted sewage.

a) Fresh shoot weight



b) Dry shoot weights



c) Leaf Area

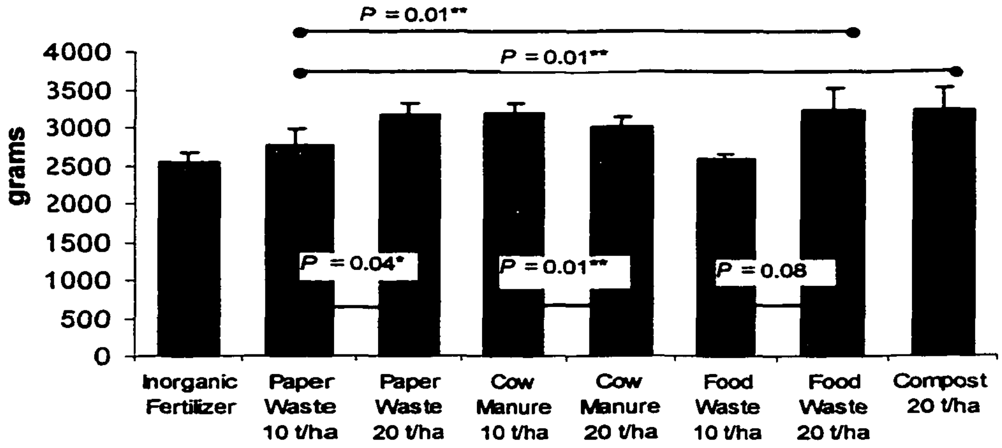
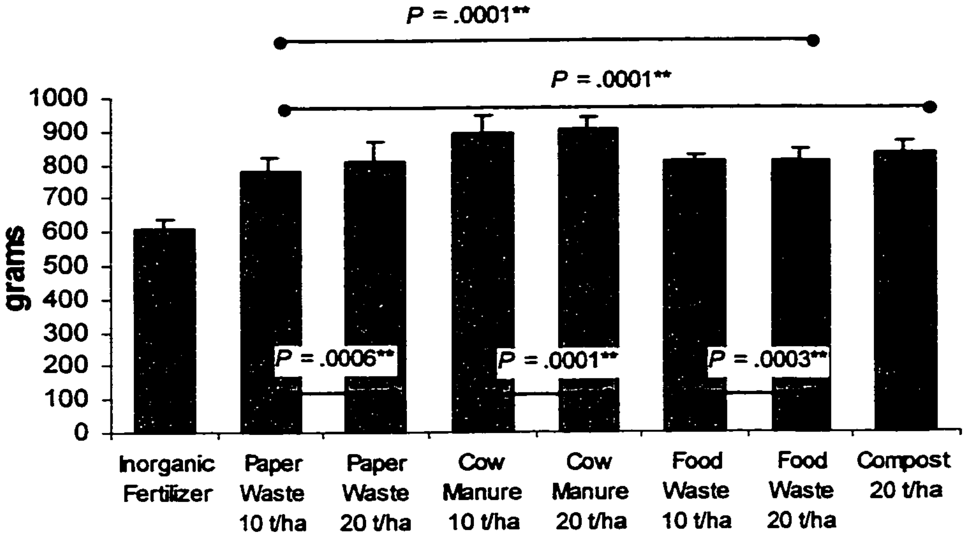


Figure 3.1

Figure 3.2. Fresh and dry shoot weights of peppers 155 days after transplanting in 1999. Bars designated by a line (•—•) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted sewage sludge.

a) Fresh shoot weights



b) Dry shoot weights

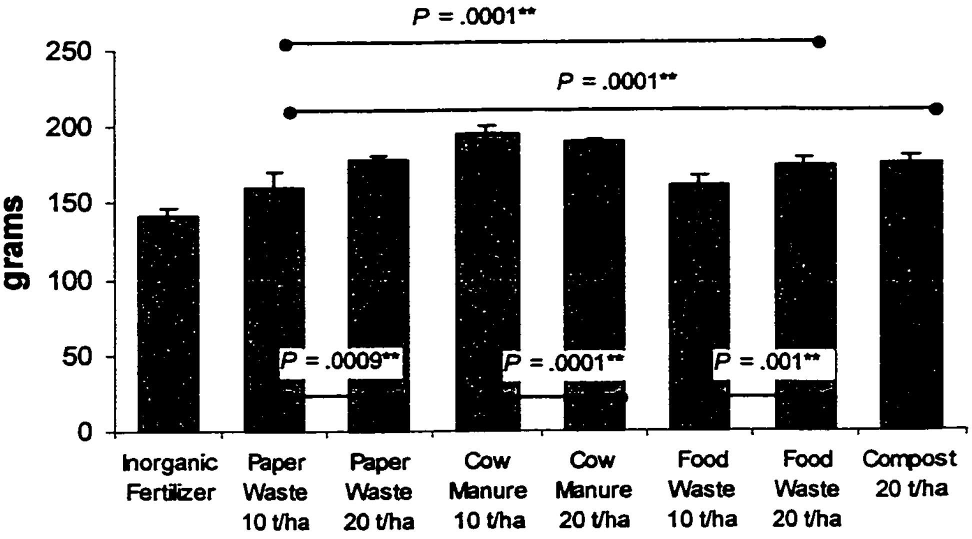


Figure 3.2.

Figure 3.3: Marketable and non-marketable yield and number of fruits of peppers in 1999. Bars designated by a line (•——•) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted sewage sludge.

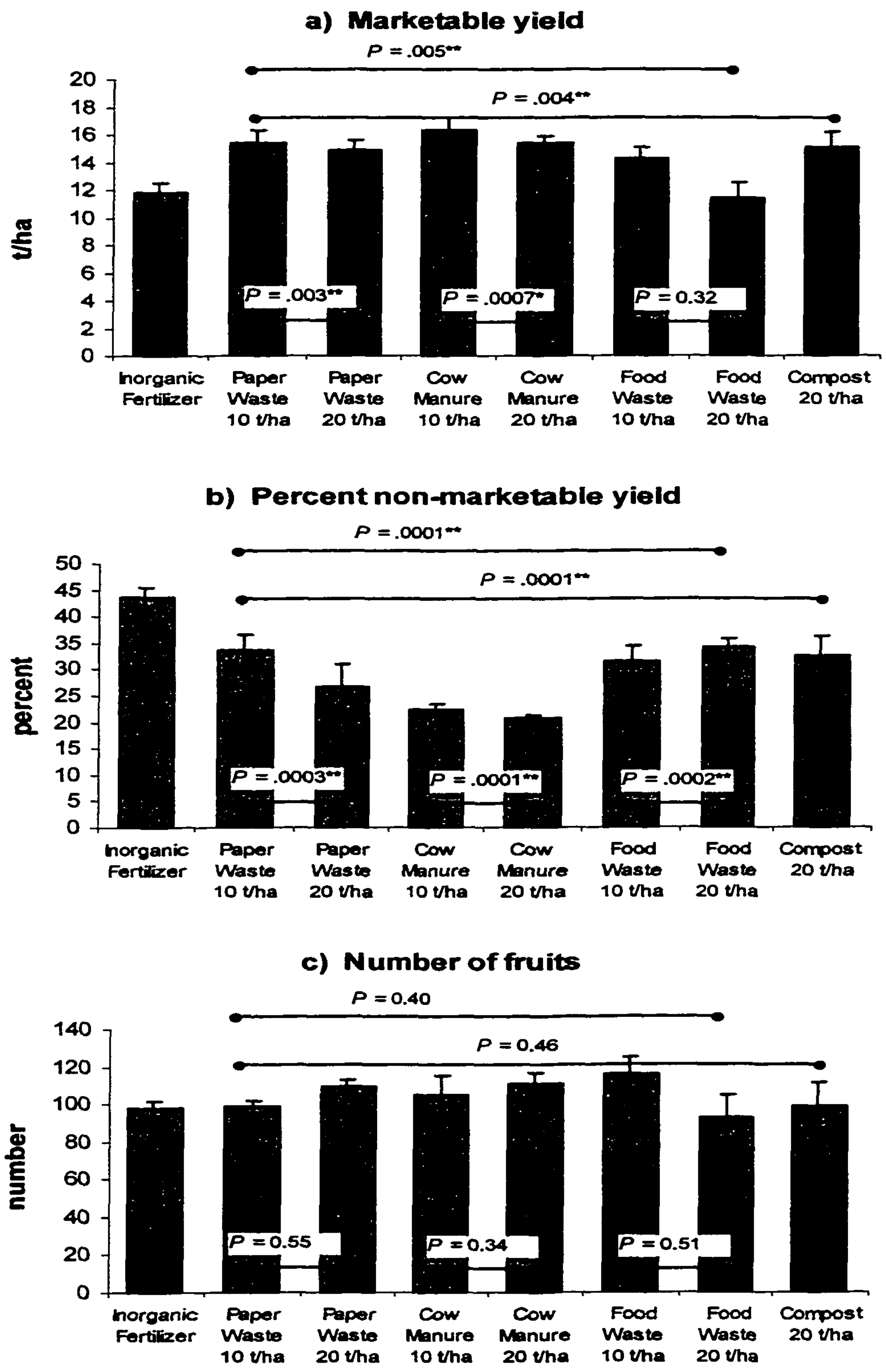

a) Marketable yield
P =.005**
P =.004**
t/ha
20
18
16
14
12
10
8
6
4
2
0
P =.003**
P =.0007*
P =0.32
Inorganic Fertilizer
Paper Waste 10 t/ha
Paper Waste 20 t/ha
Cow Manure 10 t/ha
Cow Manure 20 t/ha
Food Waste 10 t/ha
Food Waste 20 t/ha
Compost 20 t/ha
b) Percent non-marketable yield
P =.0001**
P =.0001**
percent
50
45
40
35
30
25
20
15
10
5
0
P =.0003**
P =.0001**
P =.0002**
Inorganic Fertilizer
Paper Waste 10 t/ha
Paper Waste 20 t/ha
Cow Manure 10 t/ha
Cow Manure 20 t/ha
Food Waste 10 t/ha
Food Waste 20 t/ha
Compost 20 t/ha
c) Number of fruits
P =0.40
P =0.46
number
140
120
100
80
60
40
20
0
P =0.55
P =0.34
P =0.51
Inorganic Fertilizer
Paper Waste 10 t/ha
Paper Waste 20 t/ha
Cow Manure 10 t/ha
Cow Manure 20 t/ha
Food Waste 10 t/ha
Food Waste 20 t/ha
Compost 20 t/ha

Figure 3.3

	P values of orthogonal contrast of paired treatments				
	Paper waste Vs Cow Manure	Paper Waste Vs Food Waste	Food Waste Vs Cow Manure	10 t/ha Vs 20 t/ha	Vermicompost vs Compost
Fresh Shoot Weights					
90 DAT	0.36	0.25	0.80	0.01**	0.11
At harvest (155 DAT)	0.01**	0.71	0.02*	0.73	0.96
Dry Shoot Weights					
90 DAT	0.29	0.02*	0.16	0.004**	0.22
At harvest (155 DAT)	0.0007**	0.81	0.0004**	0.08*	0.93
Leaf Area					
90 DAT	0.46	0.69	0.26	0.05*	0.21
YIELD					
Marketable Yield	0.40	0.01**	0.001**	0.04*	0.58
Percent non-marketable	0.003**	0.29	0.0002**	0.33	0.12
Number of fruits	0.64	0.94	0.70	0.76	0.47

Table 3.3: P values resulting from orthogonal contrasts of growth and yield parameters among vermicomposts and composts treatments in 1999.

Figure 3.4. Fresh shoot weights, dry shoot weights, and leaf areas of peppers 56 days after transplanting in 2000. Bars designated by a line (●—●) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted yard waste.

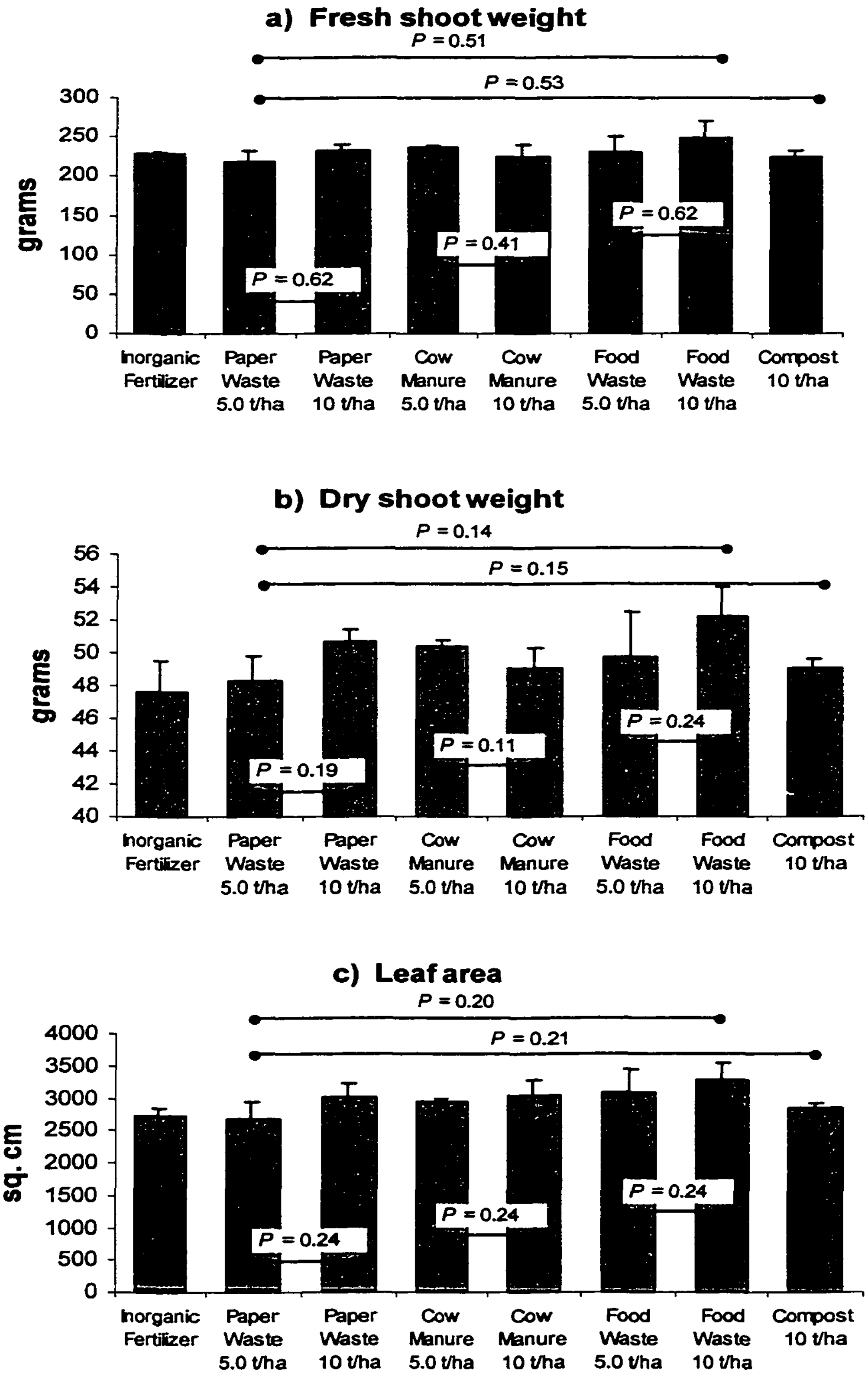
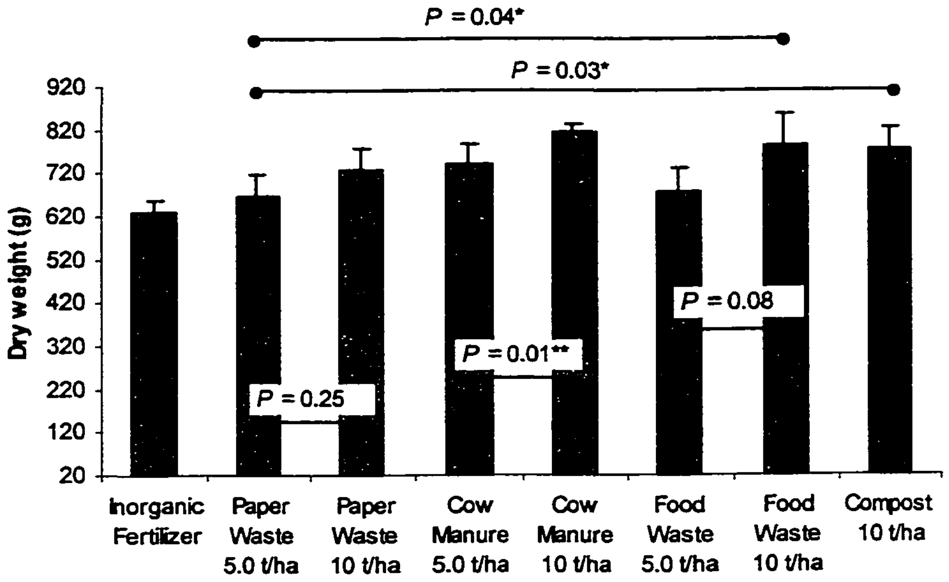

a) Fresh shoot weight
P = 0.51
P = 0.53
grams
300
250
200
150
100
50
0
P = 0.62
P = 0.41
P = 0.62
Inorganic Fertilizer
Paper Waste 5.0 t/ha
Paper Waste 10 t/ha
Cow Manure 5.0 t/ha
Cow Manure 10 t/ha
Food Waste 5.0 t/ha
Food Waste 10 t/ha
Compost 10 t/ha
b) Dry shoot weight
P = 0.14
P = 0.15
grams
56
54
52
50
48
46
44
42
40
P = 0.19
P = 0.11
P = 0.24
Inorganic Fertilizer
Paper Waste 5.0 t/ha
Paper Waste 10 t/ha
Cow Manure 5.0 t/ha
Cow Manure 10 t/ha
Food Waste 5.0 t/ha
Food Waste 10 t/ha
Compost 10 t/ha
c) Leaf area
P = 0.20
P = 0.21
sq. cm
4000
3500
3000
2500
2000
1500
1000
500
0
P = 0.24
P = 0.24
P = 0.24
Inorganic Fertilizer
Paper Waste 5.0 t/ha
Paper Waste 10 t/ha
Cow Manure 5.0 t/ha
Cow Manure 10 t/ha
Food Waste 5.0 t/ha
Food Waste 10 t/ha
Compost 10 t/ha

Figure 3.4

Figure 3.5. Fresh shoot weights, and dry shoot weights of peppers 128 days after transplanting in 2000. Bars designated by a line (●—●) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted yard waste.

a) Shoot Fresh Weights



b) Shoot Dry Weights

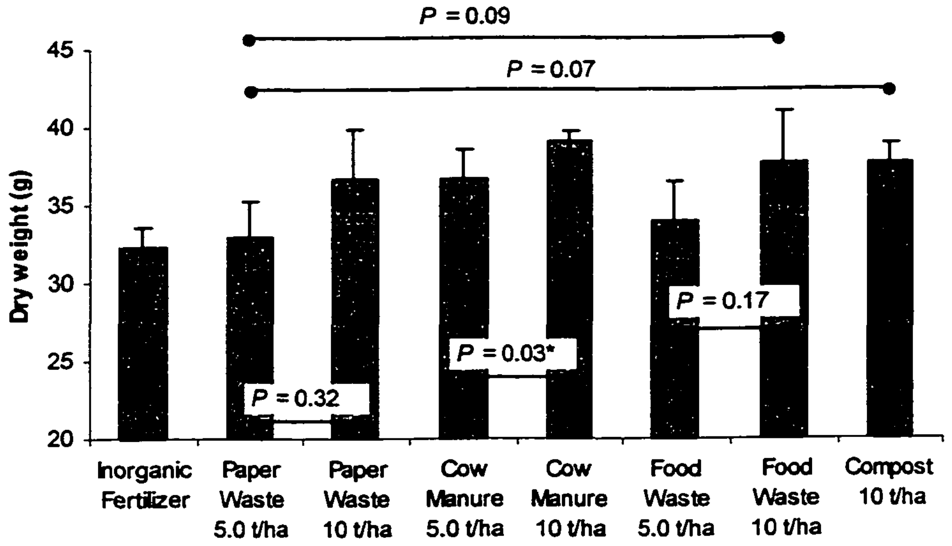


Figure 3.5.

Figure 3.6. Marketable and non-marketable yield, and number of fruits of peppers in 2000. Bars designated by a line (●——●) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted yard waste.

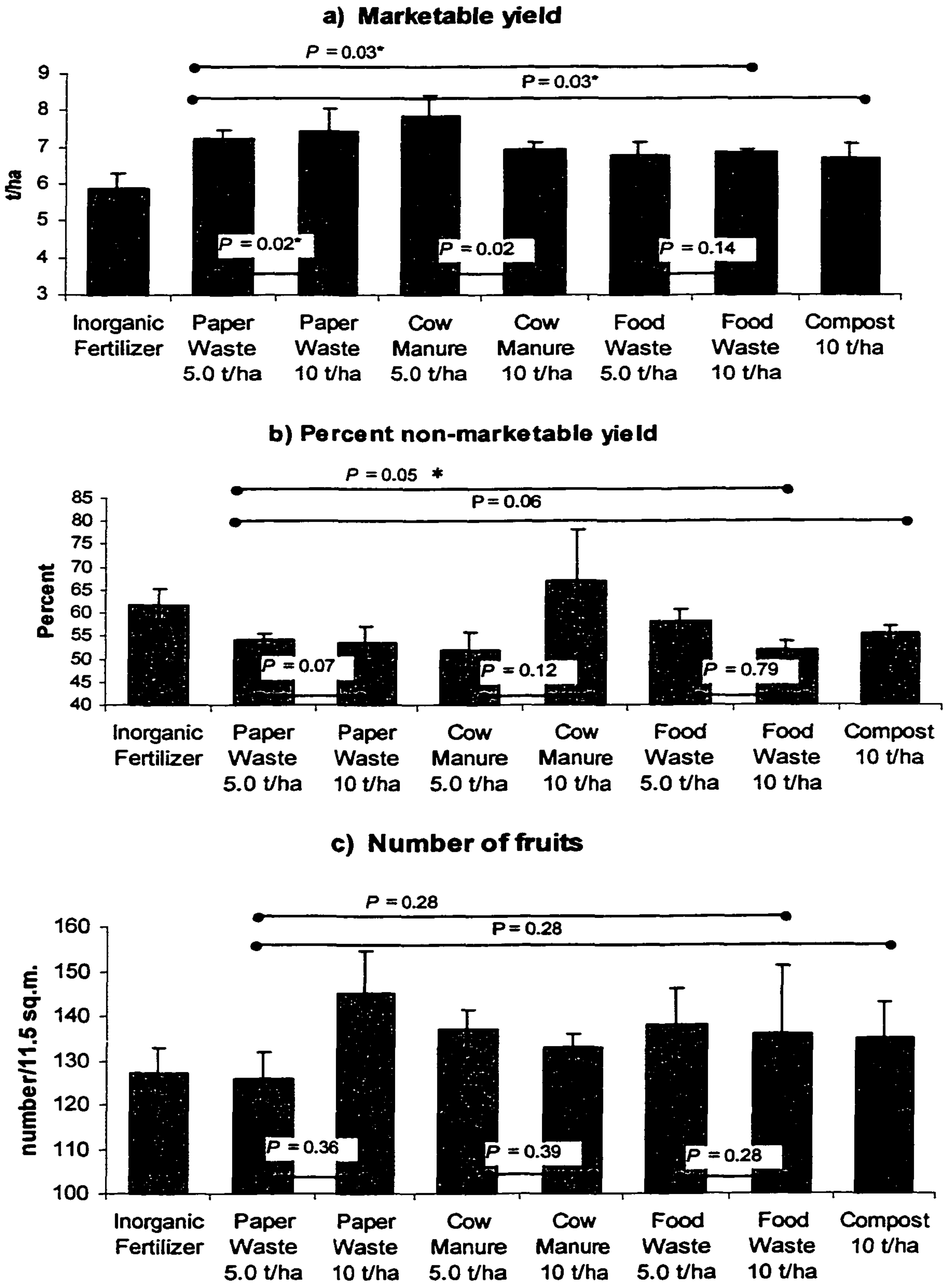

a) Marketable yield
P = 0.03*
P = 0.03*
t/ha
9
8
7
6
5
4
3
P = 0.02*
P = 0.02
P = 0.14
Inorganic Fertilizer
Paper Waste 5.0 t/ha
Paper Waste 10 t/ha
Cow Manure 5.0 t/ha
Cow Manure 10 t/ha
Food Waste 5.0 t/ha
Food Waste 10 t/ha
Compost 10 t/ha
b) Percent non-marketable yield
P = 0.05 *
P = 0.06
Percent
85
80
75
70
65
60
55
50
45
40
P = 0.07
P = 0.12
P = 0.79
Inorganic Fertilizer
Paper Waste 5.0 t/ha
Paper Waste 10 t/ha
Cow Manure 5.0 t/ha
Cow Manure 10 t/ha
Food Waste 5.0 t/ha
Food Waste 10 t/ha
Compost 10 t/ha
c) Number of fruits
P = 0.28
P = 0.28
number/11.5 sq.m.
160
150
140
130
120
110
100
P = 0.36
P = 0.39
P = 0.28
Inorganic Fertilizer
Paper Waste 5.0 t/ha
Paper Waste 10 t/ha
Cow Manure 5.0 t/ha
Cow Manure 10 t/ha
Food Waste 5.0 t/ha
Food Waste 10 t/ha
Compost 10 t/ha

Figure 3.6.

	P values of orthogonal contrast between paired treatments				
	Paper waste vs. Cow Manure	Paper Waste vs. Food Waste	Food Waste vs. Cow Manure	5 t/ha vs 10 t/ha	Vermi. vs Compost
Fresh Shoot Weights					
56 DAT	0.67	0.97	0.72	0.34	0.69
At harvest (128 DAT)	0.08	0.43	0.31	0.03*	0.44
Dry Shoot Weights					
56 DAT	0.71	0.91	0.65	0.20	0.58
At harvest (128 DAT)	0.14	0.62	0.31	0.05*	0.49
Leaf Area					
56 DAT	0.94	0.95	0.90	0.58	0.55
YIELD					
Marketable Yield	0.12	0.18	0.80	0.14	0.37
Percent non-marketable	0.06	0.58	0.16	0.05*	0.65

Table 3.4. *P* values resulting from orthogonal contrasts of growth and yield parameters among vermicomposts and composts treatments in 2000.

3.4.1 DISCUSSION

Effects of vermicompost applications of growth and yield

Differences in pepper plant shoot growth in response to vermicompost or inorganic fertilizer treatments were recorded at harvest in both 1999 and 2000. Significant differences in fresh and dry shoot weights between peppers grown in vermicompost-treated plots and those in inorganic control plots occurred with those plants grown in vermicompost-treated plots producing the greatest weights. However, leaf areas of the peppers began to differ between treatments as early as 56 days after transplanting in 1999 with plants in the cow manure vermicompost-treated plots having the greatest leaf areas. Overall, yields of peppers in the vermicompost-treated plots were greater than those in the inorganic control plots. Several workers have reported similar increases in plant growth and yield in response to traditional composts amendments. Positive yield responses to annual compost additions of 80 t/ha for bermudagrass, 143 t/ha for sorghum, and 112 t/ha for corn were reported by Mays et al (1973). Suzuki et al (1990) reported larger yields in rice yields after only after 10 years of compost applications. Cereal, potato, and sugar beet yields were also greater after municipal solid waste compost applications (Bauduin et al, 1986).

Vermicompost applications have been reported to improve seedling growth in peas, lettuce, cabbage, wheat, tomato and radishes (Edwards and Burrows, 1988). Increases in the growth of ornamentals have been also reported (Atiyeh, 1998; 2000; Scott 1988; Buckerfield et al. 1999). These increases in growth have been associated with increases in a range of growth parameters such as root lengths, lateral root numbers, shoot lengths and internode lengths of soybean seedlings (Chan and Griffiths, 1988) and better rooting in vanilla cuttings (Siddagangaiah et al, 1996). Greater shoot biomass and seed yields of cowpea were obtained after field application of vermicomposts (Mba, 1983). Increased yields of grapes (Buckerfield and Webster, 1998) and coriander (Venkatesh et al, 1999) have been reported in response to vermicompost additions.

Peppers require adequate amounts of most major and minor nutrients but appear to be less responsive to fertilizer applications, especially phosphorus, than onions, lettuce and cole crops (Cotter, 1986). However, more recent reports have concluded that peppers are very responsive to phosphorus (Haas et al, 1987, Davies and Linderman, 1991). Phosphorus deficiency symptoms in peppers include narrow leaves which are often glossy and develop a grayish green color. Davies et al, (1999) reported lower photosynthetic rates and stomatal conductance, high internal carbon dioxide concentrations and leaf-to-air vapor pressures of bell peppers plants in response to phosphorus stress which lead to low productivity. Plants with adequate P concentration could be expected to be more vigorous with higher photosynthetic rates and stomatal conductance than plants with limited P (Radin 1984, Dietz and Foyer 1986, Radin and Eudenbock 1986). Although there were no obvious differences in leaf color in my experiments, the narrower leaves, which decreased leaf areas in peppers in the inorganic plots, suggest that the peppers might have been phosphorus deficient. Most of the vermicomposts and composts used contained adequate amounts of phosphorus which enabled the plants to develop larger leaf areas, higher photosynthetic rates and stomatal conductance. Such higher photosynthetic rates would have produced greater shoot growth which in turn enabled plants to produce more marketable fruits. Cow manure vermicomposts contained most phosphorus which produced plants with the largest leaf areas compared with the other treatments. Application of larger amounts of vermicomposts meant that more phosphorus was added to the plots. This produced greater leaf areas of plants that received 20 t/ha vermicompost compared to those that received 10 t/ha.

However although nitrogen is essential, too much nitrogen can over-stimulate plant growth resulting in larger plants producing few early fruits. Excess nitrogen availability delays maturity during period of high rainfall and humidity, resulting in plants with succulent late-maturing fruits and increased risk of serious plant or pod rots (Bosland and Votava, 2000). Nitrogen deficiency symptoms in peppers include yellowing that leads to severe necrosis and abscission of the leaves. In my experiments, plants grown in inorganic control plots produced most non-marketable fruits mostly due to pod rots compared to those in the vermicompost-treated plants. However, the increases in the numbers of non-marketable fruits on plants in inorganic control plots could not be explained by excessive nitrogen availability because there was no over-growth which would have been indicated by their shoot weights. Similarly, increases in pepper shoot growth in plants in the vermicompost and compost-treated plots could not have resulted from excess nitrogen because there were lower proportions of non-marketable fruits relative to those in the inorganic controls.

Lower rates of pepper growth and yields in peppers in the inorganic control plots could also have been due to deficiencies to other microelements. For instance, magnesium deficiency is characterized in pepper plants by a pale-green leaf color, followed by interveinal yellowing, leaf drop, small plants and undersized fruit (Bosland and Votava, 2000). Although not all of these symptoms could be observed in the pepper plants grown in the inorganic control plots, smaller plants and fruits suggest that this may have been due to magnesium deficiency. Almost all of the vermicomposts used in my experiments contained adequate amounts of magnesium that could have supported plant growth in vermicompost-treated plots better than plants in the inorganic control plots.

Most damage to non-marketable fruits was due to fruit rots. The most common form of fruit rot in peppers was Blossom-End rot which probably due to calcium deficiencies. Since the inorganic control plots did not receive any calcium supplement, then it could have contributed to greater incidence of Blossom-End rots and relatively high proportions of non-marketable fruits.

Yields are highly dependent on the capacity of the plant to photosynthesize and successfully translocate the products of photosynthesis into storage organs such as fruits. Fruits are referred to as the major "sinks" and the photosynthesizing leaves as the major "source" during the reproductive stage of plants. In a sink manipulation experiment conducted by Bhatt and Rao (1997), it was reported that pepper fruits constitute the main "sink" for assimilates during the reproductive phase of the plant whereas the shoots constitute the main "source". Increased sink load due to more fruits changes the dry matter distribution in the vegetative parts (Nielsen and Vierkev, 1988). In my experiments, the mean numbers of fruits between treatments did not differ suggesting relatively equal sink i.e. potential capacity to store products of photosynthesis. Plants grown in the inorganic control plots possibly produced lower yields as a result of a greater sink relative to a lower source i.e. capacity to produce photosynthates. Increased pepper shoot growth in the vermicompost-treated plots enabled the plants to develop a more vigorous source of photosynthates that balanced well with the number of fruits.

As discussed in Chapter 2, it is possible that the high microbial populations in vermicompost may have influenced plant growth. Their activity in the soil has been reported by many authors to improve soil structure and influence the root environment and plant growth indirectly. The byproducts of their activities may include polysacharrarides that are involved directly in the aggregation of soil particles. Another known products of their activities that were reported to directly influence plant growth are plant growth-regulating substances. Several workers that have reported plant growth-regulators are found in some soils and at varying concentrations in vermicomposts. Their positive influence on plants have been detailed in Chapter 2. It is possible that the presence of plant growth-regulators in vermicomposts increased the growth and yields of peppers.

Still other work which is detailed in Chapter 2 by Muscolo et al (1999) reported that humic materials extracted from vermicompost produced auxin-like effects on plants such as carrots. It is also possible that humic acids from the vermicompost used in the experiment could have had direct positive influences on the growth and yield of peppers. In an experiment in our laboratory by Atiyeh et al. (2000), definitive evidence of the positive effects of humic acids extracted from pig manure and food waste vermicomposts were shown. In their experiments, humic acids, applied to vegetable seedlings grown on soil-less media, increased the growth of tomato and cucumber plants significantly and that the growth increases were correlated directly with the concentration of humic acids incorporated in the container medium but decreased when concentration exceeded 500-1000 mg/kg. They concluded that growth responses were either due to the ability of humic acids to have hormone-like activities or because they have plant growth regulators adsorbed onto them and that these influence growth. It seems likely that humic acids produced the vermicomposts used in the experiment have also increased growth and yield of peppers. However, it is still not clear whether the growth response are due directly to humates or to plant growth-regulators adsorbed onto them.

3.3.2 RESULTS

The biochemical changes of soil in response to vermicompost applications

Ammonium-nitrogen (NH_4-N) in the first year

In 1999, amounts of NH_4-N decreased in soil from all plots from the transplanting date to155 DAT (days after transplanting) (Figure 3.7a –f). Ammonium-nitrogen levels were significantly greater in soils from the inorganic control plots than in the vermicompost-treated plots from transplanting up to 30 DAT, $P < 0.05$. There were no significant differences in NH_4-N occurred 155 DAT in all the treatments.

Nitrate-nitrogen (NO_3-N) in the first year

Amounts of nitrate-nitrogen (NO_3-N) decreased in soils from all plots from the transplanting date to 155 DAT (Fig. 3.8a – f). Soil from plots receiving inorganic fertilizer contained significantly more NO_3-N compared to other vermicompost plots at transplanting, $P < 0.05$. Soils in cow manure vermicompost treated plots had significantly more NO_3-N from 120 DAT to 155 DAT. Among the vermicompost treatments, significant differences in soil levels of NO3-N occurred on all sampling dates (Table 3.3).

Total extractable nitrogen in the first year

Total amounts of extractable nitrogen in soil decreased in all plots from transplanting to 155 DAT (Figure 9a-f). Soil from the inorganic control plots contained more extractable nitrogen than that from any other plots from transplanting to 30 DAT. Soil in the cow manure vermicompost-treated plots contained more extractable nitrogen from 120 DAT to 155 DAT. Significant differences in total extractable nitrogen occurred on all sampling dates between the vermicompost treatments. Soils from cow manure vermicompost treatment maintained significantly greater amounts of total extractable nitrogen, $P < 0.05$ (Table 3.4).

Dissolved organic nitrogen levels in 1999

Amounts of dissolved organic nitrogen (DON) in soils decreased in all treatments from transplanting to 155 DAT (Figure 3.11a –f). No significant differences in DON in soils from all plots occurred at 65 DAT when the soil in paper waste vermicompost-treated plots had significantly less DON. Significant differences in soil DON occurred in response to all vermicompost treatments occurred 65 DAT and 90 DAT but there were no significant differences in DON contents in soils treated with vermicompost in Table 3.4.

Microbial biomass nitrogen in 1999

Amounts of microbial biomass nitrogen decreased in soil from all plots from transplanting to 30 DAT (Fig. 12a – b). However, increases in the microbial biomass N occurred 65 DAT in soils from all plots and decreased from 90 DAT to 155 DAT. No significant differences in microbial biomass in any soil occurred from transplanting to 30 DAT. However, from 65 to 155 DAT soils from the vermicompost and compost-treated plots contained significantly more microbial biomass nitrogen than those from the inorganic controls ($P < 0.05$). Soil from plots treated with paper waste and cow manure vermicomposts had more microbial biomass than those from the food waste vermicompost plots (Table 3.4). However, there were no significant differences in levels of soil microbial biomass between the different vermicompost treatments 90 DAT. Soils from plots treated with cow manure vermicompost-treated plots contained significantly greater microbial biomass nitrogen at harvest (155 DAT) than soils from food waste and paper waste vermicompost treatments.

Orthophosphate in 1999

There were increases in amounts of orthophosphate in soils from vermicompost and compost-treated plots 65 DAT to 155 DAT compared to those in soils from inorganic control plots (Fig. 3.13c). Soil from plots treated with paper waste and food waste vermicomposts contained significantly more orthophosphates than soil from those treated with cow manure, $P < 0.01$.

Dehydrogenase activity in 1999

There was increased dehydrogenase activity (DHA) in soils from vermicompost-treated plots, 30 DAT and 155 DAT compared to those in soils from the inorganic controls (Fig 3.14a – f). There were no other significant differences.

Nitrogen in 2000

Amounts of NH4-N, NO_3-N, total extractable nitrogen, and DON in soils did not differ statistically between all the plots from transplanting to 128 DAT (Fig. 3.15, 3.16, 3.17 and 3.18). Soils from the 5 t/ha vermicompost treatment rate had more NO_3-N and total extractable nitrogen compared to those treated with 10 t/ha (Table 5). There was progressive decrease in all the nitrogen parameters measured in soil from all the plots from transplanting to 128 DAT. Microbial biomass nitrogen in soils was at its lowest level 85 DAT in all plots (Fig. 3.19). Soil from the vermicompost-treated plots contained significantly more in microbial biomass from 85 DAT to 128 DAT than those in the soil from inorganic control plots, $P < 0.05$.

Orthophosphate in 2000

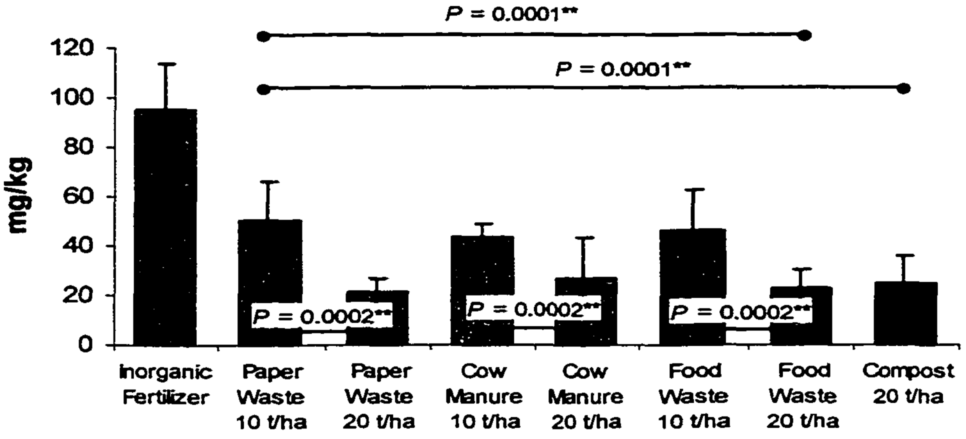
Amounts of orthophosphates were significantly greater in the soils from the vermicompost and compost-treated plots 56 to 128 DAT than in soil from inorganic control plots, $P < 0.05$ (Fig. 3.20,).

Dehydrogenase activity 2000

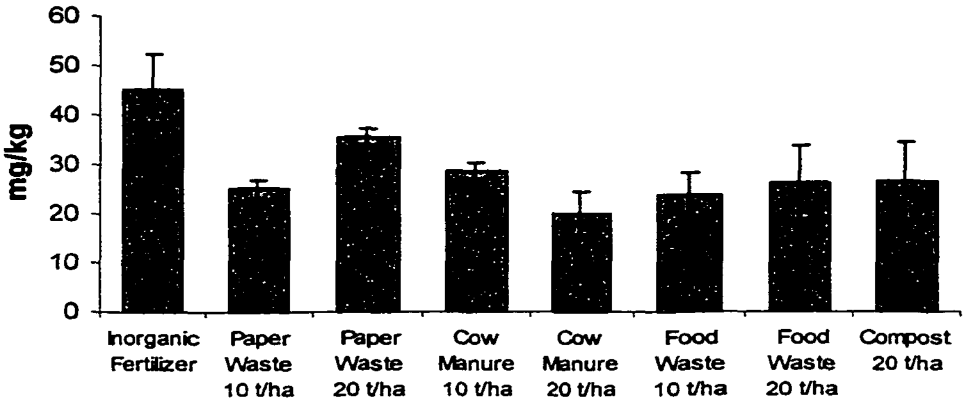
Dehydrogenase activity in soils decreased from transplanting to 128 DAT (Fig. 3.21). With no significant differences occurring between soil from the inorganic controls and the vermicompost treatments, 10 t/ha of vermicompost produced more DHA in soil than 5 t/ha, $P < 0.05$ (Table 3.5).

Figure 3.7. Ammonium-nitrogen in pepper plots at transplanting, 30, 56, 90, 120 and 155 DAT (days after transplanting) in 1999. Bars designated by a line (●——●) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted sewage sludge.

a) at Transplanting



b) 30 DAT



c) 65 DAT

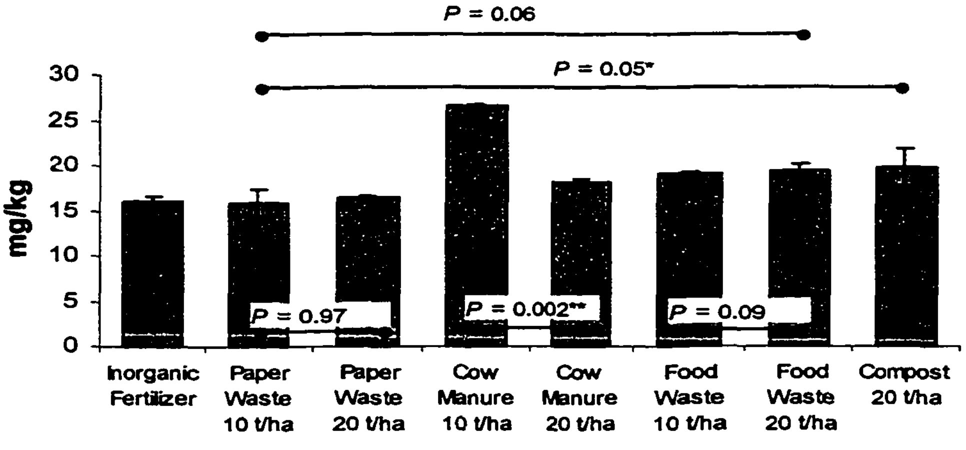
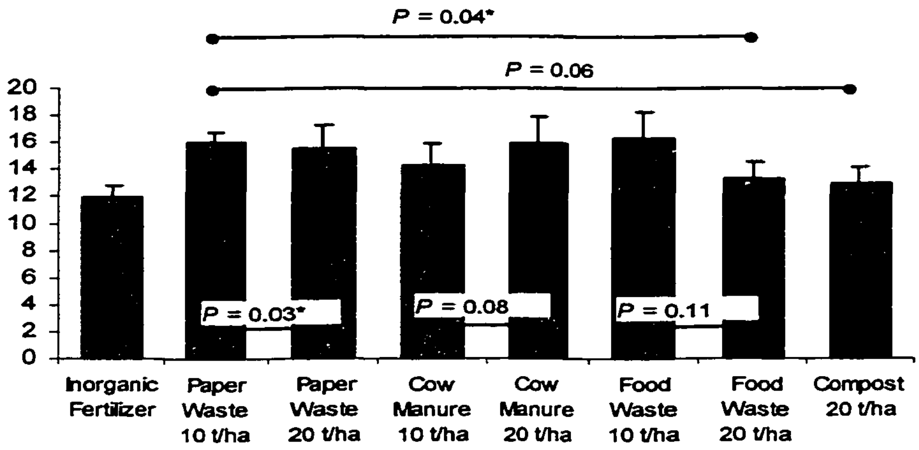


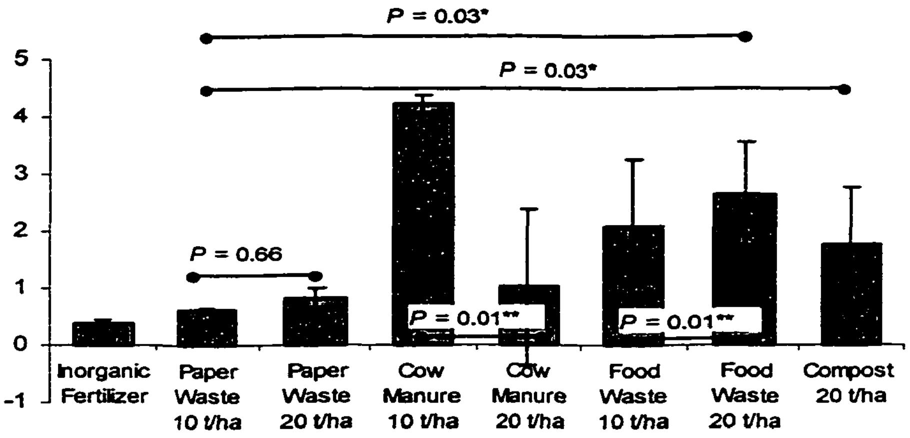
Figure 3.7. (continued)

Figure 3.7 (continued)

d) 90 DAT



e) 120 DAT



f) 155 DAT

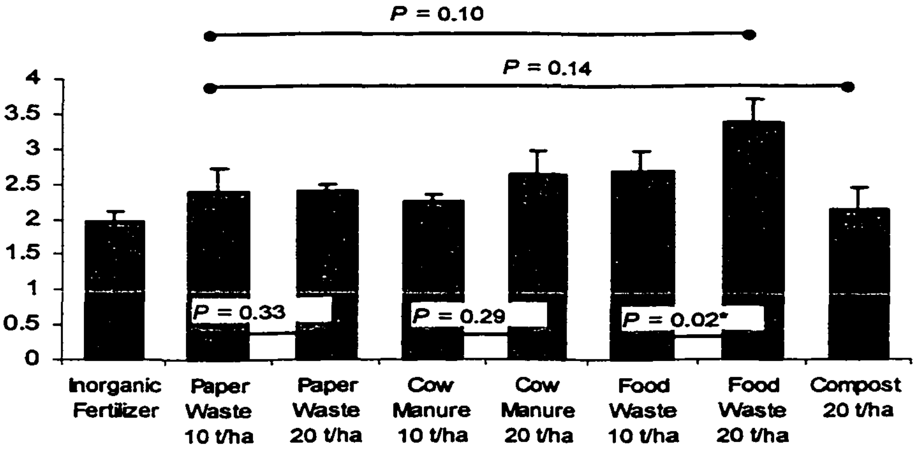
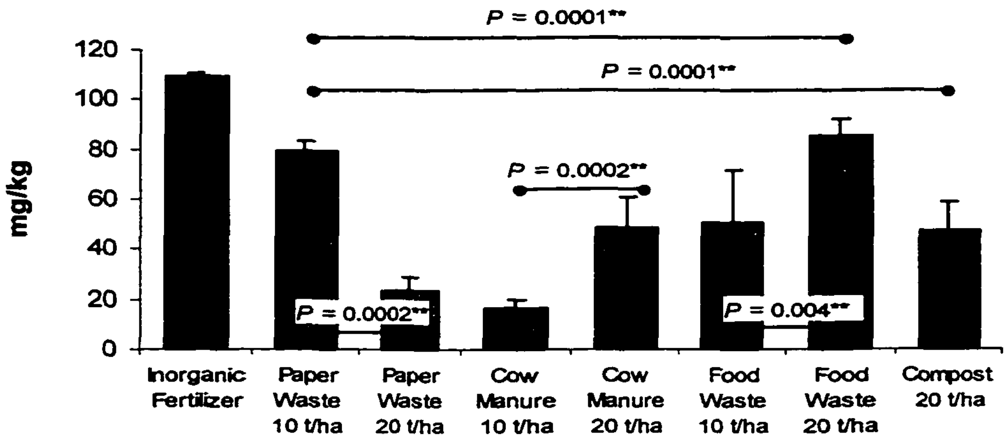
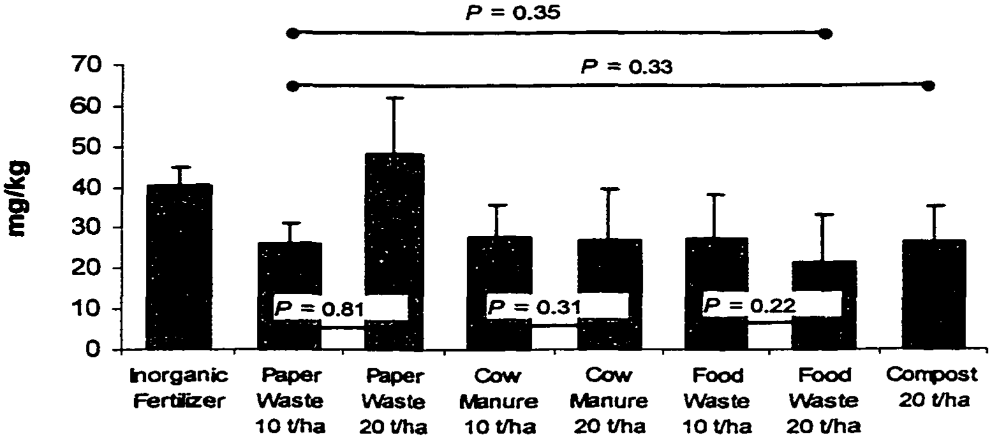


Figure 3.8. Nitrate-nitrogen (NO_3-N) in pepper plots at transplanting, 30, 56, 90, 120 and 155 DAT (days after transplanting) in 1999. Bars designated by a line (•———•) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted sewage sludge.

a) at Transplanting



b) 30 DAT



c) 65 DAT

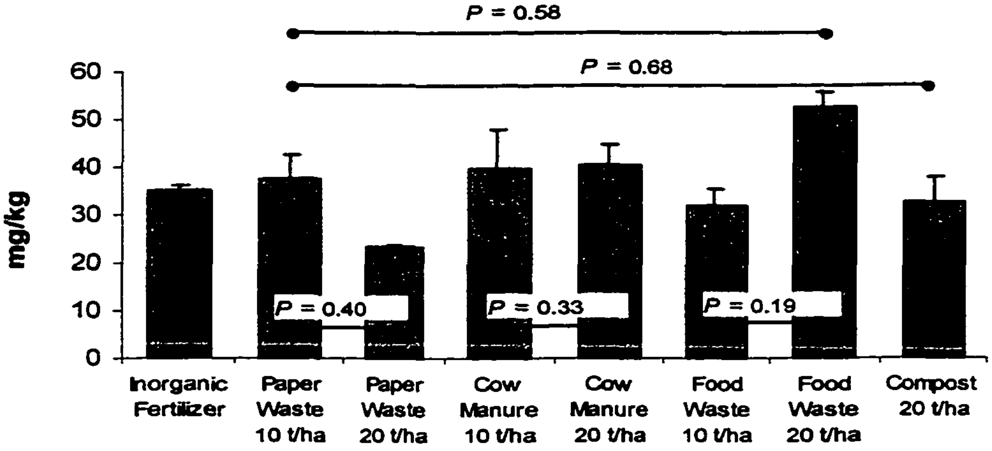
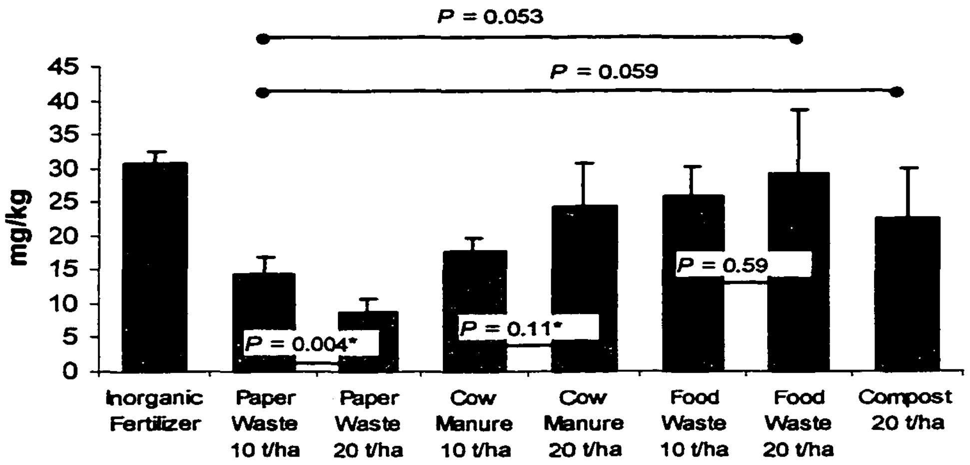


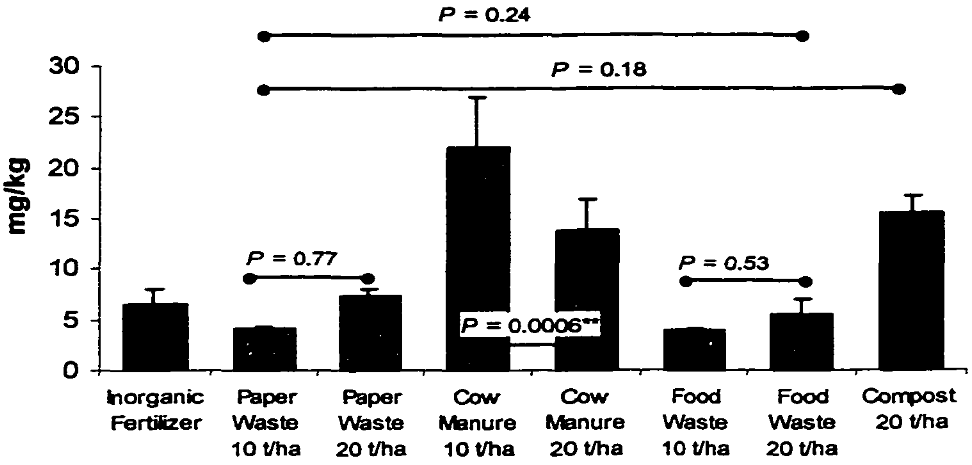
Figure 3.8 (continued)

Figure 3.8 (continued)

d) 90 DAT



e) 120 DAT



f) 155 DAT

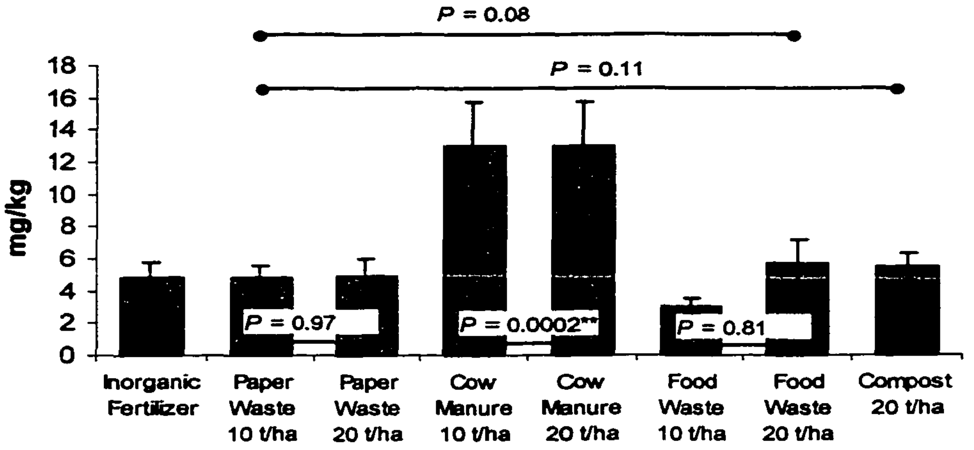
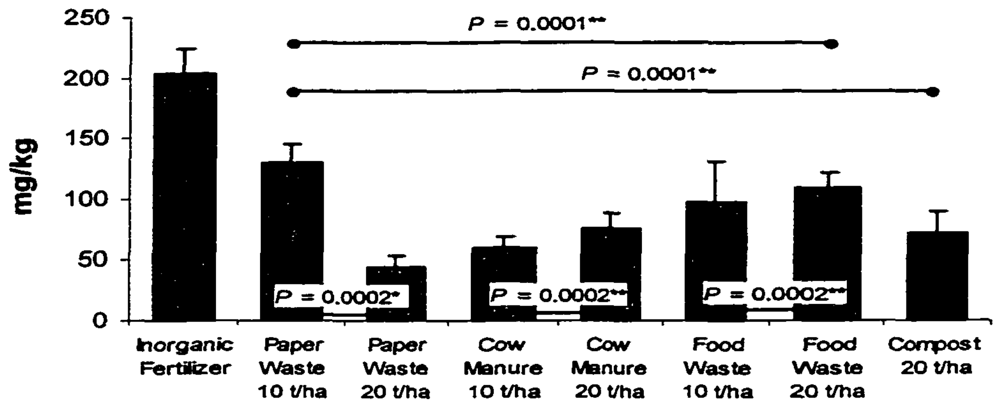
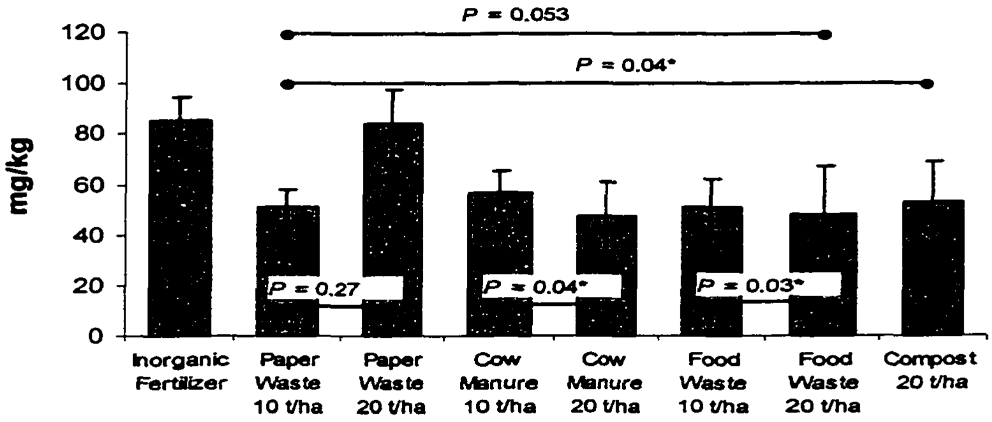


Figure 3.9. Total extractable nitrogen in pepper plots at transplanting, 30, 56, 90, 120 and 155 DAT (days after transplanting) in 1999. Bars designated by a line (•——•) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted sewage sludge.

a) at Transplanting



b) 30 DAT



c) 65 DAT

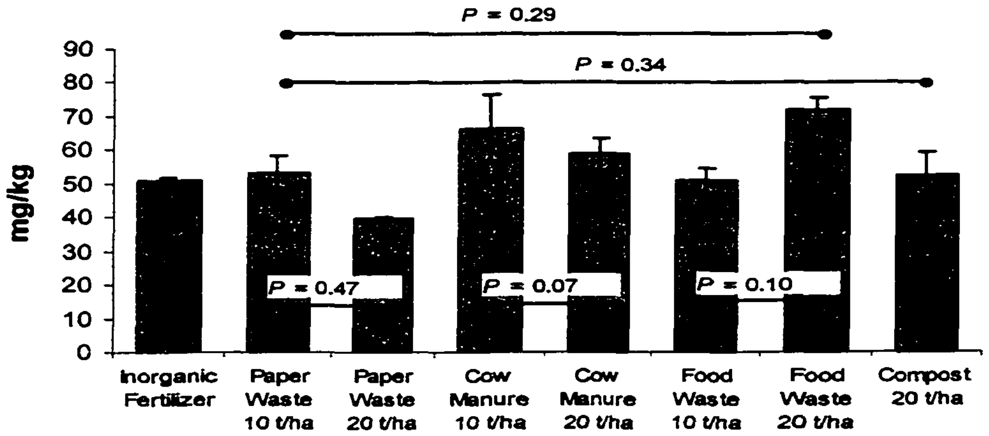
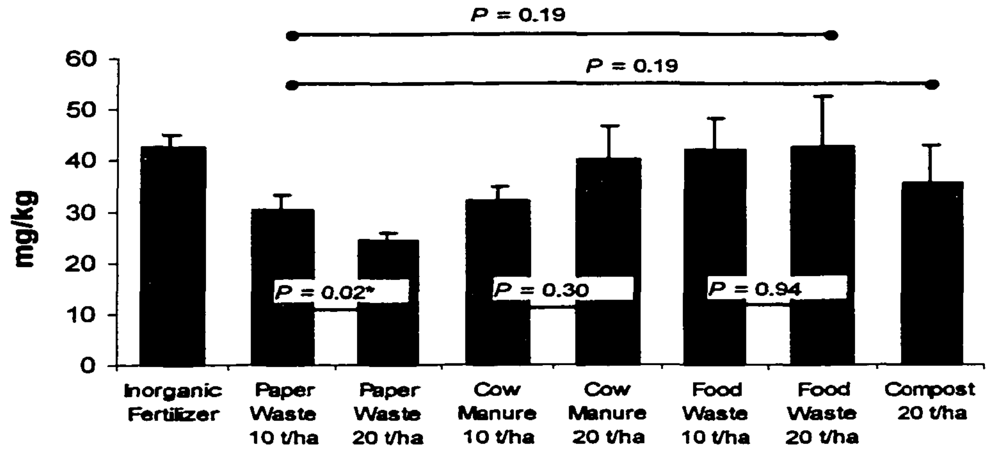


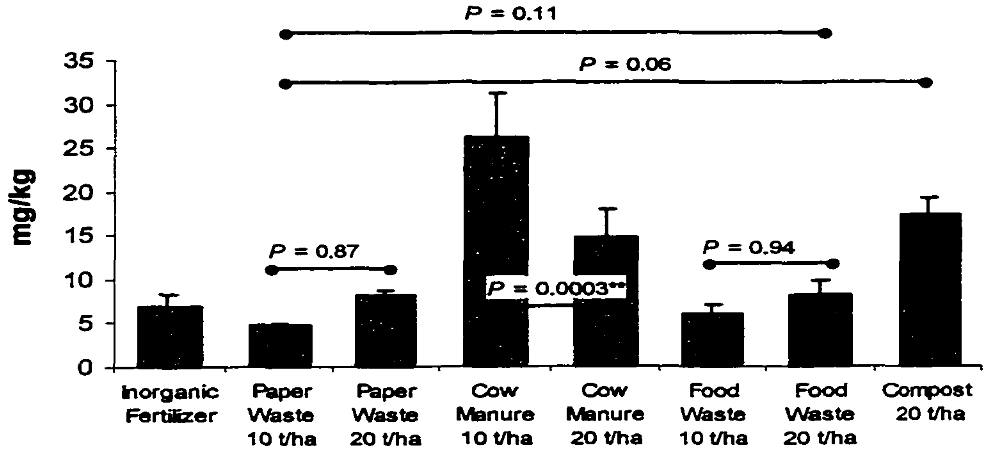
Figure 3.9 (continued)

Figure 3.9 (continued)

d) 90 DAT



e) 120 DAT



f) 155 DAT

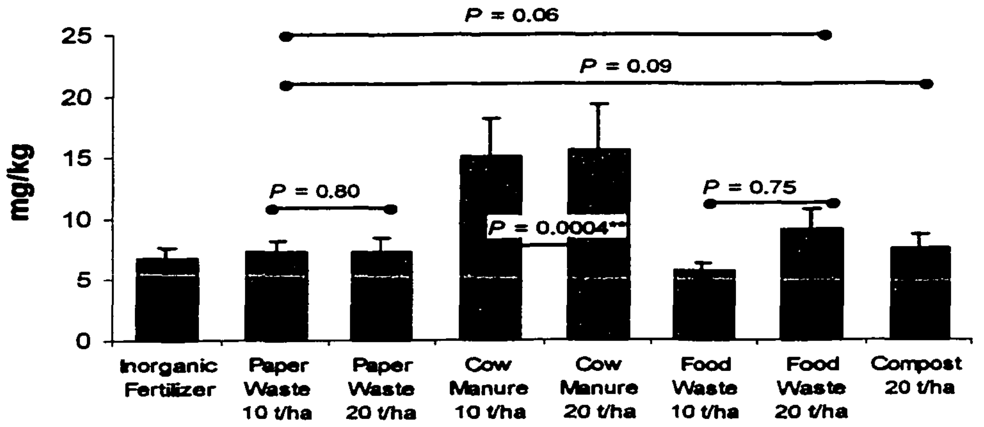


Figure 3.10: Dissolved organic nitrogen (DON) in pepper plots at transplanting, 30, 56, 90, 120 and 155 DAT (days after transplanting) in 1999. Bars designated by a line (●—●) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted sewage sludge.

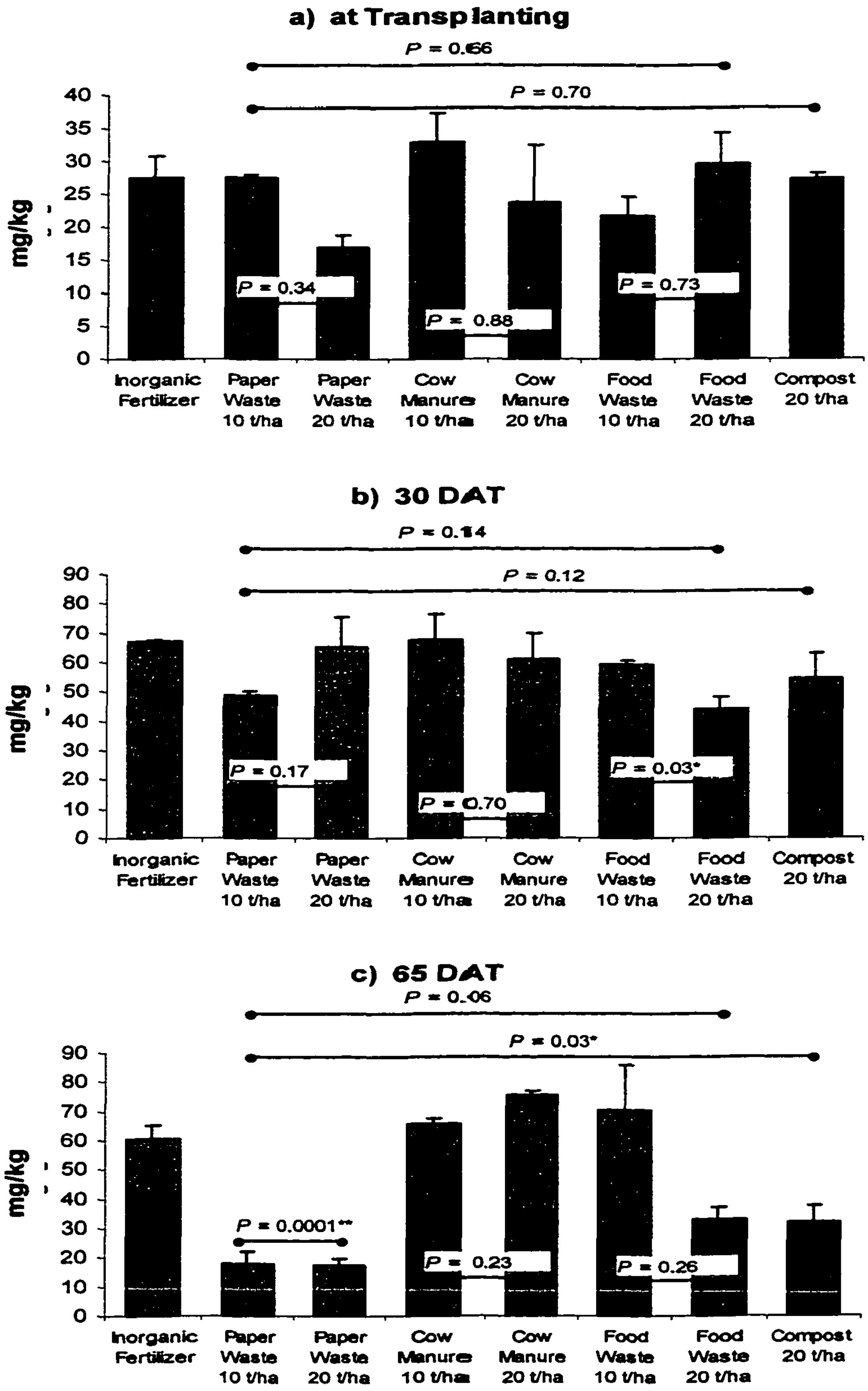
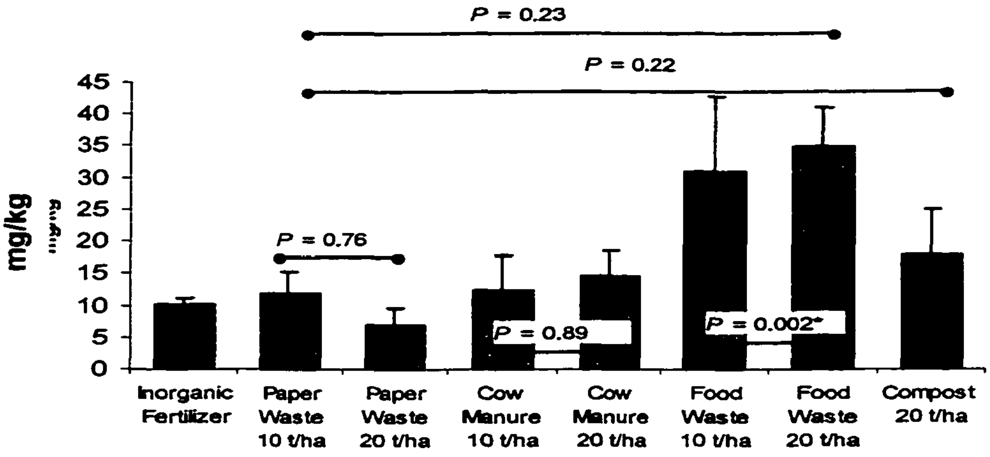


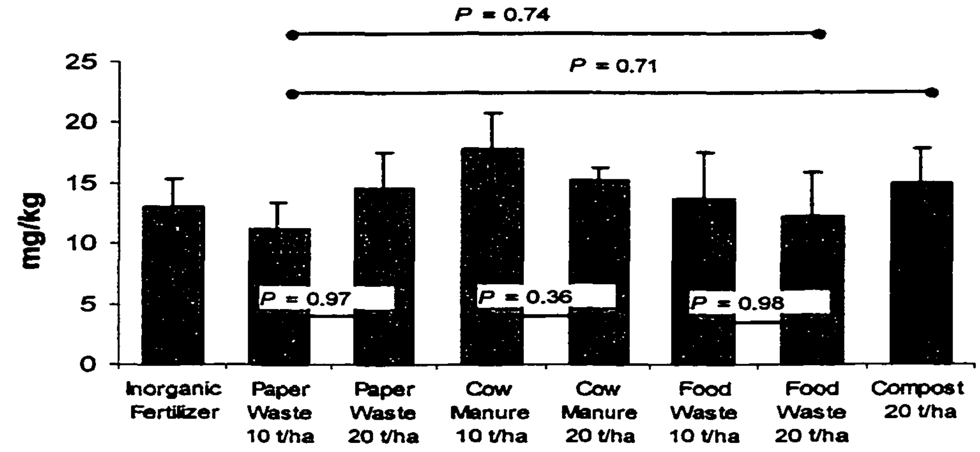
Figure 3.10. (continued)

Figure 3.10. (continued)

d) 90 DAT



e) 120 DAT



f) 155 DAT

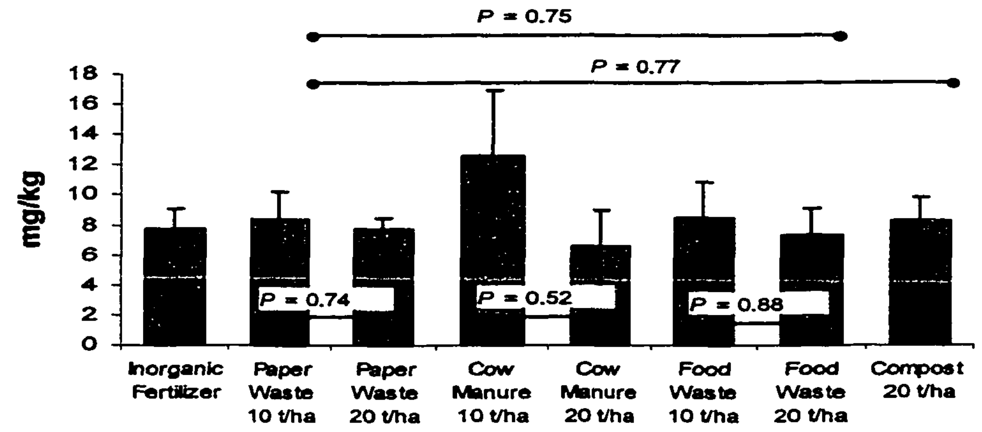
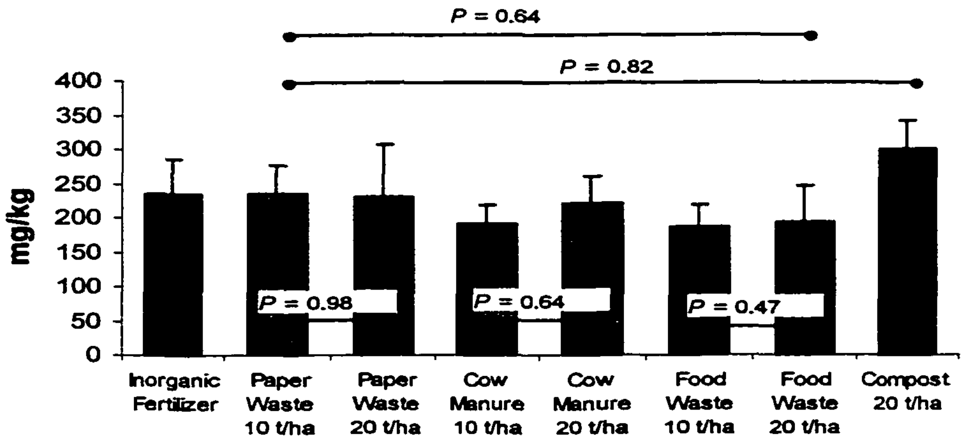
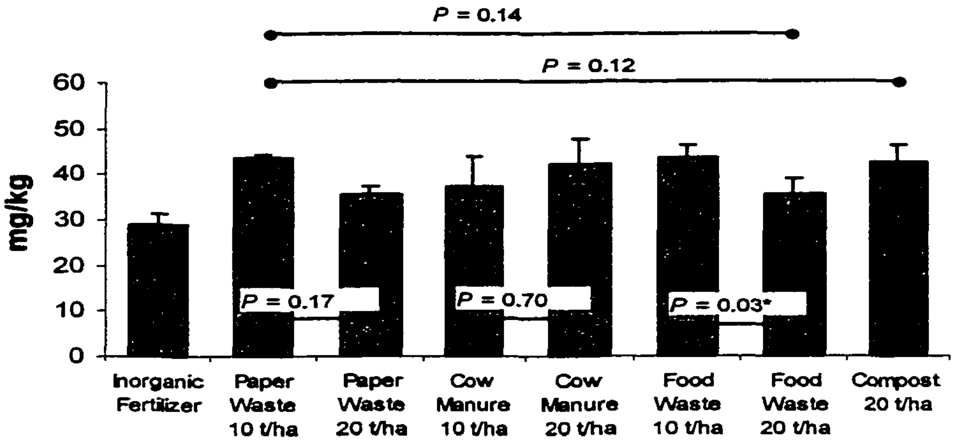


Figure 3.11. Microbial biomass nitrogen in pepper plots at transplanting, 30, 56, 90, 120 and 155 DAT (days after transplanting) in 1999. Bars designated by a line (●——●) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted sewage sludge.

a) at Transplanting



b) 30 DAT



c) 65 DAT

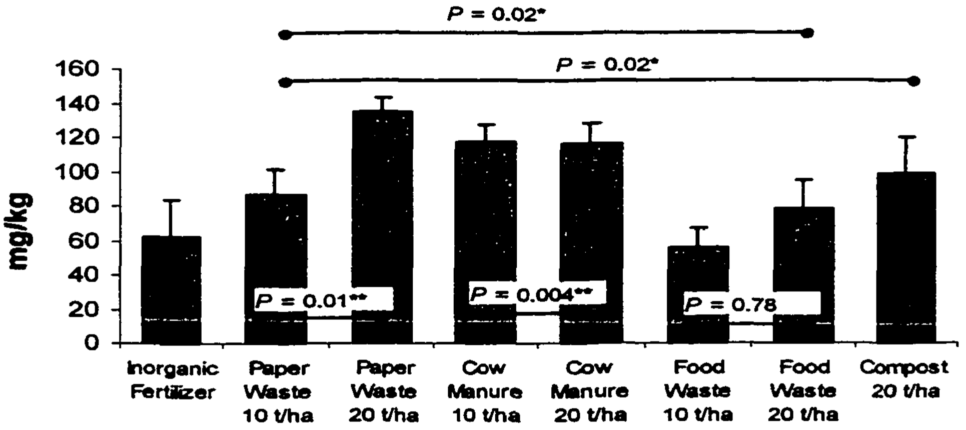
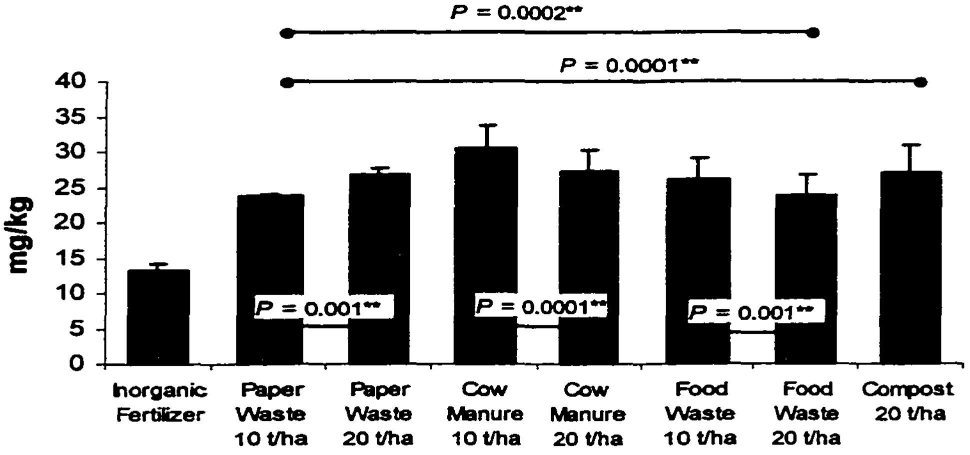


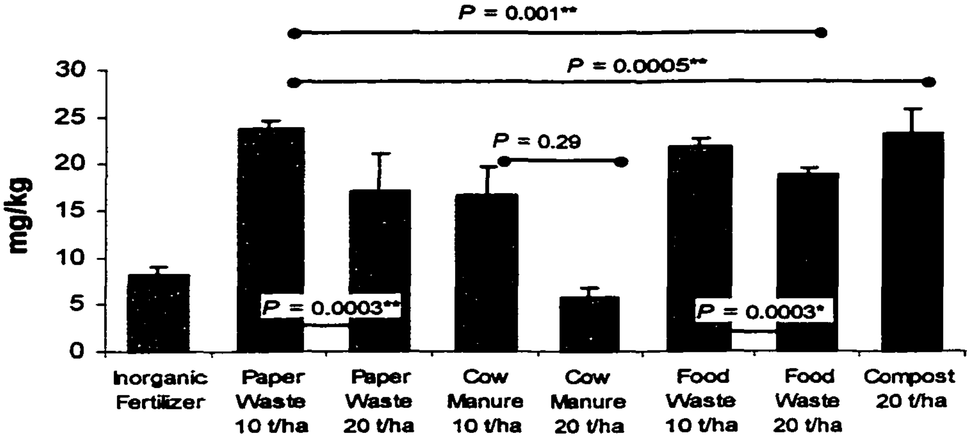
Figure 3.11. (continued)

Figure 3.11. (continued)

d) 90 DAT



e) 120 DAT



f) 155 DAT

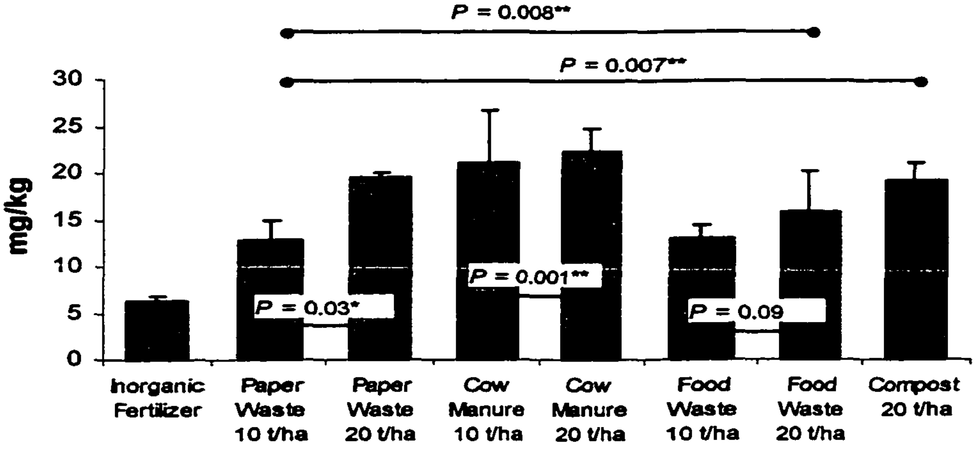
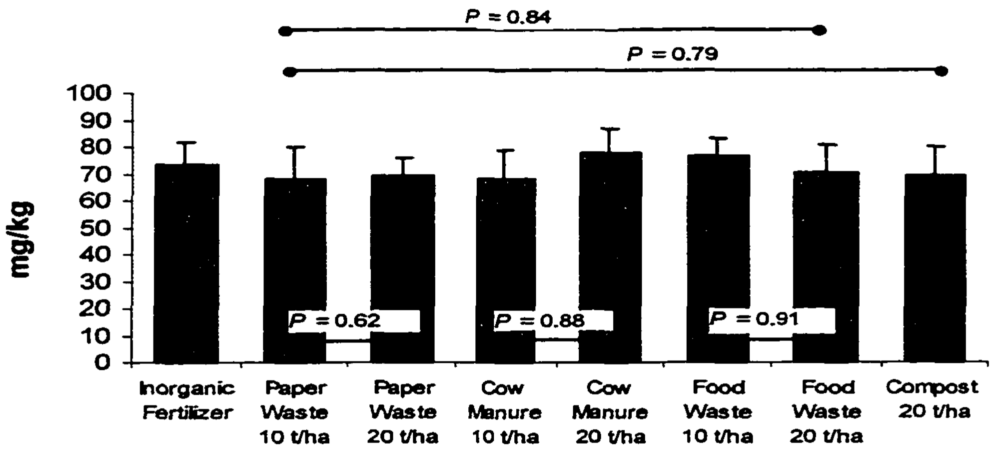
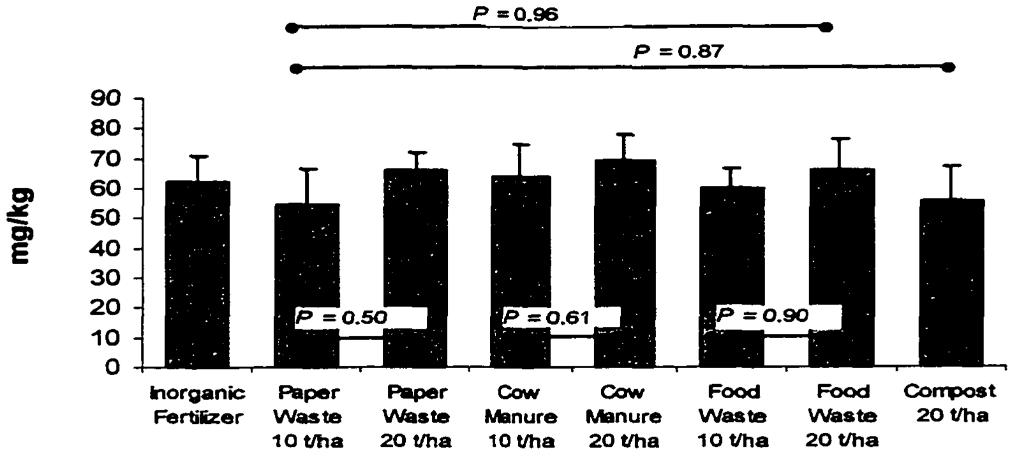


Figure 3.12. Orthophosphates in pepper plots at transplanting, 30, 56, 90, 120 and 155 DAT (days after transplanting) in 1999. Bars designated by a line (●——●) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted sewage sludge.

a) at Transplanting



b) 30 DAT



c) 65 DAT

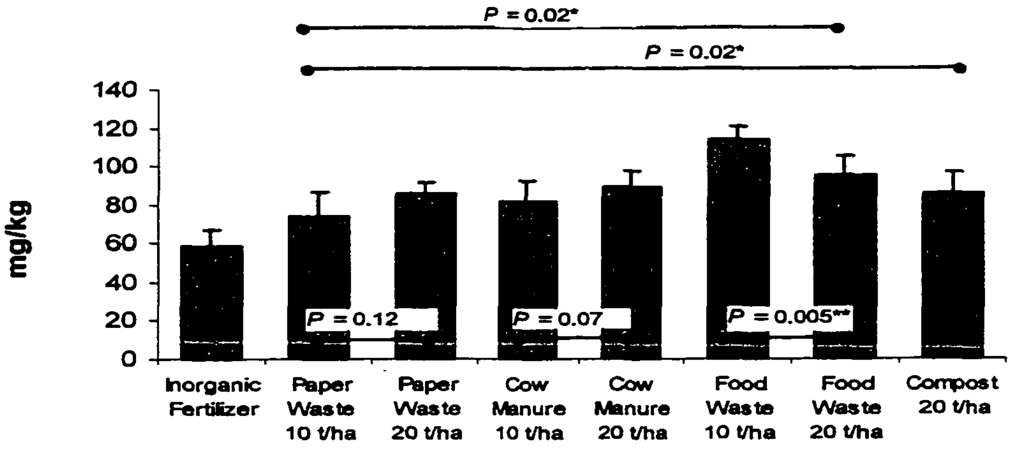
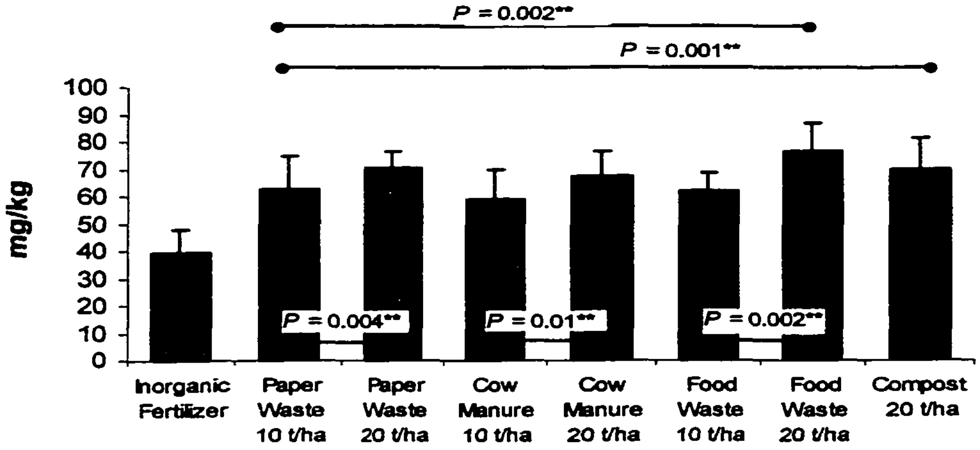


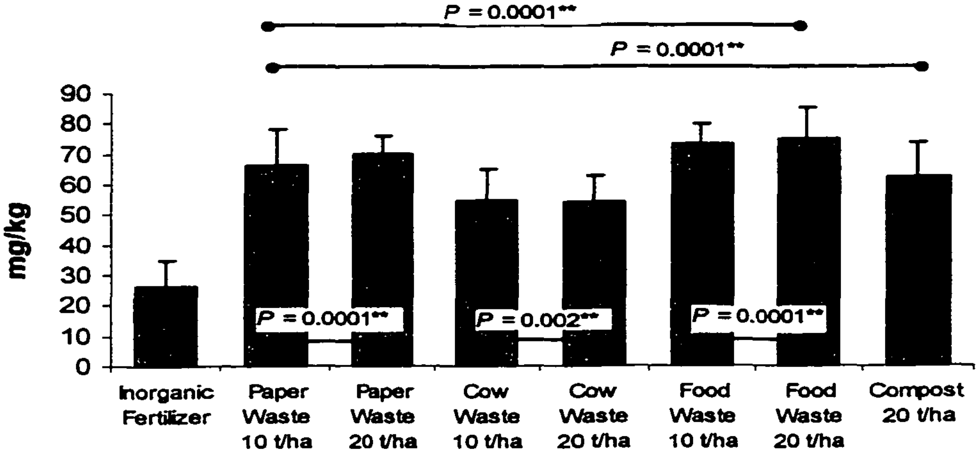
Figure 3.12 (continued)

Figure 3.12 (continued)

d) 90 DAT



e) 120 DAT



f) 155 DAT

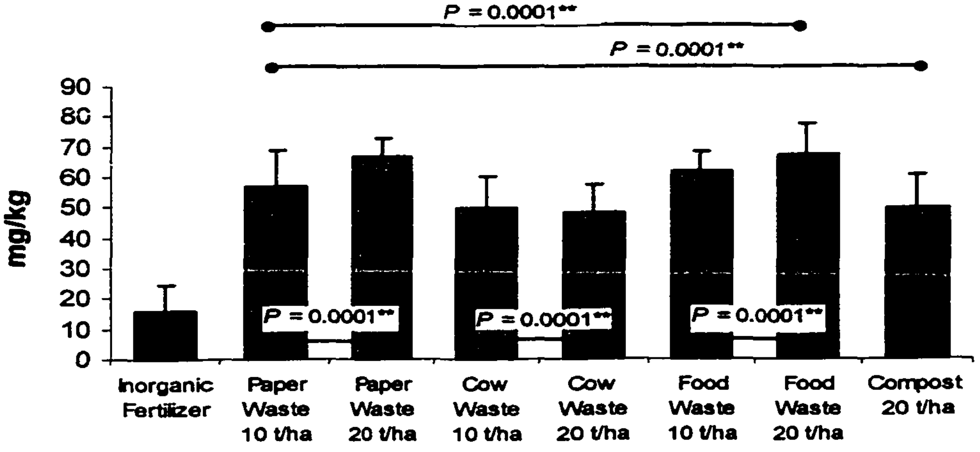
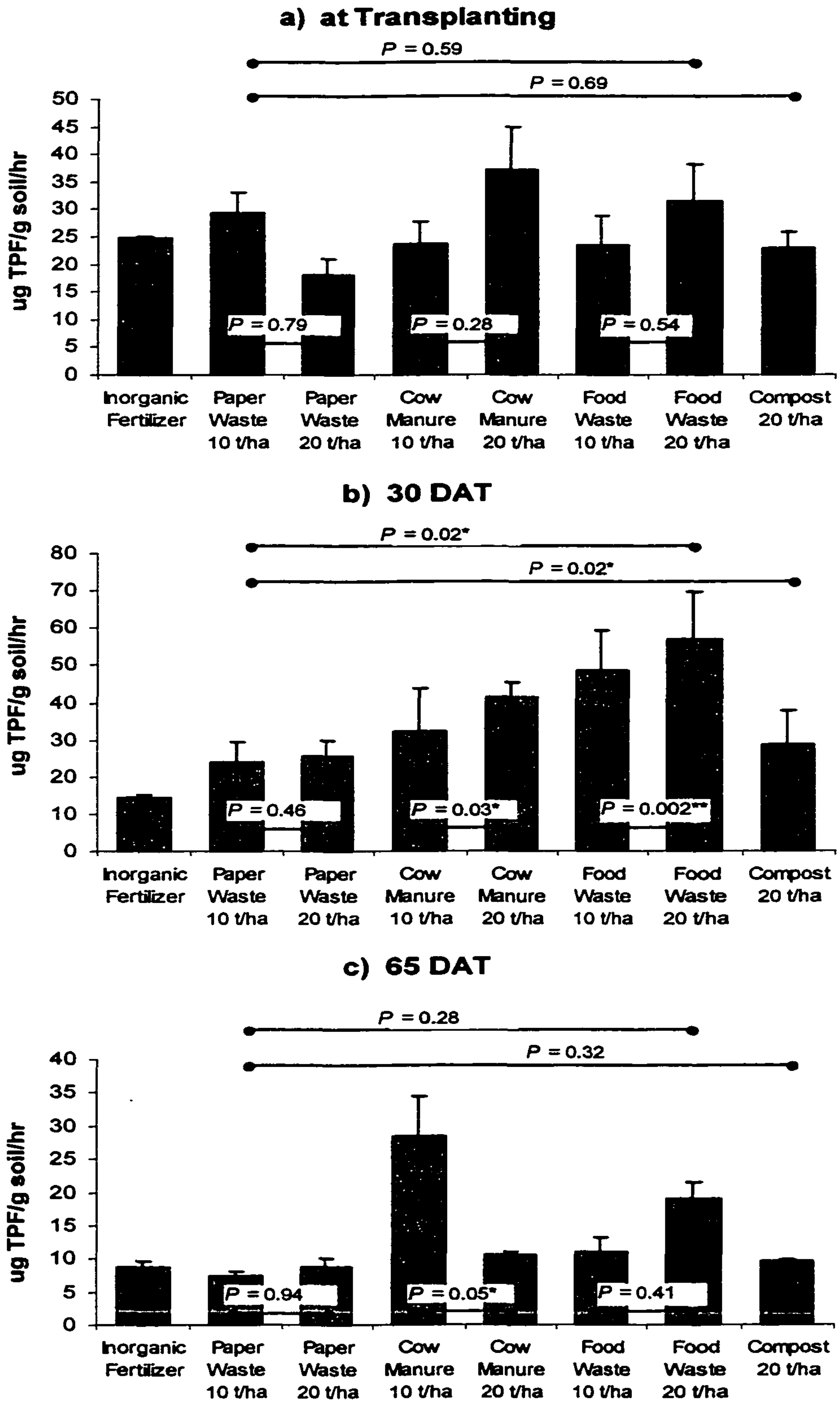


Figure 3.13. Dehydrogenase enzyme activity (DHA) in pepper plots at transplanting, 30, 56, 90, 120 and 155 DAT (days after transplanting) in 1999. Bars designated by a line (●—●) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted sewage.


a) at Transplanting

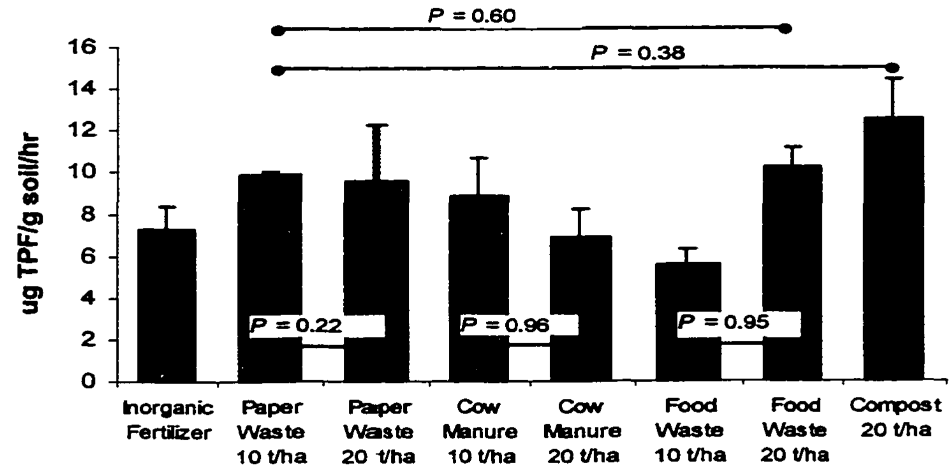
b) 30 DAT

c) 65 DAT

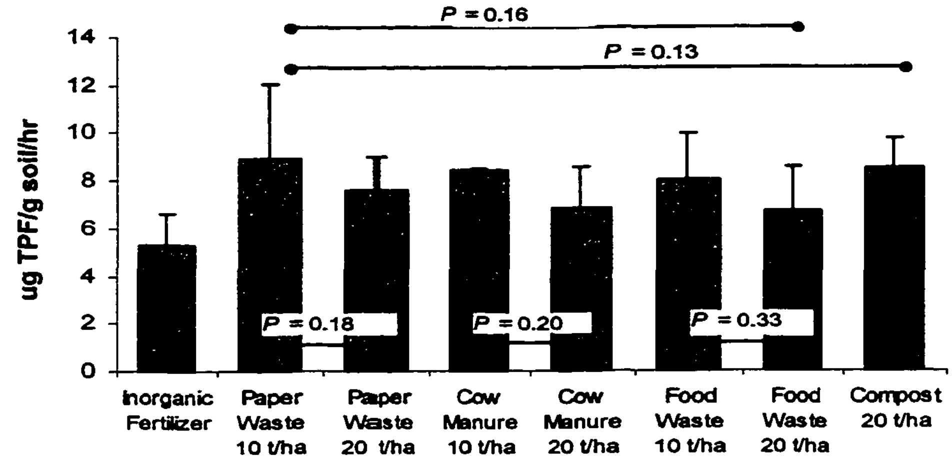
Figure 3.13 (continued)

Figure 3.13 (continued)

d) 90 DAT



e) 120 DAT



f) 155 DAT

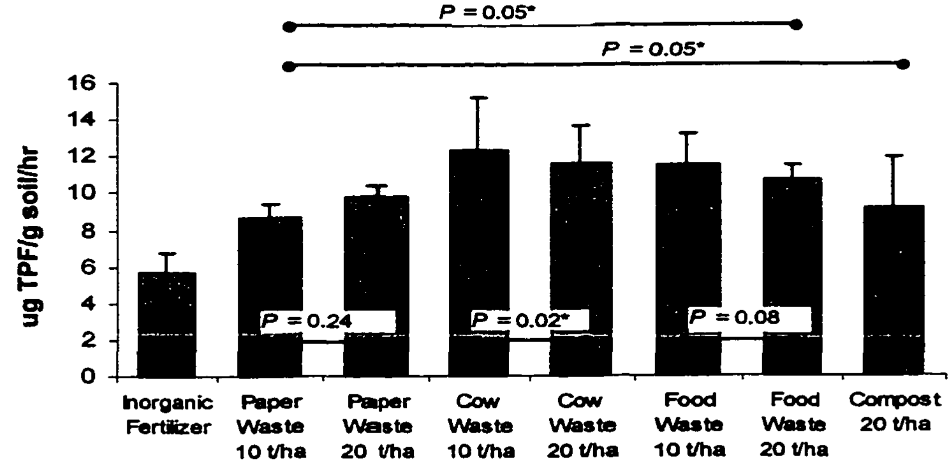


Table 3.5. P values resulting from orthogonal contrasts of soil chemical characteristics in pepper plots among vermicomposts and composts treatments in 1999. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted sewage sludge.

	P values of orthogonal contrast of paired treatments				
	Paper waste Vs Cow Manure	Paper Waste Vs Food Waste	Food Waste Vs Cow Manure	10 t/ha Vs 20 t/ha	Vermicompost vs Compost
Total Extractable N					
At Transplanting	0.26	0.35	0.04*	0.17	0.45
30 DAT	0.24	0.18	0.86	0.54	0.82
65 DAT	0.004**	0.007**	0.81	0.96	0.42
90 DAT	0.10	0.008**	0.24	0.82	0.96
120 DAT	0.0001**	0.7905	0.0001**	0.34	0.04*
155 DAT	0.0001**	0.93	0.0001**	0.35	0.15
NH4-Nitrogen					
At Transplanting	0.95	0.91	0.96	0.01**	0.37
30 DAT	0.26	0.31	0.91	0.73	0.99
65 DAT	0.0004**	0.04*	0.04*	0.05*	0.72
90 DAT	0.61	0.45	0.80	0.61	0.13
120 DAT	0.008**	0.01**	0.79	0.09	0.87
155 DAT	0.90	0.09	0.11	0.22	0.21
NO3-Nitrogen					
At Transplanting	0.08	0.11	0.002**	0.68	0.76
30 DAT	0.34	0.23	0.78	0.54	0.77
65 DAT	0.03*	0.01**	0.66	0.51	0.30
90 DAT	0.06	0.003**	0.19	0.70	0.63
120 DAT	0.0001**	0.67	0.0001**	0.55	0.02*
155 DAT	0.0001**	0.73	0.0001**	0.45	0.17
Dissolved Organic N					
At Transplanting	0.18	0.45	0.54	0.28	0.69
30 DAT	0.22	0.33	0.03*	0.72	0.64
65 DAT	0.0001**	0.0001**	0.008**	0.09	0.04*
90 DAT	0.66	0.0005**	0.003**	0.91	0.94
120 DAT	0.25	0.98	0.25	0.92	0.81
155 DAT	0.75	0.63	0.39	0.26	0.84
Biomass N					
At Transplanting	0.58	0.39	0.75	0.78	0.10
30 DAT	0.22	0.33	0.03*	0.72	0.64
65 DAT	0.69	0.005**	0.002**	0.05*	0.98
90 DAT	0.18	0.89	0.14	0.69	0.82
120 DAT	0.0005**	0.96	0.0006**	0.001**	0.02*
155 DAT	0.05*	0.60	0.02*	0.15	0.56
Orthophosphate					
At Transplanting	0.65	0.47	0.76	0.64	0.63
30 DAT	0.20	0.37	0.63	0.12	0.43
65 DAT	0.68	0.05*	0.11	0.91	0.71
90 DAT	0.64	0.65	0.36	0.07	0.62
120 DAT	0.05	0.36	0.007**	0.78	0.67
155 DAT	0.03*	0.64	0.01**	0.33	0.17
DHA					
At Transplanting	0.09	0.29	0.51	0.38	0.28
30 DAT	0.05*	0.002**	0.12	0.65	0.26
65 DAT	0.01**	0.28	0.10	0.36	0.44
90 DAT	0.14	0.15	0.97	0.53	0.01**
120 DAT	0.93	0.59	0.59	.039	0.61

Table 3.5

Figure 3.14. Ammonium-nitrogen (NH_4-N) in pepper plots at transplanting, 56, 85, 128 DAT (days after transplanting) in 2000. Bars designated by a line (•——•) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted yard waste.

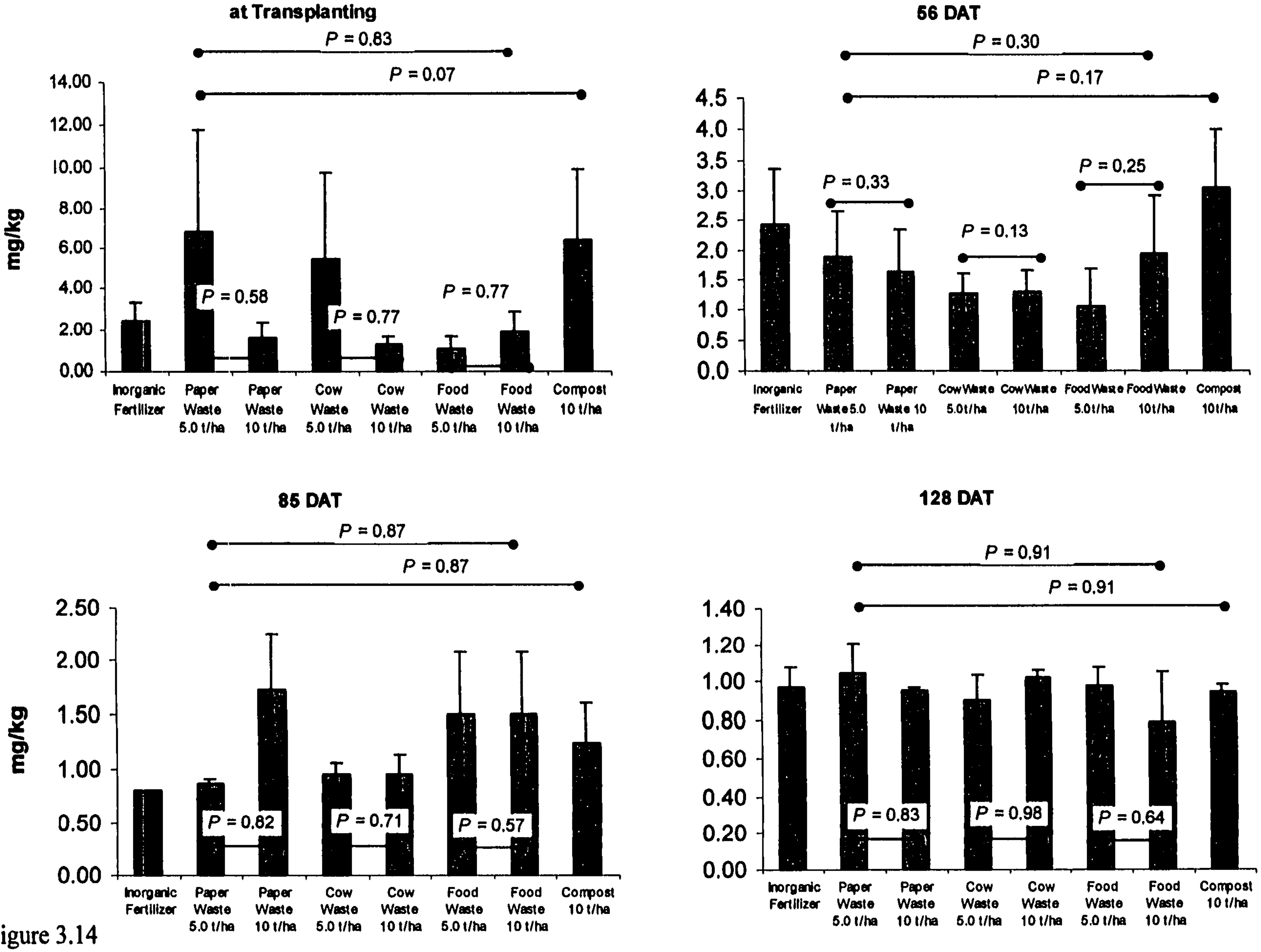

at Transplanting
P = 0.83
P = 0.07
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
mg/kg
P = 0.58
P = 0.77
P = 0.77
Inorganic Fertilizer
Paper Waste 5.0 t/ha
Paper Waste 10 t/ha
Cow Waste 5.0 t/ha
Cow Waste 10 t/ha
Food Waste 5.0 t/ha
Food Waste 10 t/ha
Compost 10 t/ha
56 DAT
P = 0.30
P = 0.17
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
P = 0.33
P = 0.13
P = 0.25
Inorganic Fertilizer
Paper Waste 5.0 t/ha
Paper Waste 10 t/ha
Cow Waste 5.0 t/ha
Cow Waste 10 t/ha
Food Waste 5.0 t/ha
Food Waste 10 t/ha
Compost 10 t/ha
85 DAT
P = 0.87
P = 0.87
2.50
2.00
1.50
1.00
0.50
0.00
mg/kg
P = 0.82
P = 0.71
P = 0.57
Inorganic Fertilizer
Paper Waste 5.0 t/ha
Paper Waste 10 t/ha
Cow Waste 5.0 t/ha
Cow Waste 10 t/ha
Food Waste 5.0 t/ha
Food Waste 10 t/ha
Compost 10 t/ha
128 DAT
P = 0.91
P = 0.91
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
P = 0.83
P = 0.98
P = 0.64
Inorganic Fertilizer
Paper Waste 5.0 t/ha
Paper Waste 10 t/ha
Cow Waste 5.0 t/ha
Cow Waste 10 t/ha
Food Waste 5.0 t/ha
Food Waste 10 t/ha
Compost 10 t/ha

Figure 3.14

Figure 3.15. Nitrate-nitrogen ($N0_3$-N) in pepper plots at transplanting, 56, 85, 128 DAT (days after transplanting) in 2000. Bars designated by a line (●——●) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted yard waste.

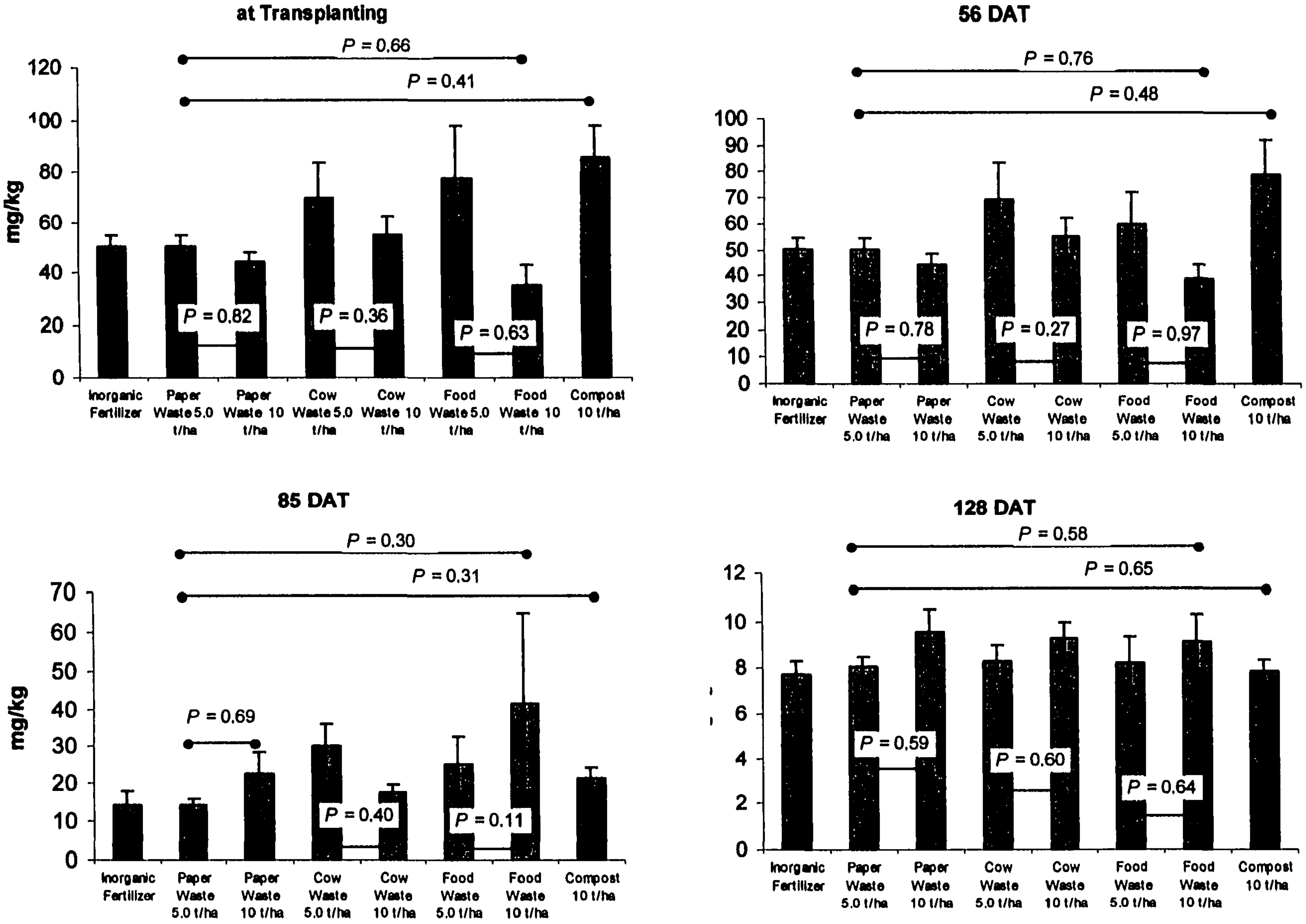

at Transplanting
P = 0.66
P = 0.41
mg/kg
120
100
80
60
40
20
0
P = 0.82
P = 0.36
P = 0.63
Inorganic Fertilizer
Paper Waste 5.0 t/ha
Paper Waste 10 t/ha
Cow Waste 5.0 t/ha
Cow Waste 10 t/ha
Food Waste 5.0 t/ha
Food Waste 10 t/ha
Compost 10 t/ha
56 DAT
P = 0.76
P = 0.48
100
90
80
70
60
50
40
30
20
10
0
P = 0.78
P = 0.27
P = 0.97
85 DAT
P = 0.30
P = 0.31
70
60
50
40
30
20
10
0
P = 0.69
P = 0.40
P = 0.11
128 DAT
P = 0.58
P = 0.65
12
10
8
6
4
2
0
P = 0.59
P = 0.60
P = 0.64

Figure 3.15.

Figure 3.16. Total extractable nitrogen in pepper plots at transplanting, 56, 85, 128 DAT (days after transplanting) in 2000. Bars designated by a line (●———●) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted yard waste.

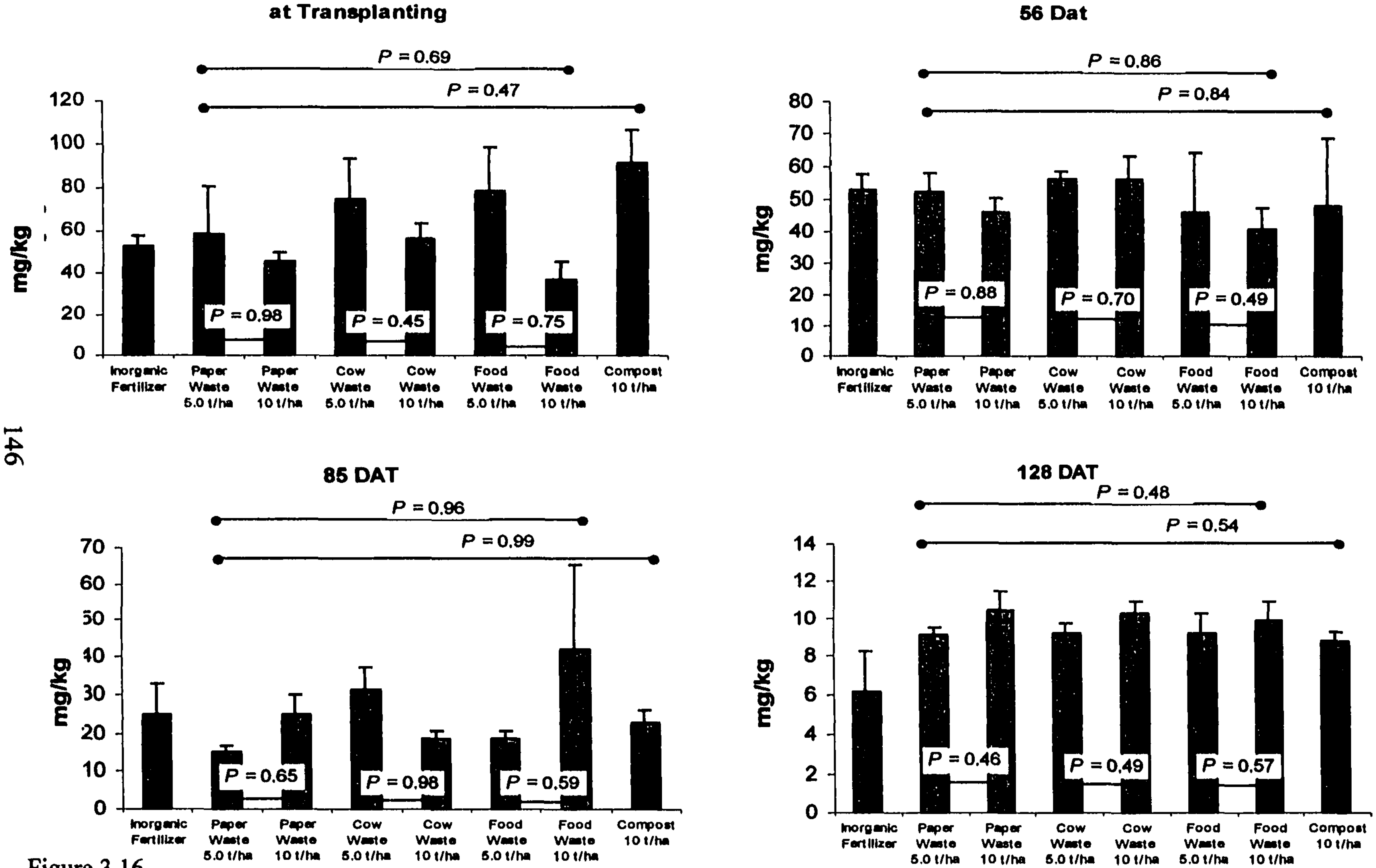

at Transplanting
P = 0.69
P = 0.47
mg/kg
120
100
80
60
40
20
0
P = 0.98
P = 0.45
P = 0.75
Inorganic Fertilizer
Paper Waste 5.0 t/ha
Paper Waste 10 t/ha
Cow Waste 5.0 t/ha
Cow Waste 10 t/ha
Food Waste 5.0 t/ha
Food Waste 10 t/ha
Compost 10 t/ha
56 Dat
P = 0.86
P = 0.84
mg/kg
80
70
60
50
40
30
20
10
0
P = 0.88
P = 0.70
P = 0.49
85 DAT
P = 0.96
P = 0.99
mg/kg
70
60
50
40
30
20
10
0
P = 0.65
P = 0.98
P = 0.59
128 DAT
P = 0.48
P = 0.54
mg/kg
14
12
10
8
6
4
2
0
P = 0.46
P = 0.49
P = 0.57

Figure 3.16.

Figure 3.17: Dissolved organic nitrogen in pepper plots at transplanting, 56, 85, 128 DAT (days after transplanting) in 2000. Bars designated by a line (●——●) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted yard waste.

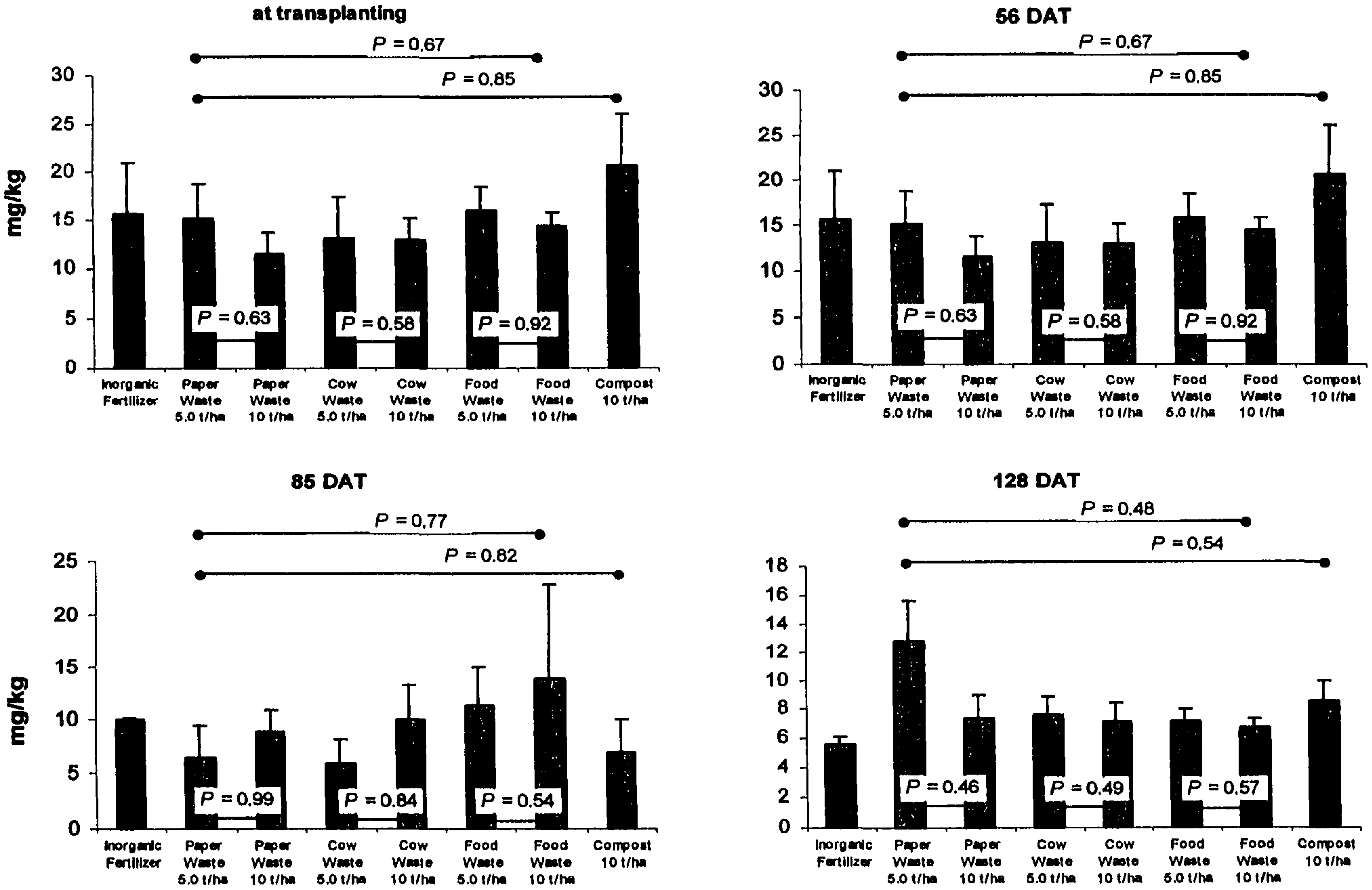

at transplanting
P = 0.67
P = 0.85
mg/kg
30
25
20
15
10
5
0
P = 0.63
P = 0.58
P = 0.92
Inorganic Fertilizer
Paper Waste 5.0 t/ha
Paper Waste 10 t/ha
Cow Waste 5.0 t/ha
Cow Waste 10 t/ha
Food Waste 5.0 t/ha
Food Waste 10 t/ha
Compost 10 t/ha
56 DAT
P = 0.67
P = 0.85
30
25
20
15
10
5
0
P = 0.63
P = 0.58
P = 0.92
Inorganic Fertilizer
Paper Waste 5.0 t/ha
Paper Waste 10 t/ha
Cow Waste 5.0 t/ha
Cow Waste 10 t/ha
Food Waste 5.0 t/ha
Food Waste 10 t/ha
Compost 10 t/ha
85 DAT
P = 0.77
P = 0.82
mg/kg
25
20
15
10
5
0
P = 0.99
P = 0.84
P = 0.54
Inorganic Fertilizer
Paper Waste 5.0 t/ha
Paper Waste 10 t/ha
Cow Waste 5.0 t/ha
Cow Waste 10 t/ha
Food Waste 5.0 t/ha
Food Waste 10 t/ha
Compost 10 t/ha
128 DAT
P = 0.48
P = 0.54
18
16
14
12
10
8
6
4
2
0
P = 0.46
P = 0.49
P = 0.57
Inorganic Fertilizer
Paper Waste 5.0 t/ha
Paper Waste 10 t/ha
Cow Waste 5.0 t/ha
Cow Waste 10 t/ha
Food Waste 5.0 t/ha
Food Waste 10 t/ha
Compost 10 t/ha

Figure 3.17.

Figure 3.18. Microbial biomass nitrogen in pepper plots at transplanting, 56, 85, 128 DAT (days after transplanting) in 2000. Bars designated by a line (●—●) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted yard waste.

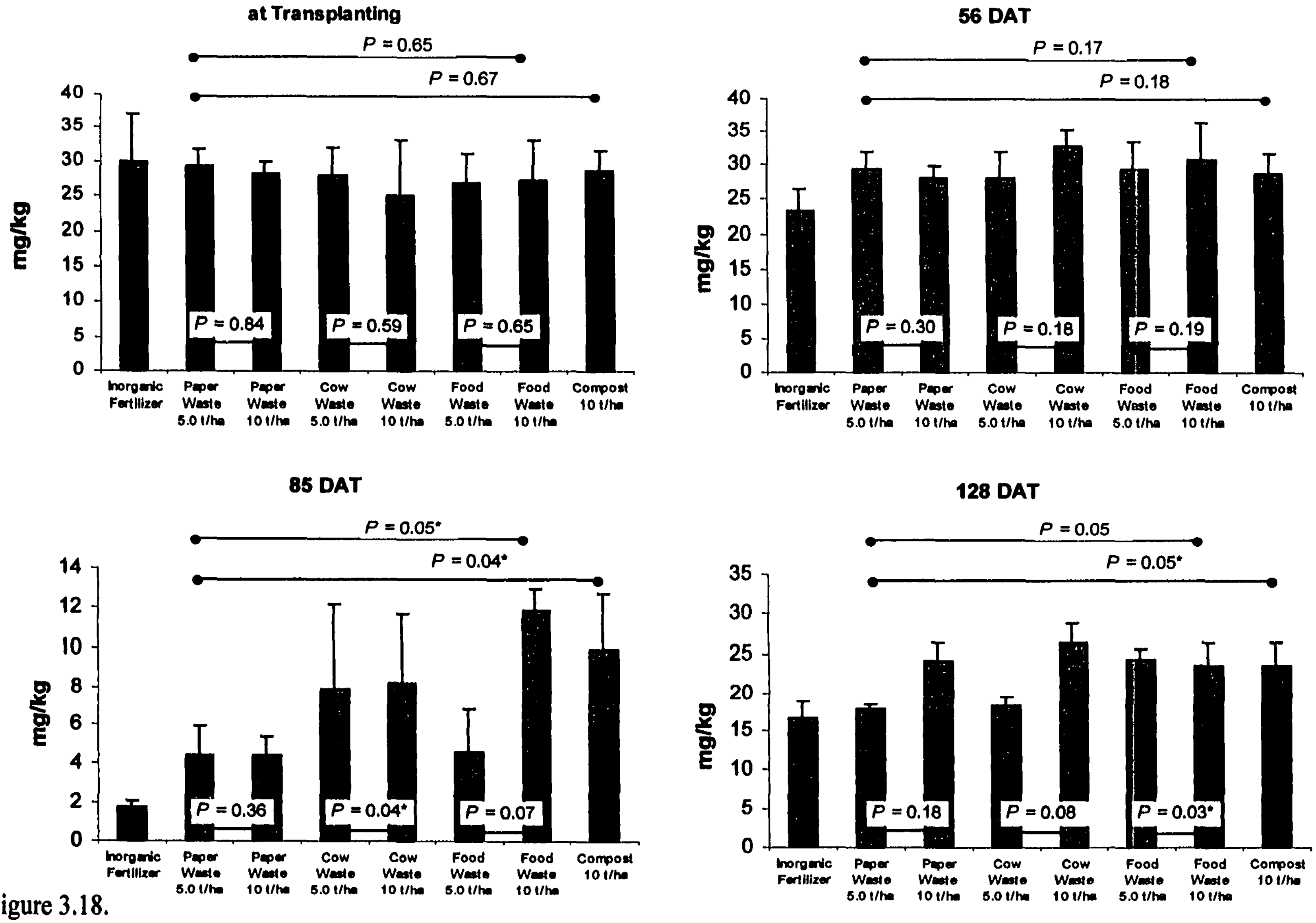

at Transplanting
P = 0.65
P = 0.67
mg/kg
0
5
10
15
20
25
30
35
40
P = 0.84
P = 0.59
P = 0.65
Inorganic Fertilizer
Paper Waste 5.0 t/ha
Paper Waste 10 t/ha
Cow Waste 5.0 t/ha
Cow Waste 10 t/ha
Food Waste 5.0 t/ha
Food Waste 10 t/ha
Compost 10 t/ha
56 DAT
P = 0.17
P = 0.18
mg/kg
0
5
10
15
20
25
30
35
40
P = 0.30
P = 0.18
P = 0.19
Inorganic Fertilizer
Paper Waste 5.0 t/ha
Paper Waste 10 t/ha
Cow Waste 5.0 t/ha
Cow Waste 10 t/ha
Food Waste 5.0 t/ha
Food Waste 10 t/ha
Compost 10 t/ha
85 DAT
P = 0.05*
P = 0.04*
mg/kg
0
2
4
6
8
10
12
14
P = 0.36
P = 0.04*
P = 0.07
Inorganic Fertilizer
Paper Waste 5.0 t/ha
Paper Waste 10 t/ha
Cow Waste 5.0 t/ha
Cow Waste 10 t/ha
Food Waste 5.0 t/ha
Food Waste 10 t/ha
Compost 10 t/ha
128 DAT
P = 0.05
P = 0.05*
mg/kg
0
5
10
15
20
25
30
35
P = 0.18
P = 0.08
P = 0.03*
Inorganic Fertilizer
Paper Waste 5.0 t/ha
Paper Waste 10 t/ha
Cow Waste 5.0 t/ha
Cow Waste 10 t/ha
Food Waste 5.0 t/ha
Food Waste 10 t/ha
Compost 10 t/ha

Figure 3.18.

Figure 3.19. Orthophosphates in pepper plots at transplanting, 56, 85, 128 DAT (days after transplanting) in 2000. Bars designated by a line (●——●) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted yard waste.

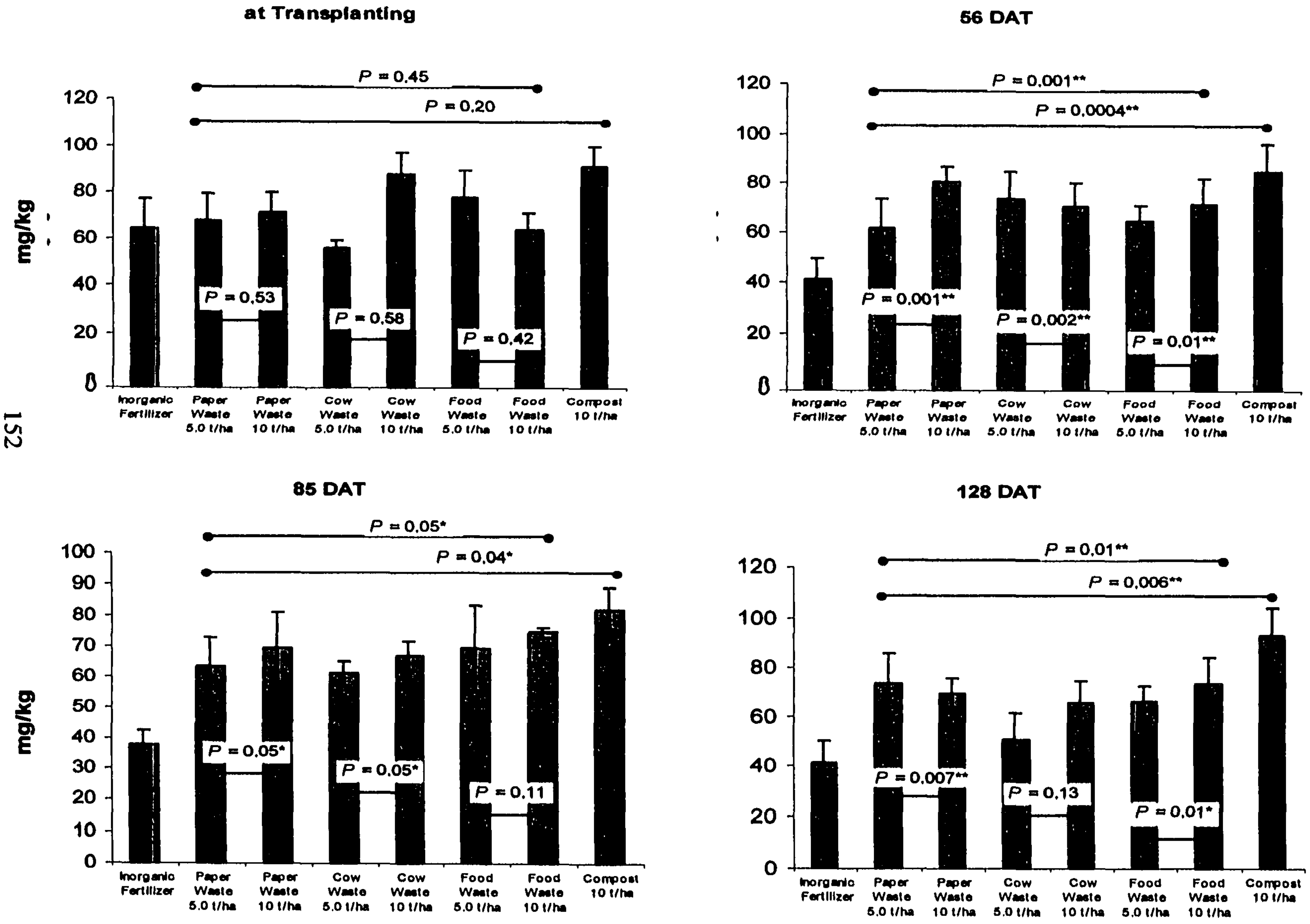
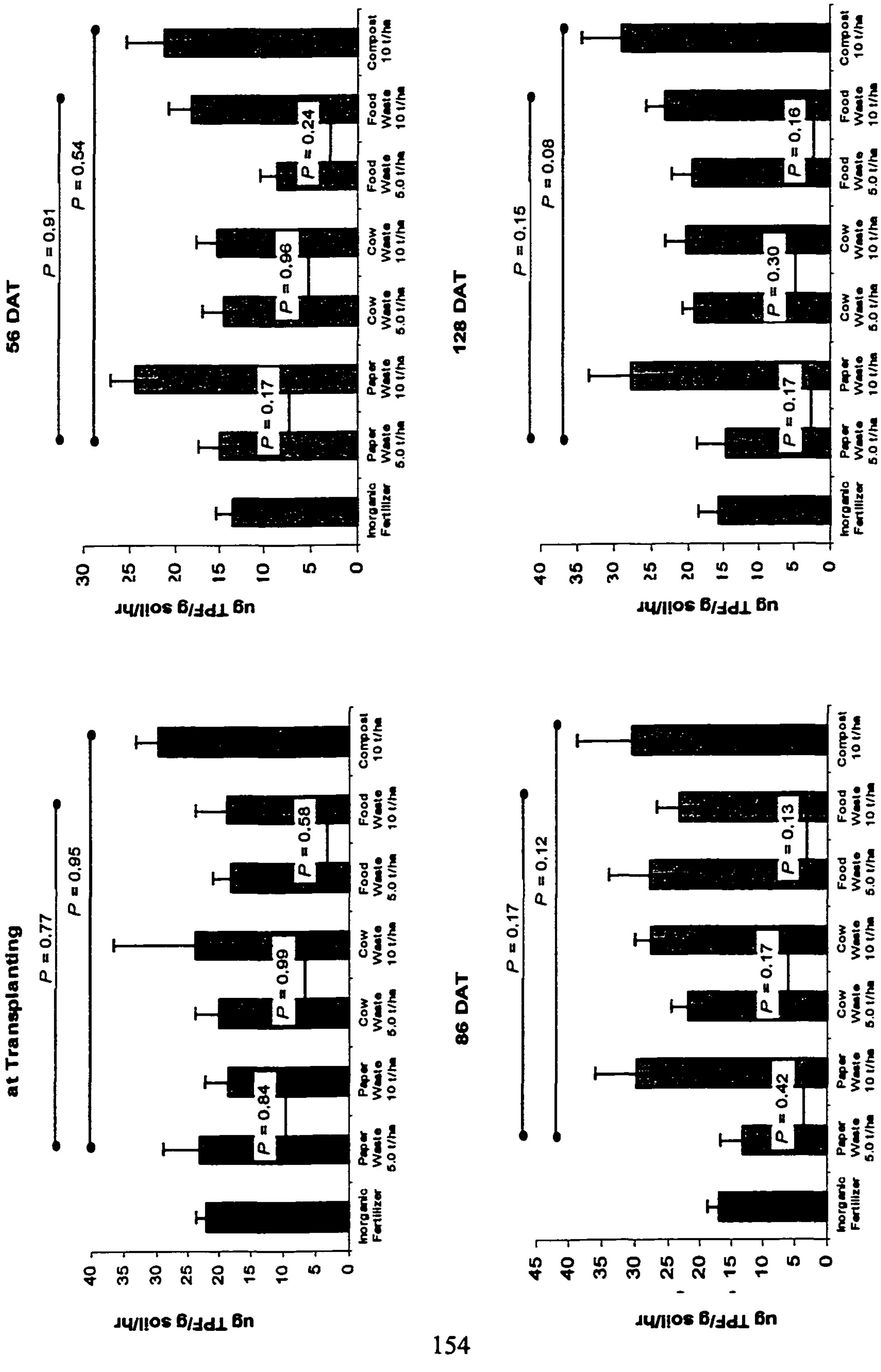

at Transplanting
mg/kg
120
100
80
60
40
20
0
P = 0.45
P = 0.20
P = 0.53
P = 0.58
P = 0.42
56 DAT
P = 0.001**
P = 0.0004**
P = 0.001**
P = 0.002**
P = 0.01**
85 DAT
100
90
80
70
60
50
40
30
20
10
P = 0.05*
P = 0.04*
P = 0.05*
P = 0.05*
P = 0.11
128 DAT
P = 0.01**
P = 0.006**
P = 0.007**
P = 0.13
P = 0.01*
Inorganic Fertilizer
Paper Waste 5.0 t/ha
Paper Waste 10 t/ha
Cow Waste 5.0 t/ha
Cow Waste 10 t/ha
Food Waste 5.0 t/ha
Food Waste 10 t/ha
Compost 10 t/ha

Figure 3.19.

Figure 3.20. Dehydrogenase enzyme activity (DHA) in pepper plots at transplanting, 56, 85, 128 DAT (days after transplanting) in 2000. Bars designated by a line (•——•) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted yard waste.



at Transplanting
P = 0.77
P = 0.95
P = 0.84
P = 0.99
P = 0.58
56 DAT
P = 0.91
P = 0.54
P = 0.17
P = 0.96
P = 0.24
86 DAT
P = 0.17
P = 0.12
P = 0.42
P = 0.17
P = 0.13
128 DAT
P = 0.15
P = 0.08
P = 0.17
P = 0.30
P = 0.16
ug TPF/g soil/hr
Inorganic Fertilizer
Paper Waste 5.0 t/ha
Paper Waste 10 t/ha
Cow Waste 5.0 t/ha
Cow Waste 10 t/ha
Food Waste 5.0 t/ha
Food Waste 10 t/ha
Compost 10 t/ha
0
5
10
15
20
25
30
35
40
45

Figure 3.20.

3.3.2 DISCUSSION

The biochemical changes in soil in response to vermicompost applications

The differences in the amounts of extractable nitrogen in soils from the vermicompost treatments in 1999 apparently corresponded with amounts of extractable nitrogen in soils from these plots compared to those in the inorganic control plots. The amounts of total extractable nitrogen in 1999 did not differ much in soil from any plots at the end of the growing cycle of peppers. Soils from the cow manure vermicompost treatment plots had even more extractable nitrogen content than soils from the inorganic control. Similarly, there was a trend towards more increasing ortho-phosphates in soil from the vermicompost and compost-treated plots towards the end of the growing cycle of peppers in both years. Increased amounts of nitrogen and phosphorus are one of benefits of applications of organic materials such as vermicomposts and composts to the soil. Astier et al. (1994) reported that manures contain such highly stabilized materials that it can supply enough available N for commercial crops if applied at high rates. They reported that soils treated with compost combined with vetch, replenished the inorganic N taken up by plants and soil microorganisms. Bevacqua and Mellano (1993) and Pascual et al (1999) reported that addition of municipal sewage sludge composts into the soil increased both levels of organic matter and primary nutrients.

Organic matter in soils can influence plant growth in a number of ways. The greatest benefits of organic matter in soil are: increased water-holding-capacity, improved soil aggregation, increase cation exchange capacity, food sources for soil microorganisms, mineralization of phosphorus and potassium to provide an important reservoir of elements needed for plant growth (Laegreid, 1999). Increases in cation exchange capacity after addition of compost have also been reported (Epstein, 1976; Gupta et al., 1986). Thus, both the ability of the soil to hold added mineral elements and the subsequent uptake by plant of these elements are increased (Dick and McCoy, 1993).

The relative lack of organic matter in soils from inorganic plots resulted in more rapid losses of nitrogen towards the end of the growing cycle of peppers compared with soils from plots treated with vermicompost and compost which retained much of the mineral nitrogen (NH4-N + NO3-N). The retention of these minerals in soils from the vermicompost treatments was probably due to the greater organic matter in the plots and the mineralization of these elements from both vermicomposts and composts.

Amounts of phosphorus in soil followed a similar trend in both years. Soils from plots that received no vermicomposts or composts had a distinct decrease in levels of orthophosphates towards the end of the growing cycle of the crop. This could be related to less organic matter which could have retained phosphorus in those plots. A high leaching rate coupled with no replenishments of orthophosphates may have resulted. Rates of mineralization in soils was linked to the decreasing amounts of dissolved organic nitrogen in the plots.

Microbial biomass nitrogen, carbon, sulfur and phosphorus all significantly increased over a 12-month period in a soil treated with municipal soil waste compost (Perucci, 1990). Since microbial biomass is considered to be the most mobile fraction of soil organic matter which represents a significant source of plant available nutrient (Smith and Paul, 1990), stimulation in size and activity of the microbial biomass by vermicomposts and composts should have the potential to improve the long term fertility of a soil (Dick and McCoy, 1993).

The bulk of soil biomass is inactive, probably because of nutrient limitations, and the addition of an available organic substrate usually results in a large increase in microbial biomass and activity (Vaughan and Malcolm, 1984). Furthermore, Vaughan and Malcolm suggested that organisms maintain a high adenylate energy charge (AEC) which explains partly their ability to make rapid responses to added exogenous substrates. In my experiments, the tremendous increases in microbial biomass in soil at transplanting, especially in the inorganic plots, was mostly the result of the activation of indigenous microorganisms in the soil which could utilize available nutrients from the inorganic fertilizers. Microbial biomass increases in soil from inorganic plots were similar to those in soil from the vermicompost-treated plots, where the sources came from the nutrient content of the vermicomposts, combined with additional nutrition from the inorganic fertilizer supplements.

The soil microbial biomass, after addition of organic substrates, declines much more quickly than indigenous biomass (Baath et al, 1978; Rovira, 1965). The reason for such a rapid "decline" is uncertain but presumably reflects the "protective capacity" of the soil. It has been known for many years that microbial cells added to soil may die very rapidly, but the proportion surviving is influenced usually by amounts organic matter, $CaCO_3$, available predators, pH and competition for available substrates (Katznelson, 1940; Lochhead and Thexton, 1947). In my experiments, soils from the inorganic control plots did not maintain more soil biomass relative to that in the organic plots which presumably had the potential to add new biomass. It is more likely that that the soil microbial biomass in the organic plots survived and multiplied more rapidly because of the availability of organic substrates from the vermicomposts and composts. The microbial biomass in soils from the inorganic control plots decreased relatively faster compared with that in the vermicompost-treated plots because there were relatively limited amounts of nutrients for the microorganisms to sustain their activity. Nutrients from the inorganic fertilizer, especially NO3-N and NH4-N, were more available and mobile so that they could easily lost from the soil by run-off, leaching, plant uptake, microbial fixation and volatilization.

Soil dehydrogenase enzyme activity has been considered to be an excellent measurement to evaluate overall soil microbial activity (Nannipieri et al., 1990). In my experiments, dehydrogenase activity increased in soils treated with both inorganic fertilizers and vermicomposts but the latter soils maintained a higher dehydrogenase value towards the end of the growing cycle. Furthermore, there was a significant positive correlation, between dehydrogenase activity with microbial biomass, towards the later growth stage of the peppers. Many authors have reported that organic fertilizers produce increases in soil microbiological activity (Bolton et al., 1986, Fraser, et al., 1988; Kirkner et al., 1993; Marinari et al. 2000). Many enzymatic activities have been reported to be correlated with the total amounts of organic C in soils (Frankenberger and Tabatabai 1981). In compost-soil incubation trials, Serra-Wittling et al (1995), reported increases in dehydrogenase activity in soils to which with increasing amounts of composts were added with the highest level of dehydrogenase activity coinciding with the mineralization flush. These increases were attributed to the intense activity of soil microorganisms in degrading easily- metabolizable compounds, hence consequent decreases in activity may be attributed to decreases in amounts of readily-biodegradable substances. Pascual et al (1999) reported increased dehydrogenase activity after 8 years of amending soil with composts annually. Masciandaro et al (1997) reported increases in dehydrogenase activity in soil following vermicompost applications at 90 t/ha.

There is a general agreement among authors who used a variety of techniques, that only a small portion of the total soil microbial biomass is active (values ranging from 2.4 – 27.4%) (Vaughan and Malcolm, 1984). The main restriction in microbial activity is usually a lack of organic substrate (Gray, 1976; Lynch, 1982) and the addition of readily available substrates to soil causes a virtually instantaneous increase in respiration representing increased soil microbial activity (Berrow, Davidson and Burridge, 1982).

Other environmental factors that decrease biomass and activity have been suggested. These include treatments such as soil drying, freezing and waterlogging which are natural events in many environments and may severely restrict the size and activity of microbial biomass (Vaughan and Malcolm, 1984). In my experiments, the marked decreases in dehydrogenase activity in all plots were probably due to relatively dry soil conditions especially in the soil samples taken towards the end of harvesting. Soil dehydrogenase activity, especially in 2000, was correlated positively with soil microbial biomass which suggests that as soon as the microbial biomass declined, its activity also declined quite rapidly. Another possible causative factor for these decreases may have been the decrease in the total nutrient contents in the soil, of all plots, as indicated in the total extractable nitrogen and phosphorus content at the end of the growth cycle of peppers. Soil phosphorus, in particular, was correlated positively with decreases in microbial biomass and dehydrogenase activity. Ladd and Paul (1973) reported such a trend when after application of organic amendments dehydrogenase activity increased together with cell numbers, reaching a maximum during a period of active metabolism of microbial products, then decreased concomitantly with the decline in bacterial numbers. It has also been reported that, like dehydrogenase, other enzymes such as caseinases (Nannipieri et al., 1979) and urease (Zantua and Bremmer, 1976) follow a similar pattern. In these studies, soil enzymes reached a maximal potential activity which took place even before organic amendments or soil pretreatments were introduced to soils with high organic matter. In my experiments, a stabilized level of dehydrogenase activity had not obviously been reached before the vermicompost applications as was indicated by the fluctuations in the amounts of dehydrogenases in the soil from transplanting to about 100 days after transplanting.

3.3.3 RESULTS

Nematode populations after vermicompost applications

The bacterivore and fungivore nematode populations in soils did not differ significantly between plots, $P > 0.05$ (Fig. 3.21 and 3.22).

Soils in the inorganic controls contained significantly more plant parasitic nematodes than soils from the vermicomposts and compost-treated plots, $P < 0.05$. No significant differences occurred in the numbers of plant parasitic nematodes among vermicompost and compost plots.

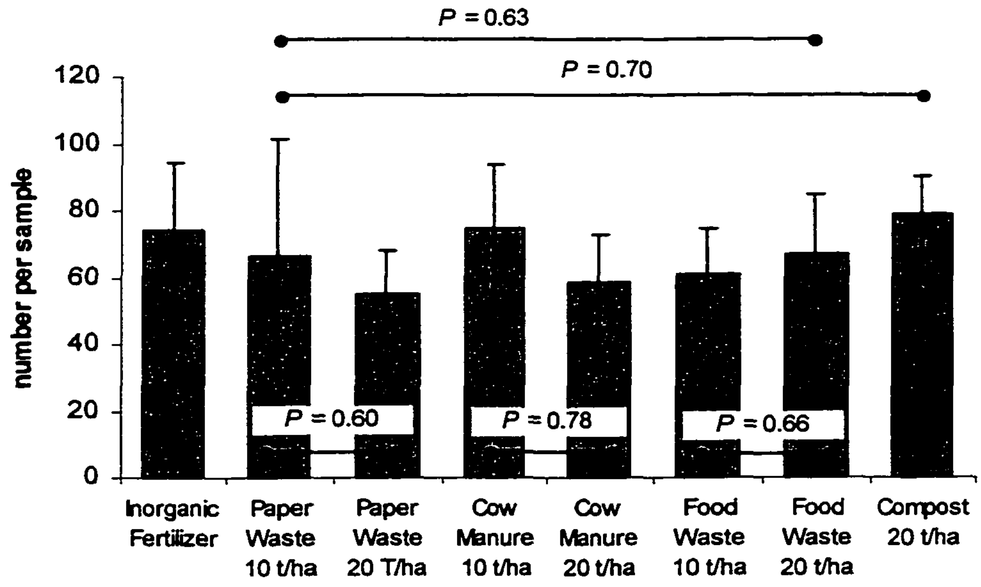


Figure 3.21. Bacterivore nematodes populations in pepper plots, 1999. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted sewage sludge.

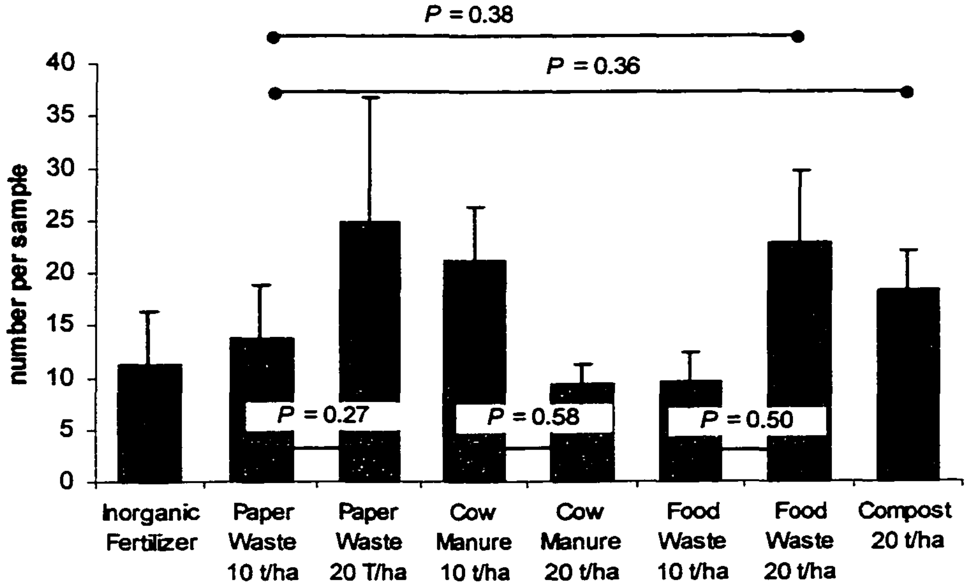


Figure 3.22. Fungivore nematode populations in pepper plots, 1999. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted sewage sludge.

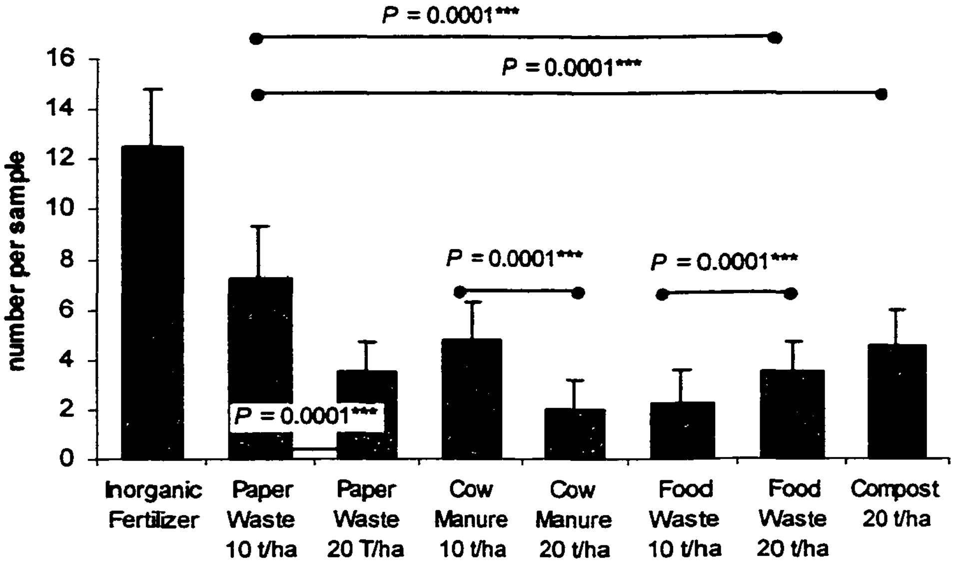


Figure 3.23. Plant parasitic nematodes in pepper plots, 1999. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted sewage sludge.

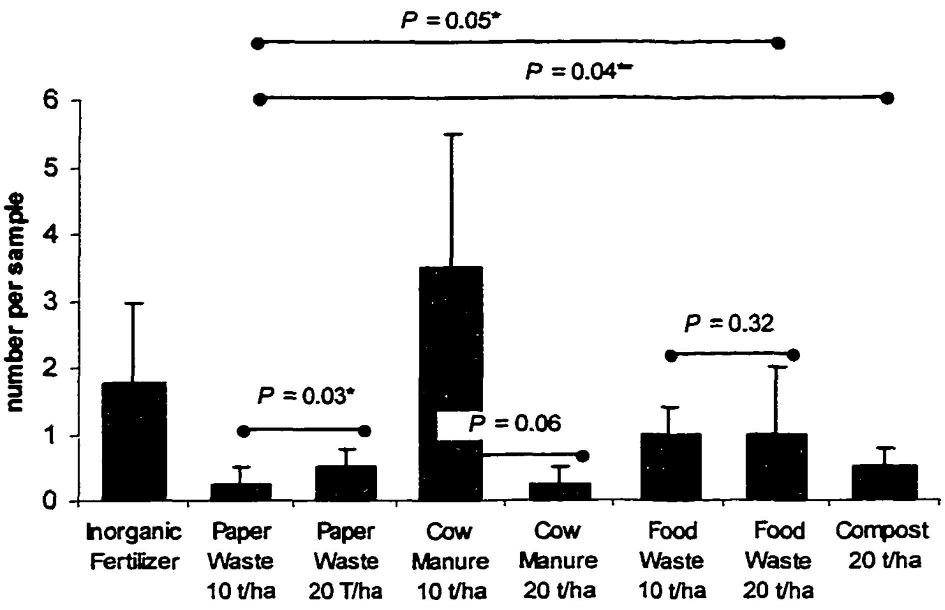


Figure 3.24. Omnivorous/carnivore nematode populations in pepper plots, 1999. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted sewage sludge.

3.3.3 DISCUSSION

Nematodes populations after vermicompost applications

Nematodes have been used as ecological indicators of soil quality because they are very responsive to changes in the soil, such as addition of fertilizers (Wasilewska, 1989), cultivation (Hendrix et al., 1986) liming (Hyvonen and Persson, 1990), and accumulation of heavy metals (Bongers, 1991). Such agricultural practices affect nematode species richness, trophic structure, as well as the succession status of nematode communities (Neher, 2001).

Trophic diversity indices describe relative abundance and evenness (Ludwig and Reynolds, 1988) of the occurrence of five nematode trophic groups. It has been demonstrated that disturbances such as cultivations (Freckman and Ettema, 1993) and additions of manure (Neher and Olson, 1999) can decrease trophic diversity. Trophic diversity tends to be greater in soils growing perennial crops than in soils sown with annual crops (Neher and Campbell, 1994). These apparent differences have been attributed mostly to declines in numbers of omnivorous and predaceous nematodes and increase in numbers of bacterial-feeding nematodes (Wasilewska, 1979; Neher and Campbell, 1994). In my experiments on peppers, the numbers of omnivorous/predaceous nematodes in soils were relatively few compared to those of the bacterivorous and the fungivorous nematodes. This result agrees with a report by Freckman and Ettena (1993).

Beneficial nematodes have been demonstrated to affect plant productivity both by increasing nutrient availability and through regulation of mineralization (Neher, 2000). Shoot biomass and the nitrogen content of plant shoots grown in the presence of protozoans and free living nematodes were greater than those of plants grown in the absence of microfauna (Yaetes and Wardle, 1996). The basis of this relationship is suggested to be that grazing on microorganisms by micro invertebrates releases and mineralizes nutrients that are immobilized in microorganisms, subsequently converting nitrogen from its organic to inorganic forms which plant can utilize (Trofymow and Coleman, 1982). In my experiments, the total populations of nematodes were correlated negatively with the total microbial biomass and activity and correlated positively with the total nitrogen content of soil in the plots. This relationship confirms the significant contribution of nematodes to nitrogen release. Soil invertebrates may be responsible for approximately 30% of nitrogen mineralization in agricultural and natural ecosystem soils (Neher, 2000). Protozoa and bacteria feeding nematodes, the main consumers of bacteria, can account for 83% of this nitrogen mineralization (Elliot et al., 1988), and are estimated to contribute about 8 to 19% of the nitrogen mineralization in conventional and integrated farming systems (Beare, 1997). Nematodes contribute directly to nitrogen mineralization by excretion of nitrogenous wastes, mostly ammonium ions (Anderson et al., 1983; Ingham et al., 1985). When nematodes die, the nutrients immobilized in their tissues are mineralized and subsequently become available to plants (Neher, 2000).

In my experiments, the numbers of plant parasitic nematodes were increased significantly by the addition of inorganic fertilizers to the pepper plots. Yardim and Edwards (1998) reported similar increases in numbers of plant parasitic nematodes in soil from tomato plantings that were treated with a full spectrum of fungicide and pesticides suggesting that plant parasitic nematode populations may be influenced pesticides. Various other reports have indicated that agrochemicals can cause increase in plant-parasitic nematode populations and these were discussed in Chapter 2. Similarly in

Chapter 2, I have identified no reports on the direct influence of the application of inorganic fertilizers on nematode populations.

Trophic composition of nematodes can be a factor in regulating their populations. According to Small (1978), predatory nematodes can play a significant role in regulating plant-parasitic nematodes. A decrease in predatory nematode populations could lead to significant increases in plant-parasitic nematode populations. In my experiment, the numbers of omnivorous/carnivorous nematodes were correlated negatively to the numbers of plant-parasitic nematodes. This suggests that decreases in the numbers of omnivorous/carnivorous nematode populations increased the numbers of the numbers of plant-parasitic nematodes.

CHAPTER 4

THE INFLUENCES OF VERMICOMPOST APPLICATIONS ON THE GROWTH AND YIELD OF TOMATOES

4.1 INTRODUCTION

Tomato (*Lycopersicon esculentum*, Mill) is the second most commonly-grown vegetable crop in the world, potato being the number one. It is the most common vegetable grown in home gardens in the United States (Jones, 1999). Over the last five years, world production of tomatoes has increased steadily from about 87,000,000 Mt in 1995 to about 100,000,000 Mt in 2000 (FAO, 2001). Forty-three percent of the total production is in Asia and 13% is in the United States. The total area harvested for tomatoes has also increased from 3.1 Mha in 1994 to 3.6 Mha in 2000. In 1985, *per capita* consumption of fresh tomatoes in the United States was 36.5 kg, increasing to 41.3 kg in 1995 (USDA, 1997)

Recently, a long-term medical study has revealed that individuals who consume either fresh tomatoes or processed tomato products on a regular basis are less likely to have some forms of cancer than those who do not. The tomato fruit is rich in vitamin A and C and contains as antioxidant, lycopene (Jones, 1999) and its versatility as a vegetable with a superior nutritional value is perhaps one of the greatest contributing factors of its ever-increasing consumption and production.

The methods of production of tomatoes, since its time of domestication has progressed tremendously to improve yields. Many of the aspects of its cultivation like management procedures, time of operations, land preparations, seedbed conditions, fertilizer and irrigation requirements, crop spacing, transplant setting, plant training, fruit ripening, harvesting and fruit handling in field production have been thoroughly studied. Fertilization remained one of the most critical cultural practices in tomato production owing to the wide diversity of new varieties and soils where they are grown. For instance, in the United States, recommended rates of nitrogen fertilization for commercial field tomatoes range from 136 – 247 kg N/ha; P_2O_5 from 90 - 180 and K_2O from 62 – 336 kg/ha between California farmlands and in irrigated lands of Florida (Jones, 1999). In most cases, inorganic fertilizers are the main sources of the recommended nutrients.

There have been numerous reports on the rise of environmental and economic problems brought about by the use of agrochemicals such as inorganic fertilizers. These include movement of nutrients to groundwater and hence nutrient loading in water bodies, fed by groundwater that trigger eutrophication (Laegreid, 1999) resulting in imbalances in phytoplankton growth and decreased diversity of marine phytoplankton. Leaching of minerals like nitrates from the soil surface to the groundwater table has polluted drinking water which poses health hazards such as methemoglobinemia in infants.

The growing awareness of the ecological and economic problems associated with the use of inorganic fertilizers has prompted agricultural scientists to seek alternative sources of nutrients in vegetable production, particularly tomatoes. In fact, the United States reduced fertilizer use from 20,037,976 Mt in 1995 to 19,773,802 Mt in 2000 (FAO, 2001). However, total world fertilizer consumption increased from 129,234,292 Mt in 1995 to 137,355,043 Mt in 2000. The decreases in inorganic fertilizer consumption in the United States could be due to several production strategies – the development of new varieties that are adaptable to lower fertilization levels and the use of organic amendments as potential substitutes for inorganic fertilizers.

The use of organic amendments like traditional composts has long been recognized as an effective substitute for inorganic fertilizers. Their importance to the soil and positive effects on plant growth have been widely researched. Numerous works on organic amendments are fully discussed in Chapter 2. Vermicomposts, as another newer type of organic amendments, have received considerable attention recently in the horticultural realm. Positive responses of plants grown in the greenhouse and field and improvements in the soil properties have been reported in various works which are also discussed in the Chapter 2.

There is considerable current interest in the use of vermicomposts in the production of vegetable crops, as a result of the negative consequences of the use of inorganic fertilizers. However, the use of organic fertilization, although practiced for a long period of time, has often been considered to be not as appealing to many growers owing to a greater degree of complexity in management usually associated with their use. Some such complexities are because organic materials come in different forms, sources, maturity, and nutrient contents. These lead to differences in their capability to supply nutrients to crops especially in large-scale production systems. Jones (1999), whose book presented one of the most updated consolidation of recent advances in tomato production failed to present advances in organic tomato production in a large scale.

Positive results from the applications of vermicomposts for growth of greenhouse vegetables lead me to explore further the influences of vermicomposts on field crops that are grown commercially, such as tomatoes. For this research, I anticipated positive responses of vermicomposts on the growth and yield of tomatoes, that can be associated with positive changes in soil properties.

The main objectives of the research in this chapter are:

1. To assess the effects of the application of different application rates of vermicomposts on the growth and yields of tomatoes in the field,
2. To assess their effects on soil chemical and biological changes that occur throughout the growth cycle of tomatoes and,
3. To determine the effects of vermicomposts on the incidence of fruit diseases and changes of nematode trophic structure and populations.

4.2 MATERIALS AND METHODS

Two sets of experiments were conducted at the Ohio State University Centers at Piketon in 1999 and 2000. Brief descriptions of the experimental site from the soil survey by the USDA-Soil conservation service and local weather stations are presented in Chapter 2.

Plot layout and design

Raised soil beds were constructed measuring 1.5 x 5.5 m (8.25 sq.m. per plot). Paper waste, cow manure and food waste vermicomposts were used in the trials. The paper waste vermicompost was provided by American Resource Recovery, Stockton

(CA), the food waste vermicompost was provided by Oregon Soil Corporation, Portland, (OR). The cow manure vermicompost was produced by Soil Ecology Lab, Columbus (OH) at OARDC. Vermicomposts were applied at two dosage rates: equivalent to 10 t/ha and 20 t/ha (wet weights) in 1999. Lower rates of 5 t/ha and 10 t/ha (wet weights) were used 2000. The vermicompost were analyzed for major elements and vermicompost-treated plots were supplemented with amounts of inorganic fertilizer to equalize their nutrient contents with total recommended full rate of nitrogen and potassium. An application rate of 50 kg N/ha was applied as preplant fertilizer. Preplant inorganic fertilizer applications to vermicompost-treated plots were adjusted accordingly with their total available N content. Additional 30 kg/ha was applied to all plots through ferti-irrigation 30 days after transplanting. Vermicomposts and inorganic fertilizers were spread manually and incorporated using a rotavator into the top 10 cm of each bed before planting. The yard waste compost from Kurtz Bros, Columbus (OH) was used in 1999 and Com-Til, a composted sludge, was used in 2000. The following were the treatments:

T1: Inorganic Fertilizer (Control)

T2: Paper Waste Vermicompost (10 t/ha in 1999 and 5 t/ha in 2000)

T3: Paper Waste Vermicompost (20 t/ha in 1999 and 10 t/ha in 2000)

T4: Cattle Manure Vermicompost (10 t/ha in 1999 and 5 t/ha in 2000)

T5: Cattle Manure Vermicompost (20 t/ha in 1999 and 10 t/ha in 2000)

T6: Food Waste Vermicompost (10 t/ha in 1999 and 5 t/ha in 2000)

T7: Food Waste Vermicompost (20 t/ha in 1999 and 10 t/ha in 2000)

T8: Compost (20 t/ha Biosolids in 1999 and 10 t/ha Yard waste in 2000)

Plastic mulch and drip irrigation systems were set-up over the raised beds after vermicompost and fertilizer applications. Four-week old tomato seedlings variety BHN 543 F1 were transplanted into a single row in each bed with 38 cm between plants totaling 12 plants each plot. Plants were staked 4 weeks after transplanting and tied to a twine trellis accommodating 2 plants between stakes. Suckers were removed up to the one just below the first flower cluster. Treatments were replicated four times in a randomized complete block design. Guard rows were set between each replication.

Pest Control

A disease severity index (DSV) of 21 days was used in initiating fungicide applications. Quadris and Terranil were applied alternately at the rate of 6.2 oz and 3 pn/A starting fruit setting to peak of fruiting in both years.

Data Collected

Plant sampling

Four whole designated plant samples were harvested for assessment of leaf area and shoot fresh and dry weights 65 and 120 days after transplanting in 1999 and 49 and 114 days after transplanting in the second year.

All fresh leaves were removed from each sample plant and passed through a portable leaf area measuring machine LI 3100 (LI-COR Inc., Lincoln, Nebraska, USA) to make leaf area measurements. All leaves and stems of each plant were weighed to determine fresh shoot weights, placed into paper bags, oven-dried at 60 ^{0}C for 92 hours and weighed to make dry shoot weights.

All pink to red ripe fruits were harvested and graded into marketable and non-marketable and weighed for yields. Fruits were classified as non-marketable when signs of rots, insect feedings, and sunscalding, fruit cracking, and malformations were seen on the fruit surface. These indices of non-marketability were transformed to percentages of total non-marketable fruits. The proportions of non-marketable fruits were determined by calculating their percentage from those of the total fruits harvested.

Soil sampling and analysis

Eight 2.5 cm diameter x 20 cm deep soil samples were taken from the plant root zones in each plot (about 4-8 cm away from plant base). Five sets of samples were taken during 1999: at transplanting, 30, 65, 90 and 120 DAT (days after transplanting) and four sets in 2000: at transplanting, 49, 84 and 114 DAT.

Moist soil samples were passed through a 2mm-sieve and stored in the cold room at 4 ^{0}C until chemical analyses. Unsieved subsamples were separated and extracted for nematode populations assessment. Three 20-gram soil subsamples stood in water in glass Baermann filters/funnel for 48 hours (MacSorley and Welter, 1991). Nematodes were identified to trophic levels under a stereomicroscope (Edwards et al., 1991).

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 0.5M K_2SO_4 for 1 hour 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 EL211sx automated microplate reader. Soluble phosphorus was assessed using NH_4-HCl reagent. Three-gram soil samples were extracted with Bray no.1 extracting reagent. Color in the sample filtrates was developed with stannous chloride and ammonium paramolybdate and absorbance was measured using Bio-Tek EL211sx automated microplate reader. A more complete nutrient analysis was done on vermicompost samples following nitric acid/perchloric acid digestion (Singer and Hanson, 1969). Extracts were analyzed for P, K, Ca, Mg, B, Cu, Fe, Mn, S, and Zn by inductively coupled plasma-atomic emission spectroscopy (ICP-AES) (Munter and Grande, 1981). Total carbon and nitrogen were measured in vermicomposts and composts by dry combustion using Carlo-Erba apparatus.

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 EL211sx automated microplate reader. 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.

Nematode and fruit disease sampling

Nematodes were extracted from 20-gram unseived soil subsamples stood in water in glass Baermann filters/funnel for 48 hours (MacSorley and Welter, 1991). Nematodes were identified to trophic levels under a stereomicroscope (Edwards et al., 1991). Non-marketable fruits were inspected for surface damages due to fruit rots, malformations, sun scalding, blossom-end-rots, and insect feedings.

Statistical analyses

The means of parameters measured were grouped for comparisons and differences were separated by orthogonal contrasts using SAS (SAS Inc., 1990). Contrasts were made between grouped means to determine differences in the following: 1) between vermicomposts versus inorganic fertilizers 2) among the three kinds of vermicomposts and 3) between the two rates of vermicompost applications on tomato growth, yield and changes in the soil properties.

4.3 RESULTS AND DISCUSSIONS

Results and discussions are divided into following subsections to:

4.3.1 Effects of vermicompost applications on growth and yield of tomatoes

4.3.2 Changes in soil nitrogen, phosphorus, microbial biomass and dehydrogenase enzyme activity resulting from vermicompost applications

4.3.3 Fruit disorders, diseases and soil nematode populations after vermicompost applications

4.3.1 RESULTS

Effects of vermicompost applications on tomato growth and yields

The vermicomposts used in this research came from the same batch used in the pepper trial. The results of the analyses of the their major elements are presented in table 3.1

There was over-irrigation that caused waterlogging in all tomato plots during peak of fruiting (about 65 days after transplanting). All plants wilted partially for a week with heavier wilting in plants grown in the vermicompost-treated plots.

Soils in the experimental area were analyzed before any soil amendment was applied in 1999. A summary of the soil nitrogen and phosphorus content is presented in table 4.1. The soil contained low amounts of ammonium-nitrate (1.01 mg/kg) and nitrate-nitrogen (7.04 mg/kg). It contained 20.30 mg/kg and 48.21 mg/kg of dissolved organic nitrogen and microbial biomass nitrogen, respectively. Total phosphorus was 106 ppm.

Shoot Weights and Leaf Area

There were no statistically significant differences between the grouped means of tomato shoot weights and leaf areas between plants in the vermicompost-treated plots and those in the inorganic control plots 65 and 120 days after transplanting in 1999 (Figure 4.1 and 4.2). Food waste vermicompost-treated tomatoes plants had significantly lower shoot weights and leaf areas 65 days after transplanting, $P < 0.05$. However, there were no statistically significant differences in shoot weights between plants treated with food waste vermicompost and those grown in the inorganic control plots. In 2000, there were no statistically significant differences in shoot weights and leaf areas, between plants grown in inorganic control plots and those grown in the vermicompost-treated plots, 49 days after transplanting (Figure 4.3). The plants in the food waste vermicompost-treated plots had significantly lower fresh shoot weights that those grown in the inorganic control plots 114 days after transplanting, $P < 0.05$ (Figure 4.4). However, the grouped means of fresh shoot weights from all the vermicompost treatments did not differ significantly from those grown in inorganic control plots. Dry shoot weights did not differ significantly between plants grown in the inorganic control plots and those grown in vermicompost-treated plots.

Significant differences in shoot weights were recorded between plants grown in cow manure and food waste vermicompost-treated plots (Table 4.1). Plants in the cow manure vermicompost-treated plots had greater fresh shoot weights than those grown in food waste vermicompost-treated plots, 120 days after transplanting in 1999 ($P < 0.05$). The cow manure vermicompost applications produced plants with significantly greater dry shoot weights 65 and 120 days after transplanting ($P < 0.05$). In 2000, plants in food waste vermicompost-treated plots had greater dry weights than those grown in cow manure vermicompost-treated plots only114 days after transplanting.

Yields

No significant differences occurred in total marketable yields between plants grown in the inorganic control plots and those of the vermicompost treatments based on grouped means or in the compost treatments in both years (Figure 4.5 and 4.6). However, plants in the paper waste vermicompost treated plots had a lower percentage of non-marketable fruits compare to the in the inorganic control plots, ($P < 0.05$) (Figure 4.6b).

No significant differences occurred in yields in 1999 among any of the vermicompost treatments. The application rate of 20 t/ha vermicompost produced plants with significantly more marketable tomato fruit yields than the 10 t/ha application rate (Table 4.1). In the second year, the paper waste and cow manure vermicomposts treatments produced tomato plants with significantly greater marketable yields than those from the food waste vermicompost treatments ($P < 0.05$) (Table 4.2). However, no significant differences occurred in marketable yields between the rates of vermicompost applications. Significantly more non-marketable fruit yields were produced by plants in food waste vermicompost treatment plots than in those grown with in the paper waste vermicompost treatments ($P < 0.05$).

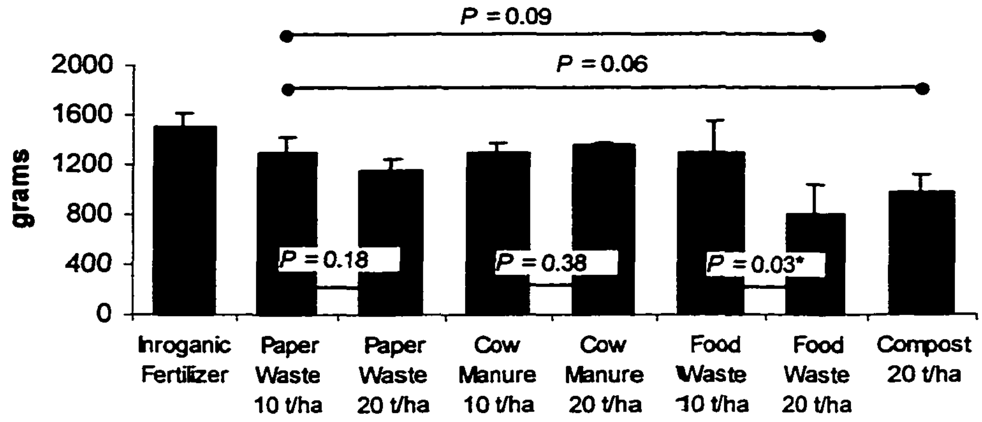
The vermicompost treatments produced significantly more marketable fruits in 1999 than the compost treatments ($P < 0.05$) (Table 4.3). However, no significant differences in tomato marketable yields between plants in vermicompost and compost treated plots occurred in 2000 (Table 4.4).

[redacted]	[redacted]
NH_4-N	1.01
NO_3-N	7.14
DON	20.30
Bio-N	48.21
Total Phosphorus	106.00

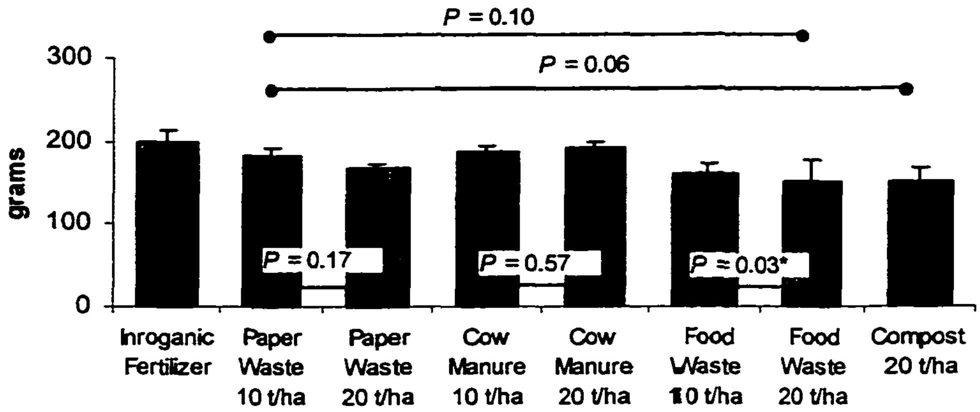
Table 4.1. Nitrogen and total phosphorus content of tomato plots in 1999.

Figure 4.1. Fresh shoot weights, dry shoot weights, and leaf areas of peppers 65 days after transplanting in 1999. Bars designated by a line (●——●) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted sewage sludge.

a) Fresh shoot weight



b) Dry shoot weight



c) leaf area

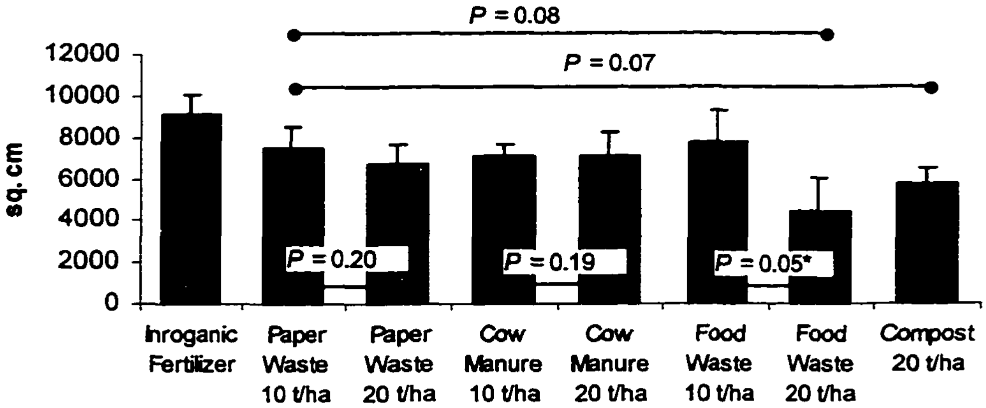
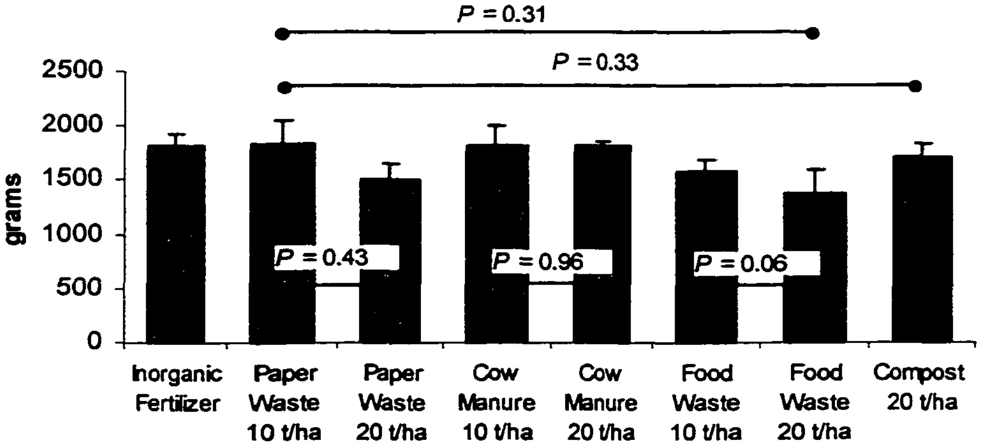


Figure 4.1.

Figure 4.2. Fresh shoot weights, dry shoot weights, of tomatoes 120 days after transplanting in 1999. Bars designated by a line (●———●) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted sewage sludge .

a) Fresh shoot weights



b) Dry shoot weights

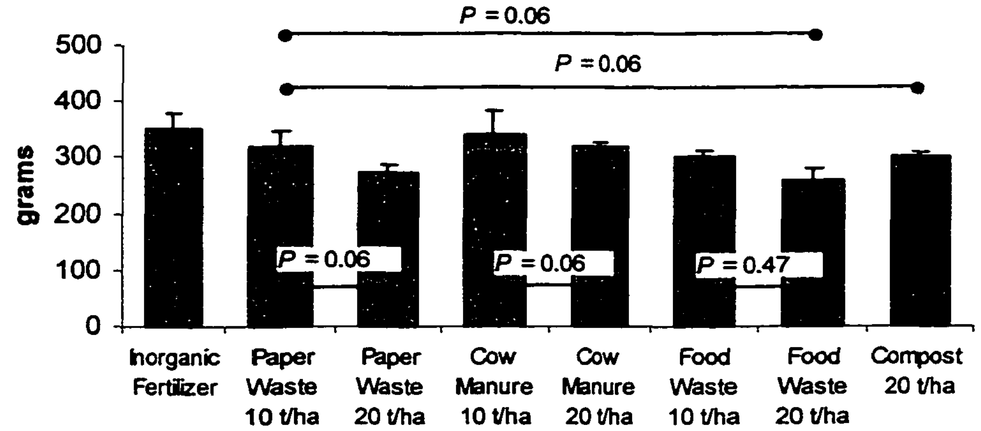


Figure 4.2.

Figure 4.3. Fresh shoot weights, dry shoot weights, and leaf areas of tomatoes 49 days after transplanting in 2000. Bars designated by a line (•——•) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted yard waste.

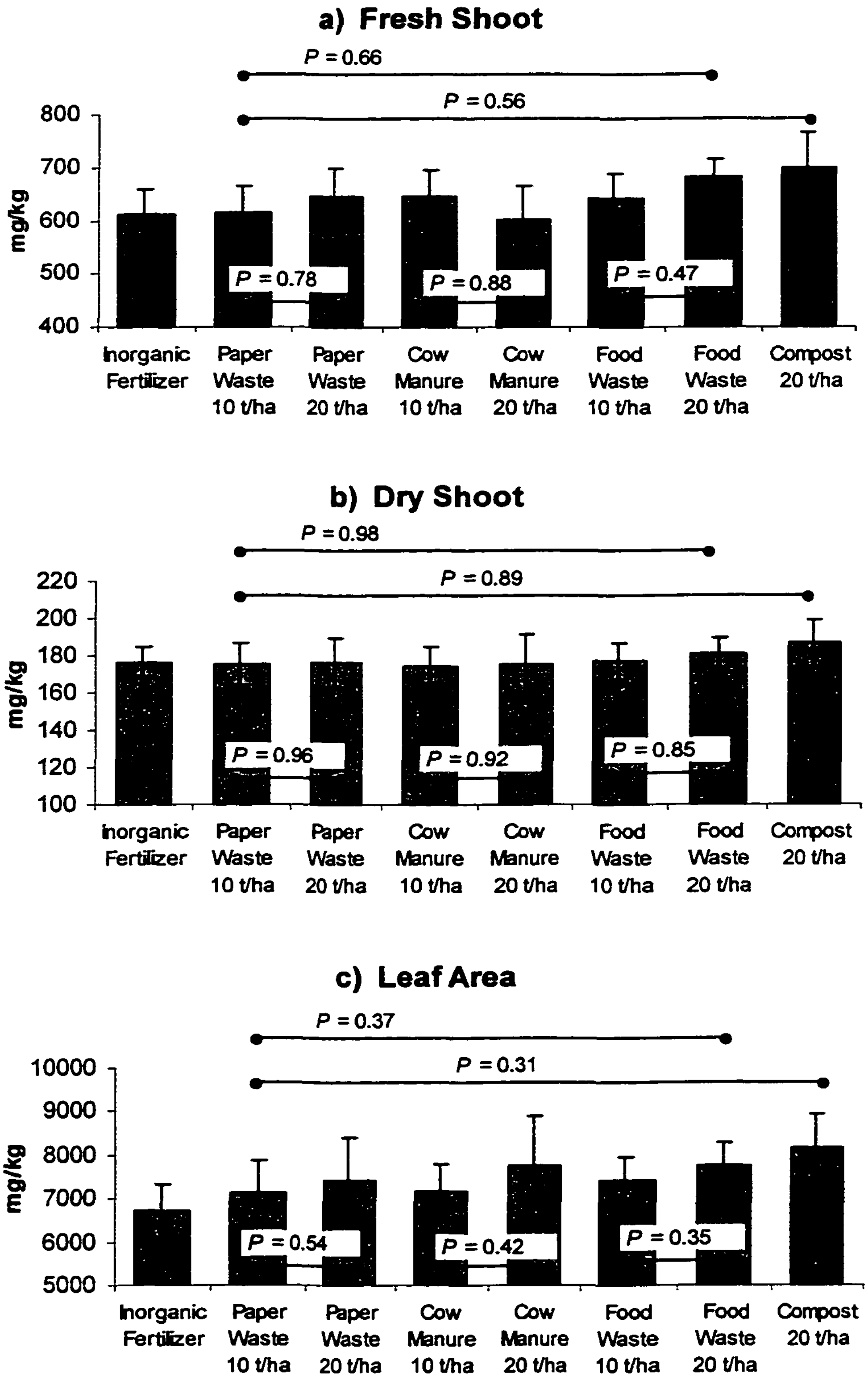
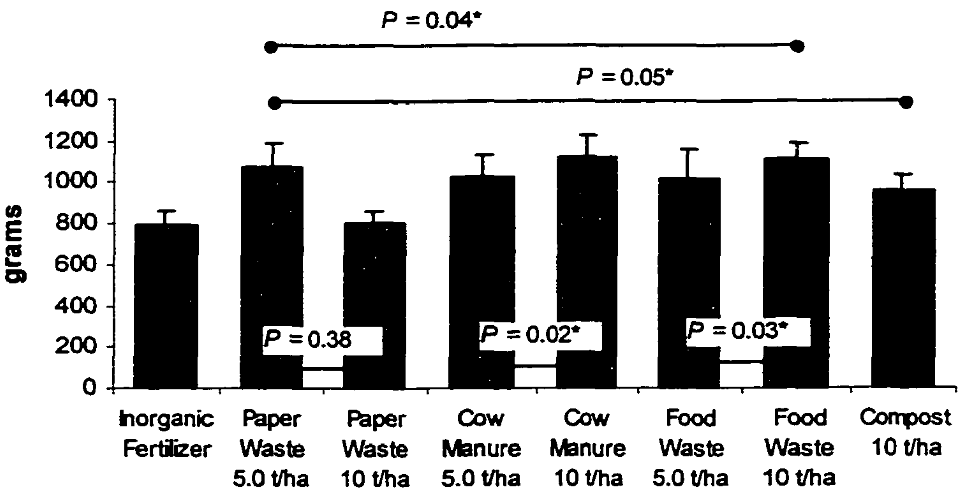
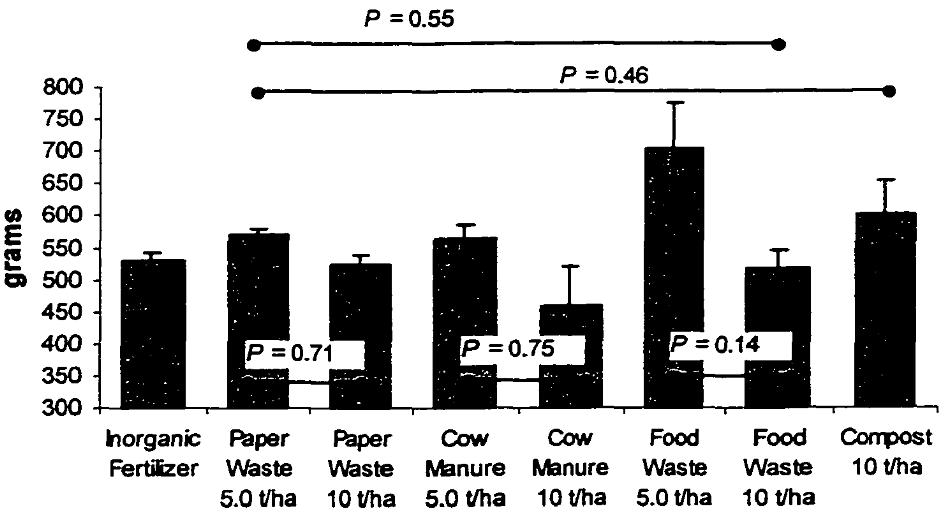

a) Fresh Shoot
P = 0.66
P = 0.56
800
700
600
500
400
mg/kg
P = 0.78
P = 0.88
P = 0.47
Inorganic Fertilizer
Paper Waste 10 t/ha
Paper Waste 20 t/ha
Cow Manure 10 t/ha
Cow Manure 20 t/ha
Food Waste 10 t/ha
Food Waste 20 t/ha
Compost 20 t/ha
b) Dry Shoot
P = 0.98
P = 0.89
220
200
180
160
140
120
100
mg/kg
P = 0.96
P = 0.92
P = 0.85
Inorganic Fertilizer
Paper Waste 10 t/ha
Paper Waste 20 t/ha
Cow Manure 10 t/ha
Cow Manure 20 t/ha
Food Waste 10 t/ha
Food Waste 20 t/ha
Compost 20 t/ha
c) Leaf Area
P = 0.37
P = 0.31
10000
9000
8000
7000
6000
5000
mg/kg
P = 0.54
P = 0.42
P = 0.35
Inorganic Fertilizer
Paper Waste 10 t/ha
Paper Waste 20 t/ha
Cow Manure 10 t/ha
Cow Manure 20 t/ha
Food Waste 10 t/ha
Food Waste 20 t/ha
Compost 20 t/ha

Figure 4.3.

Figure 4.4. Fresh shoot weights and dry shoot weights of tomatoes 114 days after transplanting in 2000. Bars designated by a line (●—●) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted yard waste.



a) Fresh shoot weight

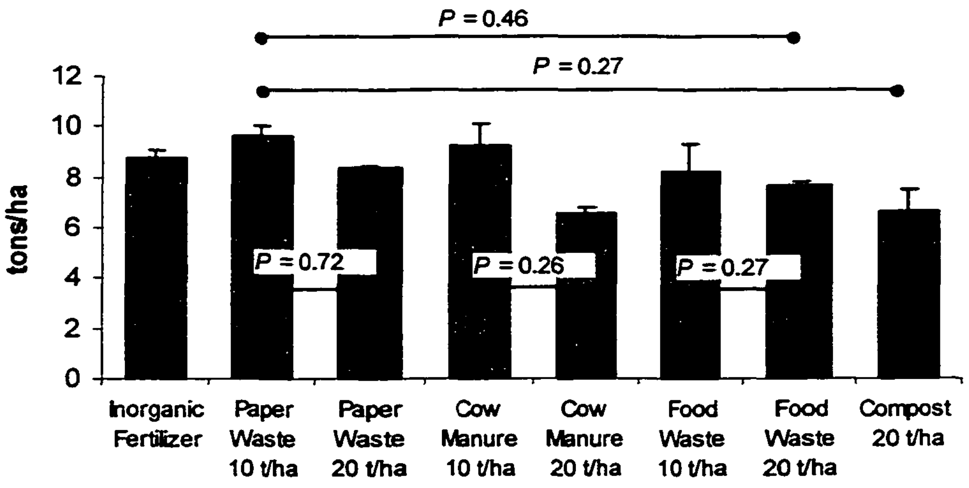


b) Dry shoot weights

Figure 4.4.

Figure 4.5. Marketable yield of tomatoes 120 days after transplanting in 1999. Bars designated by a line (●——●) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted sewage sludge in 1999 .

a) Marketable yield



b) Percent Non-Marketable yield

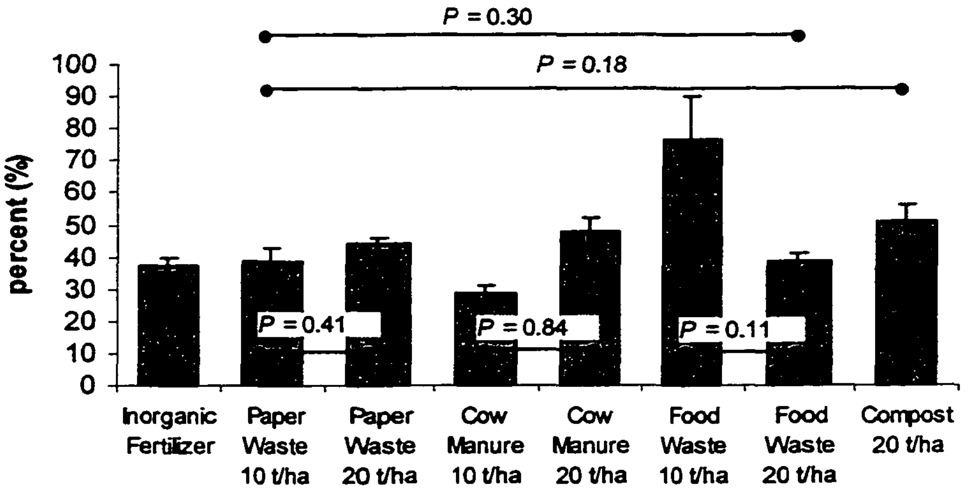
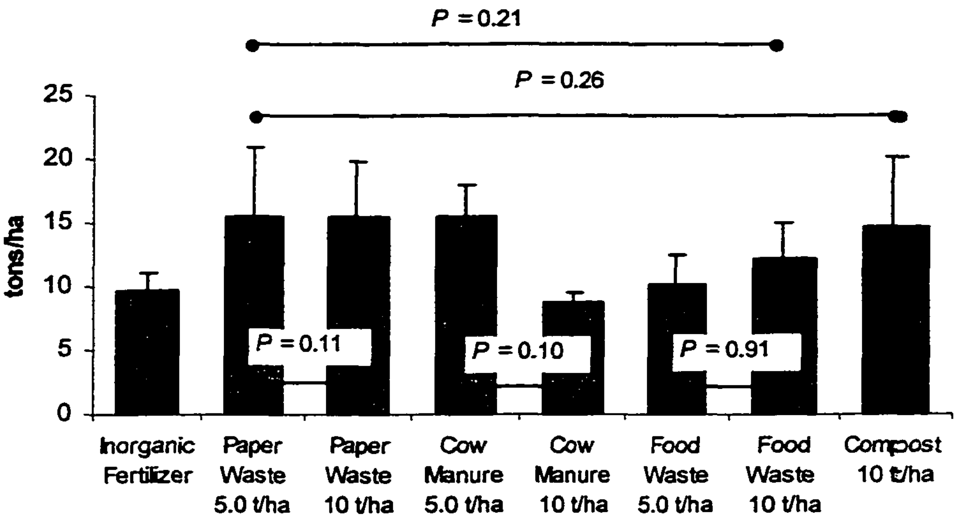


Figure 4.5

Figure 4.6. Marketable yield of tomatoes 114 days after transplanting in 2000. Bars designated by a line (●——●) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted yard waste.

a) Marketable yield



a) Percent non-marketable yield

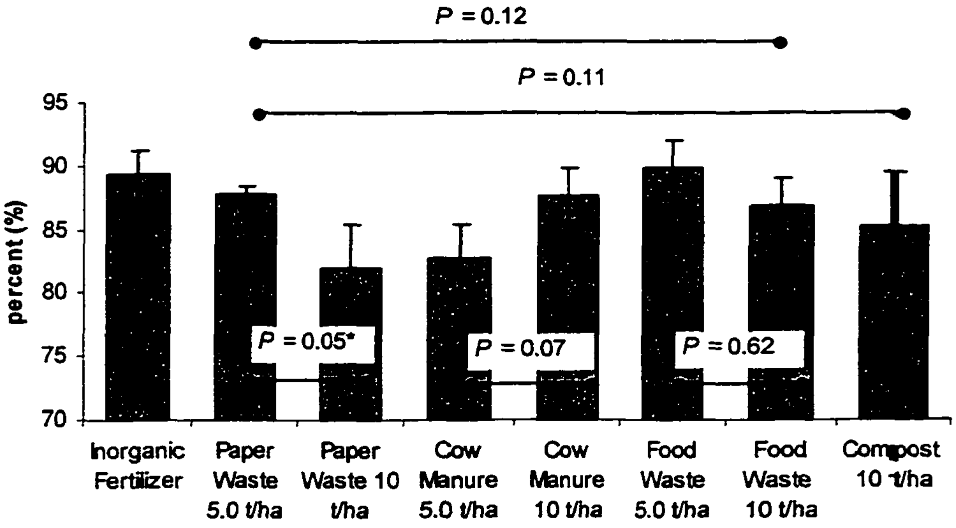


Figure 4.6.

	***P* values of orthogonal contrast of paired treatments**				
	Paper waste Vs Cow Manure	Paper Waste Vs Food Waste	Food Waste Vs Cow Manure	10 t/ha Vs 20 t/ha	Vermicompost vs Compost
Fresh Shoot Weights					
65 DAT	0.54	0.27	0.09	0.15	0.20
At harvest (120 DAT)	0.31	0.16	0.02*	0.14	0.17
Dry Shoot Weights					
65 DAT	0.31	0.21	0.03*	0.62	0.18
At harvest (120 DAT)	0.16	0.54	0.05*	0.06	0.99
Leaf Area					
65 DAT	0.97	0.38	0.40	0.17	0.45
YIELD (120 DAT)					
Marketable Yield	0.07	0.10	0.94	0.01**	0.02*
Percent non-marketable	0.44	0.31	0.09	0.31	0.03*

Table 4.2 . *P* values resulting from orthogonal contrasts of growth and yield parameters among vermicomposts and composts treatments in tomato plots 65 and 120 days after transplanting in 1999.

	***P* values of orthogonal contrast of paired treatments**				
	Paper waste Vs Cow Manure	Paper Waste Vs Food Waste	Food Waste Vs Cow Manure	10 t/ha Vs 20 t/ha	Vermicompost vs Compost
Fresh Shoot Weights					
49 DAT	0.87	0.58	0.48	0.85	0.32
At harvest (114 DAT)	0.13	0.16	0.91	0.54	0.58
Dry Shoot Weights					
49 DAT	0.94	0.78	0.73	0.84	0.44
At harvest (114 DAT)	0.42	0.21	0.03*	0.005**	0.36
Leaf Area					
49 DAT	0.81	0.68	0.86	0.54	0.38
YIELD (114 DAT)					
Marketable Yield	0.90	0.04*	0.04*	0.42	0.21
Percent non-marketable	0.71	0.03*	0.06	0.35	0.79

Table 4.3. . *P* values resulting from orthogonal contrasts of growth and yield parameters among vermicomposts and composts treatments in tomato plots 49 and 114 days after transplanting in 2000.

3.3.1 DISCUSSION

Effects of vermicompost applications on tomato growth and yields

The soil nitrogen and phosphorus contents of soils in the experimental plots (Table 4.1) were high even before any soil amendments applied. This may be because the area had been planted previously to well fertilized asparagus for about 6 years. The area was then fallowed and native grasses were allowed to grow for a year before the tomato plots were set up. Six years of asparagus growth could have built up the microbial biomass as was indicated by a high value of microbial biomass nitrogen. The previous fertilization program of asparagus could have directly influenced the high phosphorus concentrations in the experimental area. Hence, no P was applied to any plots in either year.

It is interesting to note that the tomato shoot weights, leaf area and yield did not differ significantly between plants in all treatments, except in those that were treated with food waste vermicompost, which produced lower plant shoot weights and leaf areas 65 days after transplanting. There have been many reports on increases of growth and yield after organic amendment to crops most of which occurred after occurred after a few years of continuous applications of organic matter. These reports have been discussed in details in the previous chapter.

Atiyeh et al. (2000) reported significant increases in tomato yield after substituting 20 % commercial soilless potting mixes with 20% pig manure vermicomposts which could have been attributed to the high mineral N content of pig manure vermicompost. However, since the plants were supplied with nutrients, they suggested that factors other than mineral N probably played major roles in increasing yields, because all of the potting media were supplied with a complete nutrient solution on a regular basis. In my experiments, it was possible that the macronutrients supplied by the vermicomposts in combination with the inorganic fertilizer supplement met the minimum macronutrient requirements to allow plants to grow and produced yields with those in the inorganic controls. The rates of growth of tomatoes, expressed as mean shoot weights and leaf areas, did not differ between plants grown in the inorganic control plots and those in the vermicompost-treated plots suggesting that nitrogen availability was sufficient in all plots. Nitrogen deficiency symptoms in tomato plants included restricted shoot growth and spindly plant appearances (Jones, 1999). Severe nitrogen deficiency can turn the entire plant pale green. However, such deficiency symptoms were not noted in any of the plots suggesting that the amounts of nitrogen supplied were within the required range for tomatoes.

Many factors can affect the availability of nutrients such as nitrogen to in the plots that were treated with vermicomposts and composts. Vermicomposts could have supplied macronutrients continuously by mineralization and still have retained relatively more nutrients in the soil, as result of increased cation exchange capacity in the clay and organic fractions of the soil, relative to that in the inorganic control plots. Various workers (Follet et al., 19811989; Laegreid et al., 1999) have reported consistently that cation exchange capacity increases after the addition of organic matter into the soil. The presence of rich microbial biomass in the vermicompost could also have contributed significantly to the mineralization of nutrients from vermicomposts.

The presence of micronutrients in the vermicomposts (Table 3.1) could also have contributed to the increased growth and yield of tomatoes. Roodra van Eysinga and

Smilde (1981) provided comprehensive descriptions of the visual symptoms of micronutrient deficiencies most of which can be observed on tomato leaves, such as change of color from green to yellow, purpling, scorching and other forms of discoloration and stunting. However, none of these symptoms, were observed in the tomatoes inorganic control plots suggesting that the soil had enough microelements to support the tomato plants.

It was possible any increases in growth and yields in tomatoes treated with vermicomposts could have been suppressed because vermicompost-treated plants wilted more heavily than those plants in the inorganic controls. Heavy wilting took longer time for tomatoes in the vermicompost-treated plots to recover relative to those in the inorganic controls. Plots treated with vermicomposts could have retained more water for a longer period due to the more organic matter from vermicompost applications. Over-irrigation could also have washed away available nutrients and plant-growth regulators in the vermicompost-treated plots. Hence, waterlogging of the soil in the tomato plots resulting from over-irrigation could have masked any significant differences between the treatments.

In 2000, vermicomposts were applied at rates of 10t/ha and 5 t/ha, on a wet weight basis, and the inorganic fertilizer supplements were also applied to equalize N and K contents in the plots. As a result, all plots initially contained equal amounts of macronutrients specifically N and K. The inorganic control plots produced inferior tomato yields to those in some of the vermicompost treatments although the differences were not statistically significant. There were also significant differences in tomato yields among the plants treated with the different vermicomposts. Plants with paper waste and cow manure vermicompost applications both produced significantly greater yields than those in the food waste vermicompost. This shows clearly that yields were not purely a response to macronutrient availability. The differences in the micronutrient contents of the vermicomposts may also have influenced the tomato plants ability to produce greater yields. Cow manure contained the greatest amounts of boron, potassium and sodium and second greatest amounts of iron, phosphorus, sulfur and zinc (Table 3.1). Paper waste vermicomposts by contrast, contained the greatest amounts of calcium and second greatest amounts of iron, magnesium and manganese. No single microelement could be pinpointed as being solely responsible for increased yields.

Differences in other properties of vermicomposts could also have contributed to the differences in the yield response of tomatoes to the amendments. One of these could be the presence and/or amounts plant growth-influencing substances, and the composition of the microbial biomass and microbiological activity the kinds of vermicomposts. Some reports on vermicomposts have reported the presence of humic acids and plant growth regulator analogues in a number of vermicomposts. Tomati and Grappeli (1987) demonstrated consistently that the presence of large quantities of gibberellins, auxins and cytokinins derived from vermicomposts increased plant growth in ornamental crops. Muscolo (1999) has demonstrated positive effects of humic acids extracted from vermicomposts on the growth of carrots. Their effects were similar to those of auxins. High levels of humic substances were found in animal manures (Masciandaro, 1997) and when tested on plants, humic substances increased plant growth even in conditions of adequate nutrition. It is possible that cow manure and paper waste vermicomposts that are in sufficient quantities that increased tomato yields more than food waste vermicomposts.

In a greenhouse experiment at the Ohio State University (unpublished data) using humic extracts from food waste and pig manure vermicomposts, it was demonstrated consistently that humic acids extracted from both kinds of vermicomposts applied at a high rate i.e. 2000 – 4000 ug/L suppressed the growth of cucumber seedlings.

4.3.2 RESULTS

The biochemical changes of soil in response to vermicompost applications

First Year

Ammonium nitrogen (NH_4-N),

In 1999, significant differences in soil NH_4-N contents occurred 30 and 65 days after transplanting. Soil in vermicompost-treated plots had significantly lower NH_4-N contents than soils from the inorganic control plots ($P < 0.001$) (Figure 4.7b and c). Only soils from cow manure vermicompost-treated plots contained NH_4-N concentrations that were significantly greater then those in soils from the inorganic control plots 65 days after transplanting ($P < 0.05$) (Figure 4.7c). There was a general decrease in amounts of soil NH_4-N towards the end of the growing cycle of the tomato crops in all treatments (Figure 4.7a-e).

Significant differences in NH_4-N bettween occurred 65 days after transplanting, $P < 0.05$, but no significant differences occurred 120 days after transplanting (Table 4.3). Between the rates of vermicompost application, 20 t/ha contained greater NH4-N content than those in 10 t/ha 65 days after transplanting (Table 4.3).

Nitrate nitrogen ($N0_3$-N)

Nitrate-nitrogen concentrations were significantly greater in soils from the inorganic control plots than in the soils from vermicompost plots, 30 days after transplanting ($P < 0.001$) (Figure 4.8). Soils from paper waste vermicompost-treated plots contained significantly more $N0_3$-N than soil from in the inorganic control plots, 90 days after transplanting ($P < 0.05$) (Figure 4. 8d).

Significant differences in NO_3-N contents between vermicompost-treated soils occurred 30, 65 and 90 days after transplanting with no vermicompost applications consistently maintaining a larger concentration of NO_3-N (Table 4.2). There were significant differences in NO_3-N concentrations in soils from all vermicompost-treated plots 120 days after transplanting (Figure 4.8e). Soils from plots treated with 10 t/ha vermicompost contained more NO_3-N than those treated with 20 t/ha vermicompost at transplanting, 30 and 90 days after transplanting.

Total Extractable-N

Soils from cow manure and paper waste vermicompost-treated plots had significantly less total extractable nitrogen than soils from the inorganic control plots, 30 days after transplanting ($P < 0.001$) (Figure 4.9b).

Differences total extractable in soil N concentrations among the different vermicompost treatments occurred as early as 30 days after transplanting; food waste vermicompost-treated plots contained more extractable soil N concentrations than those with treatments with cow manure vermicompost. Soil from none of vermicompost treatments contained consistently more extractable N than those from the other treatments 65 and 90, until 120 days after transplanting when no significant differences occurred between treatments (Table 4.3).

The application rate of 10t/ha vermicomposts to soil produced significantly more extractable N in soil at transplanting and 30 days after transplanting. Soil from the 20 t/ha vermicompost treatment contained more extractable N than those in soil from the 10 t/ha treatment, 90 days after transplanting (Table 4.3)

Dissolved organic nitrogen (DON)

Soils from the vermicompost-treated plots contained significantly more dissolved organic nitrogen (DON) than soils from the inorganic control plots, 65 and 90 days after transplanting ($P < 0.05$) (Figure 4.10c and d). Soils from vermicompost-treated plots did not differ significantly in DON from soil in those in inorganic control plots, 120 days after transplanting (Figure 4.10e). There were significant differences in DON concentrations between soils from the different vermicompost-treated plots 65 and 90 days after transplanting but there were no differences in DON 120 days after transplanting (Table 4.2).

Microbial biomass nitrogen

Soil from vermicompost-treated plots contained significantly more microbial biomass nitrogen compared to soil from the inorganic control plots 30, 65 and 90 days after transplanting ($P< 0.05$) (Figure 4.11). Soil from plots treated with cow waste vermicompost contained significantly more microbial biomass N than soils from the inorganic control plots, 120 days after transplanting ($P < 0.05$) (Figure 4.11e). There was a trend for decreases in microbial biomass nitrogen in all soils from transplanting to 120 days after transplanting.

Significant differences in soil microbial biomass among the three vermicompost applications occurred 30 and 65 days after transplanting. Soils treated with food waste vermicompost contained least soil microbial biomass N on both sampling dates (Table 4.2).

In soil from plots treated with 20 t/ha vermicomposts there was significantly more microbial biomass N than those in soil from plots treated with 10 t/ha, 30 and 120 days after transplanting.

Orthophosphate

There were no significant differences in amounts of orthophosphates in soils from the inorganic control plots and the vermicompost-treated and compost-treated plots on all sampling dates (Figure 4.12).

Soils from food vermicompost-treated plots contained significantly more orthophosphates than those soils from the cow manure vermicompost-treated plots, 90 and 120 days after transplanting (Table 4.3). Amounts of orthophosphates in soil did not vary significantly on all sampling dates.

Dehydrogenase enzyme activity (DHA)

Soil from vermicompost-treated plots had significantly more dehydrogenase activity compared with soil from the inorganic control plots 30, 65 and 90 days after transplanting ($P < 0.05$) (Figure 4.13). There were no significant differences in DHA in soil from the three kinds of vermicomposts on all sampling dates (Table 4.3).

Soils from plots treated with 20 t/ha vermicomposts had significantly more DHA than soil from plots with 10 t/ha, 90 days after transplanting.

Second Year

Ammonium-nitrogen (NH_4-N)

There were no significant differences in amounts of NH_4-N in soil from plots on all sampling dates (Figure 4.14).

Nitrate-nitrogen (NO_3-N)

Soils from cow manure vermicompost-treated plots contained significantly more NO_3-N than soils from the inorganic control plots only 114 days after transplanting (Figure 4.15). Soil from compost-treated plots contained more NO_3-N than soil from the vermicompost-treated plots 114 days after transplanting, $P < 0.01$ (Figure 4.15d).

Total Extractable Nitrogen

Soils from cow manure vermicompost-treated plots contained significantly more total extractable nitrogen than soils from the inorganic control plots only 114 days after transplanting ($P < 0.05$) (Figure 4.16).

Dissolved organic nitrogen (DON)

Soil from the vermicompost-treated plots had significantly more DON than soil from the inorganic control plots after 114 days from transplanting ($P < 0.05$) (Figure 4.17). There was a general trend of decreases in DON in soil from all plots towards the end of the growing cycle of tomatoes.

Microbial biomass nitrogen

Soils from vermicompost-treated plots contained significantly more soil microbial biomass nitrogen than soil from the inorganic control plots at transplanting and 114 days after transplanting ($P < 0.05$) (Figure 4.18). Soil microbial biomass decreased in soil from all plots towards the end of the growing cycle of tomato plants.

Orthophosphates

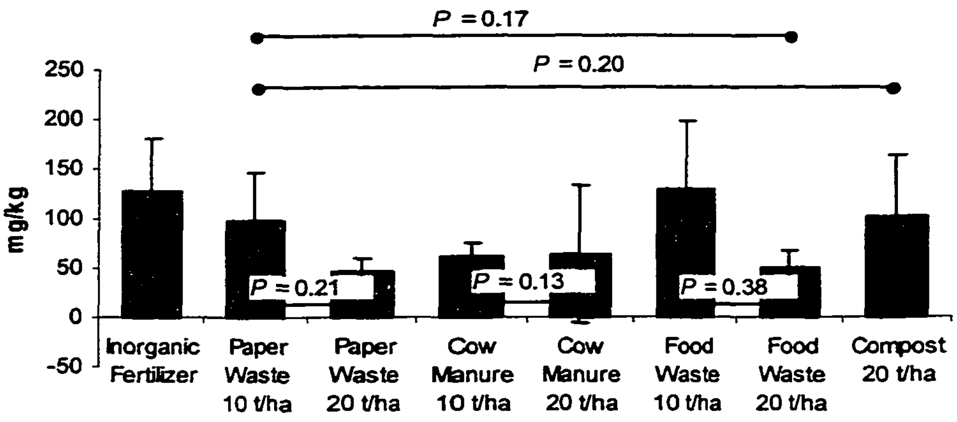
There were no significant differences in amounts of the orthophosphates in soil between soil the vermicompost-treated plots and in soil from the inorganic control plots on all sampling dates. Soil from compost-treated plots contained significantly more orthophosphates compared with soils from the vermicompost-treated plots 49, 84 and 114 days after transplanting.

Dehydrogenase enzyme activity (DHA)

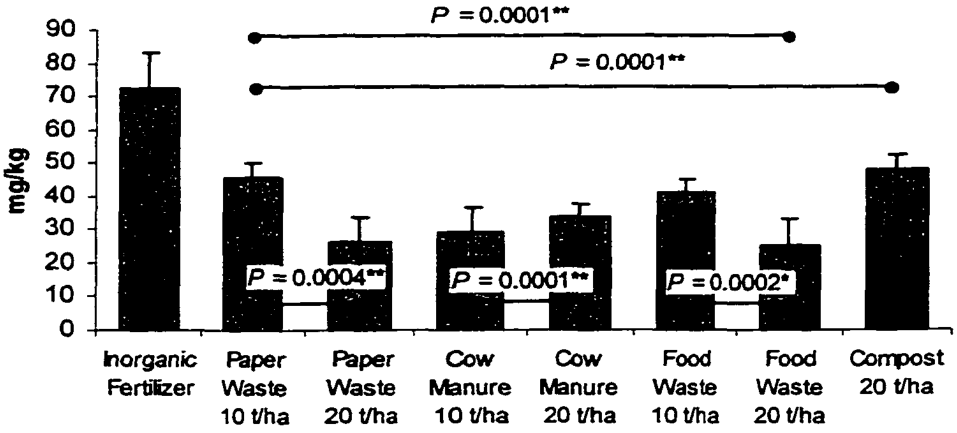
There were no significant differences in DHA in all treatment soils on all sampling dates. A trend for decrease DHA was observed in all plots towards the end of the growing cycle of the tomato plants.

Figure 4.7. Ammonium-nitrogen (NH_4-N) contents of the tomato plots in 1999. Bars designated by a line (●—●) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted sewage sludge.

a) at Transplanting



b) 30 DAT



c) 65 DAT

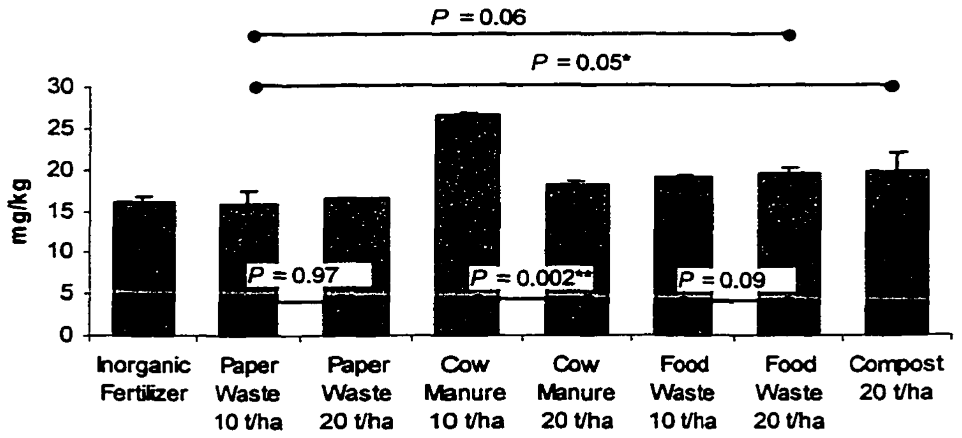
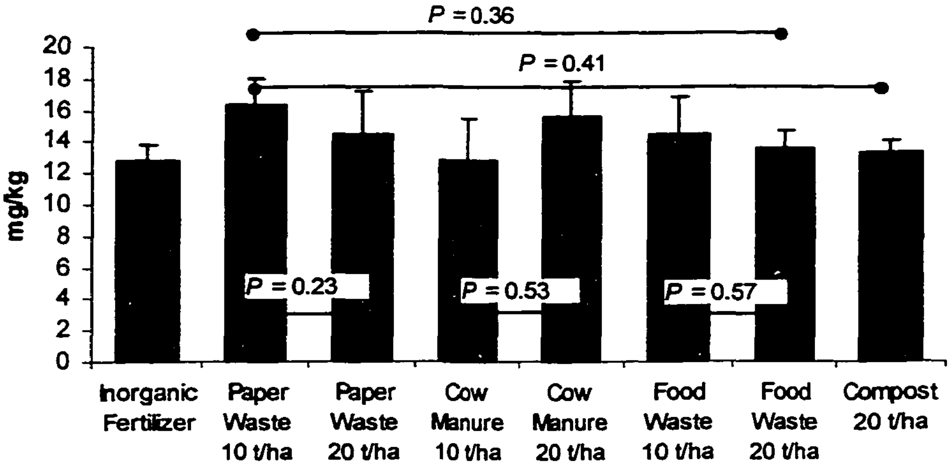


Figure 4.7. (continued)

Figure 4.7. (continued)

d) 90 DAT



e) 120 DAT

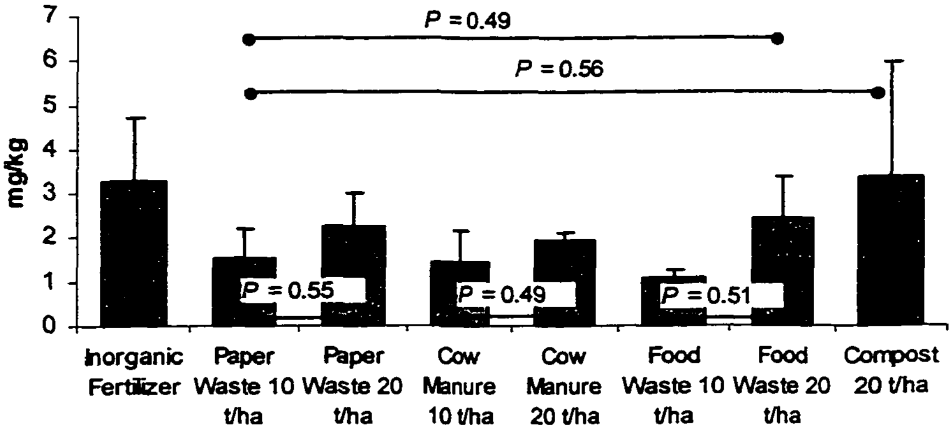
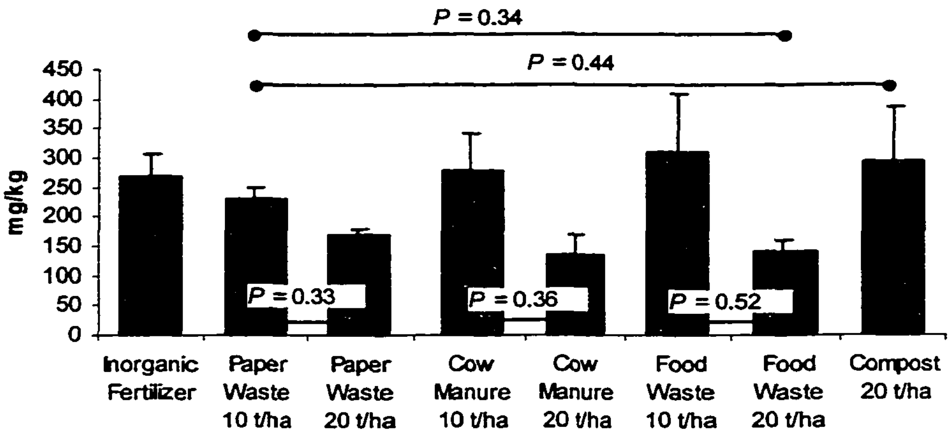


Figure 4.8. Nitrate-nitrogen (NO3-N) contents of the tomato plots in 1999. Bars designated by a line (●——●) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted sewage sludge.

a) at Transplanting



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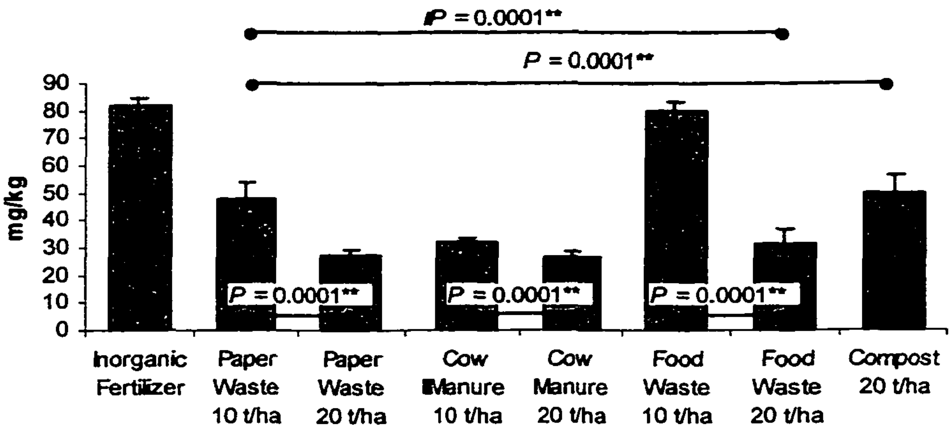


c) 65 DAT

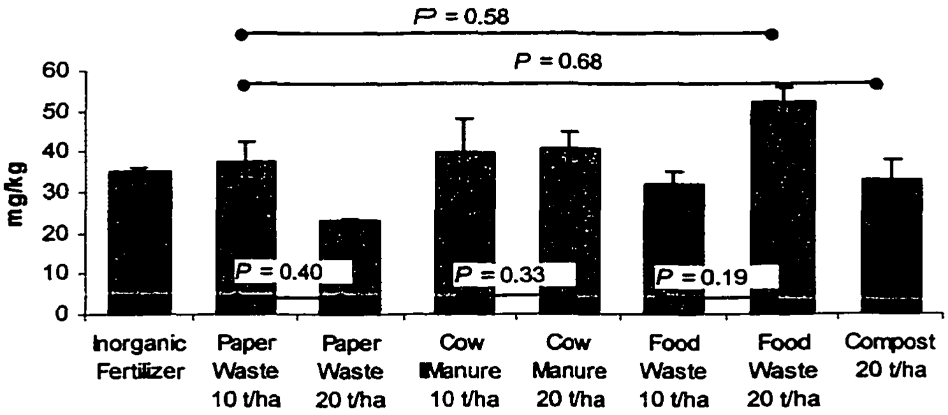
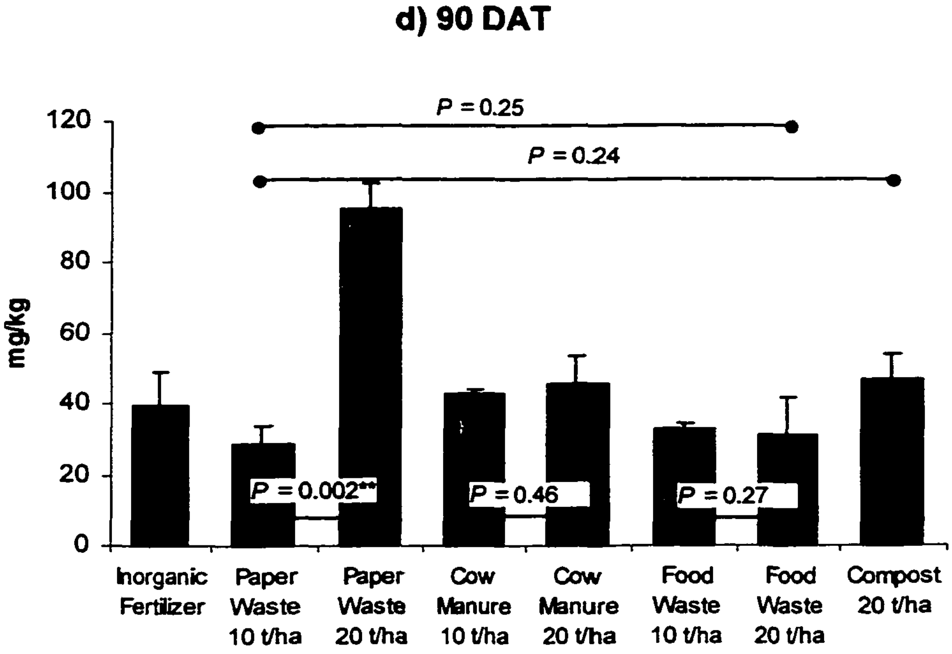


Figure 4.8 (continued)

Figure 4.8 (continued)



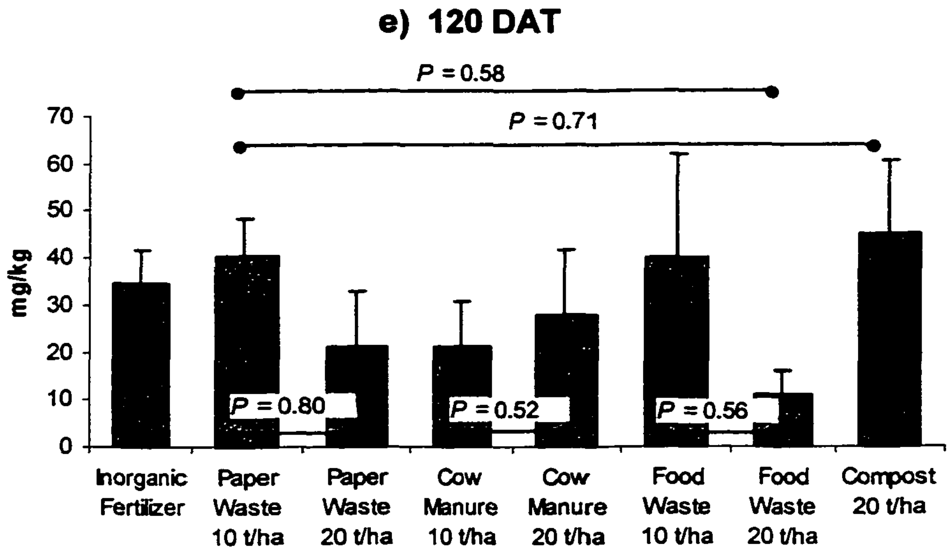
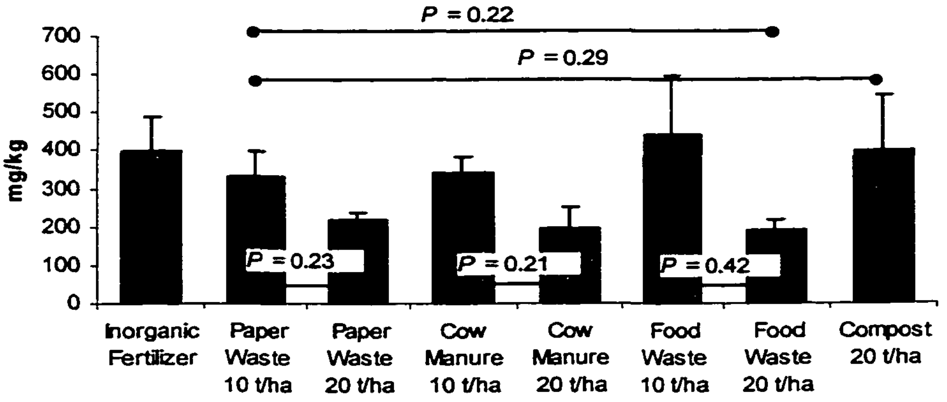
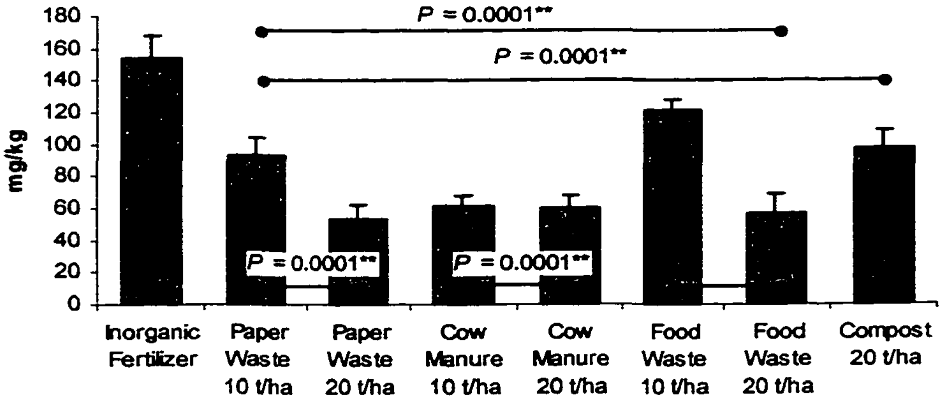


Figure 4.9. Total extractable nitrogen content of the tomato plots in 1999. Bars designated by a line (●——●) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted sewage sludge.

a) at Transplanting



b) 30 DAT



c) 65 DAT

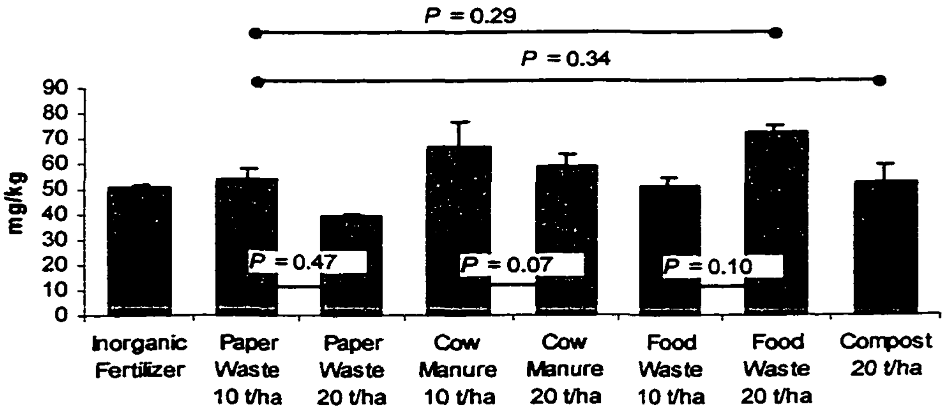
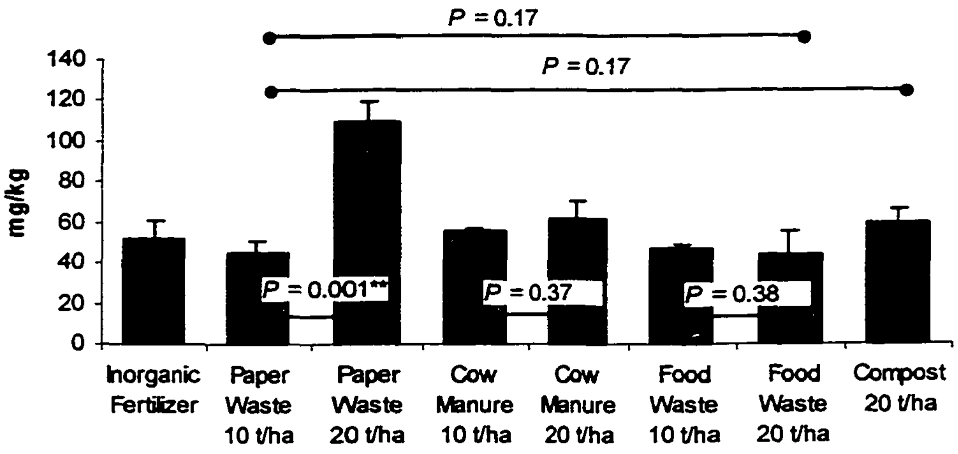


Figure 4.9 (continued)

Figure 4.9 (continued)

d) 90 DAT



e) 120 DAT

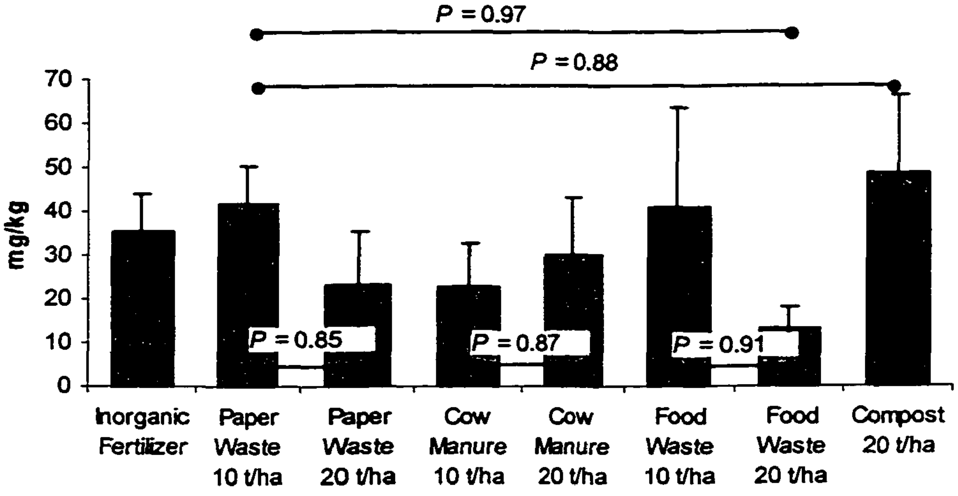
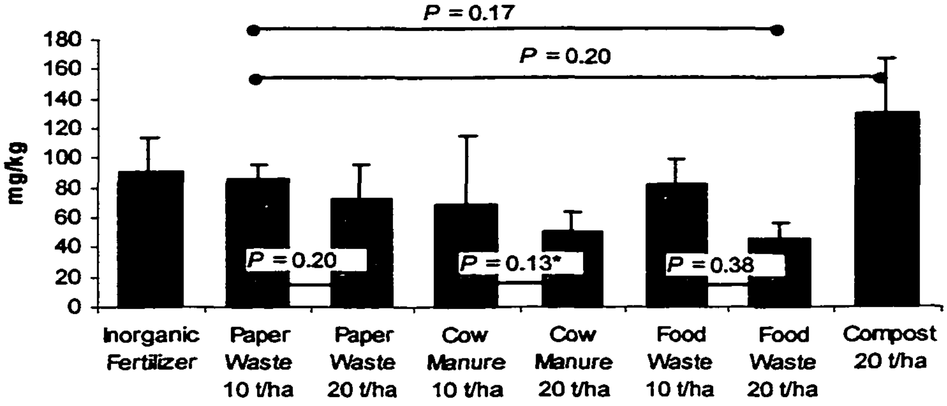
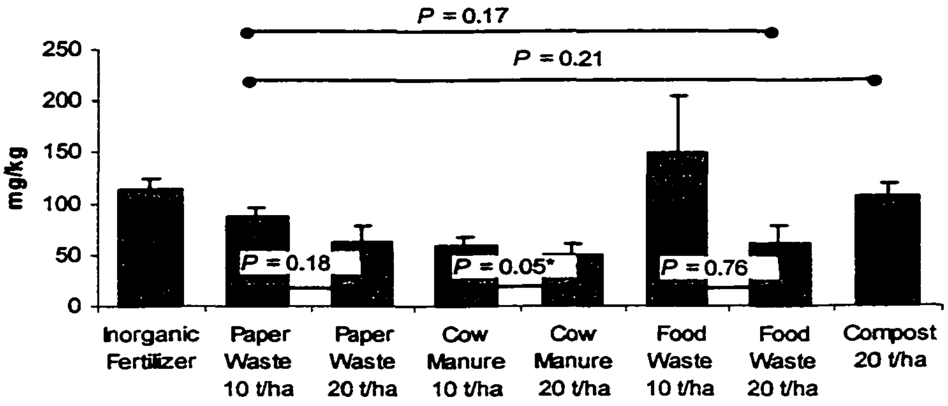


Figure 4.10. Dissolved organic nitrogen (DON) contents of the tomato plots in 1999. Bars designated by a line (•——•) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted sewage sludge.

a) at Transplanting



b) 30 DAT



c) 65 DAT

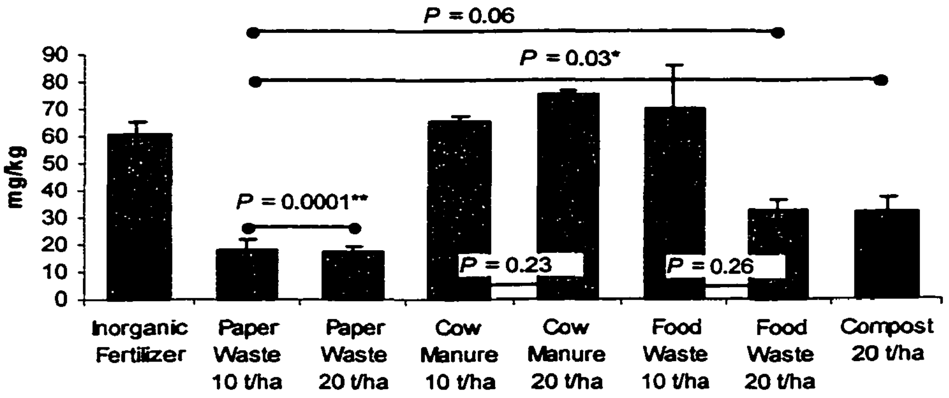
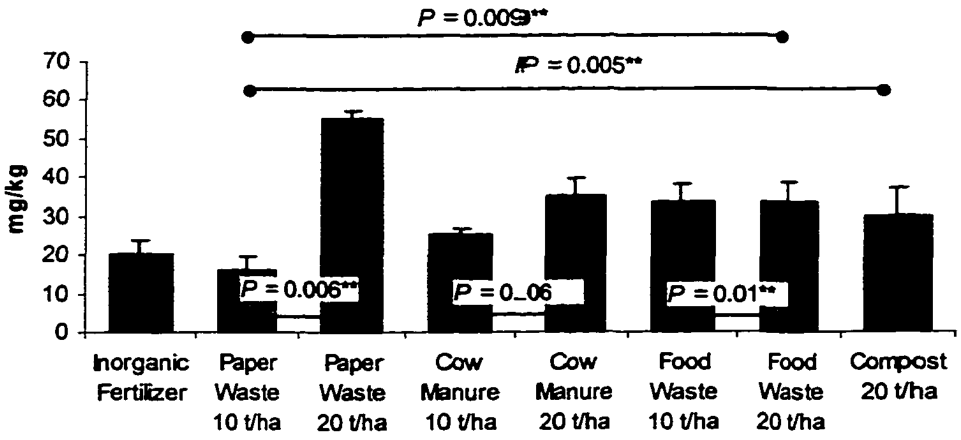


Figure 4.10. (continued)

Figure 4.10 (continued)

d) 90 DAT



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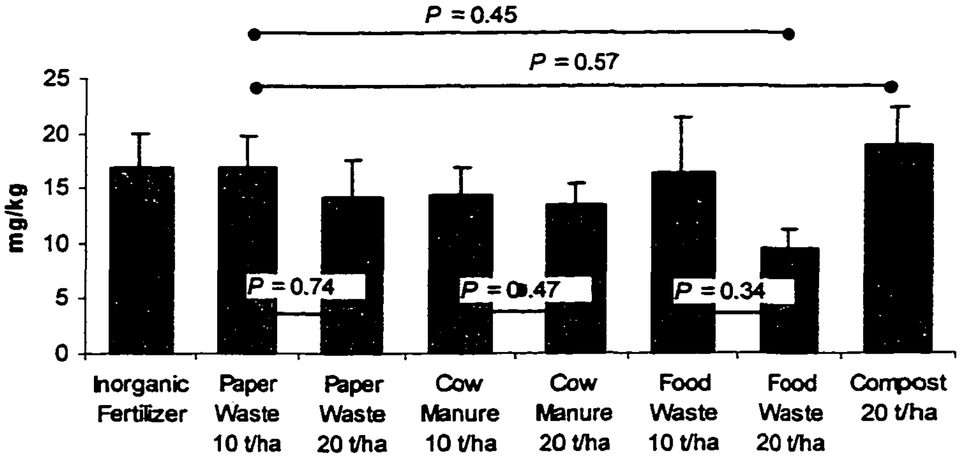
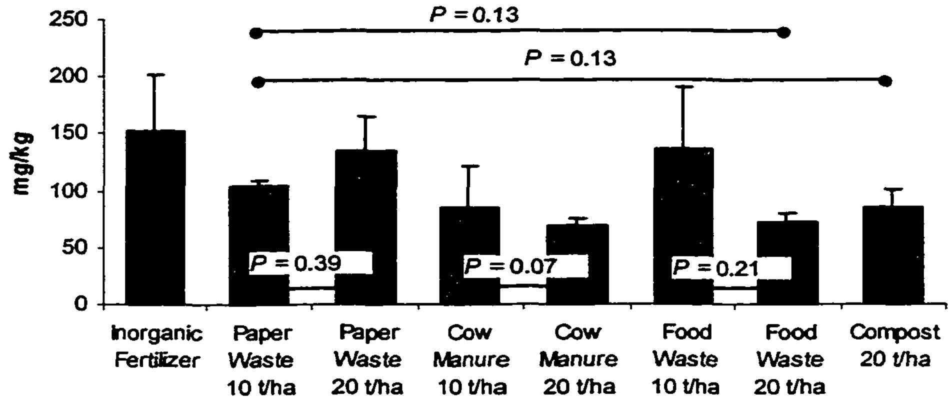
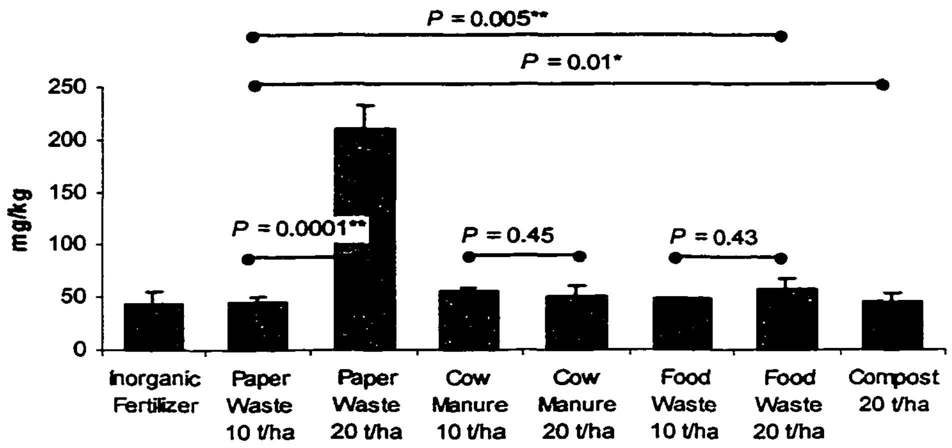


Figure 4.11. Microbial biomass nitrogen contents of the tomato plots in 1999. Bars designated by a line (●——●) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted sewage sludge.

a) at Transplanting



b) 30 DAT



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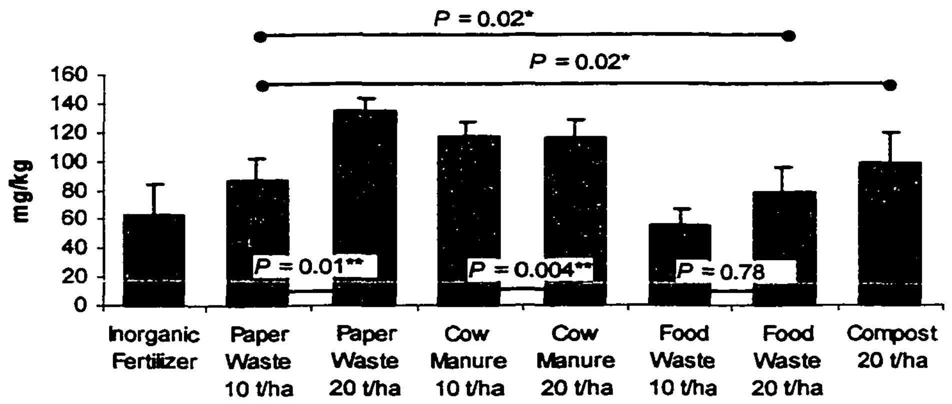

Figure 4.11 (continued)

Figure 4.11 (continued)

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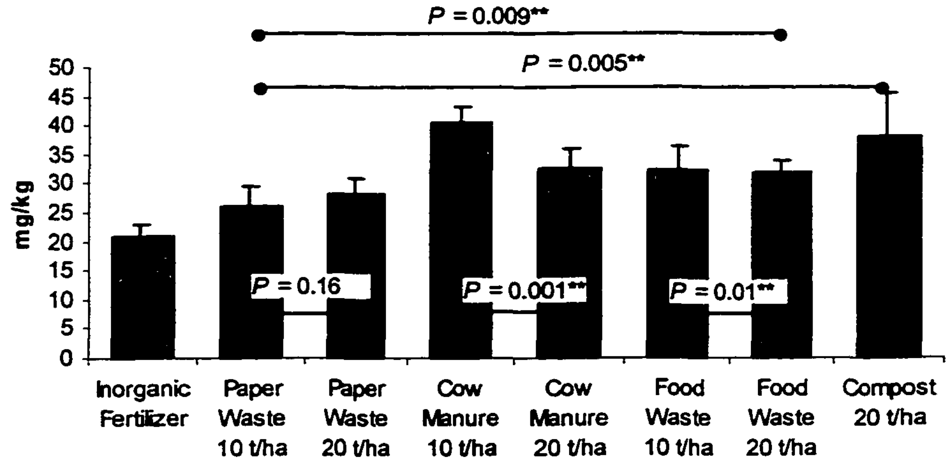


e) 120 DAT

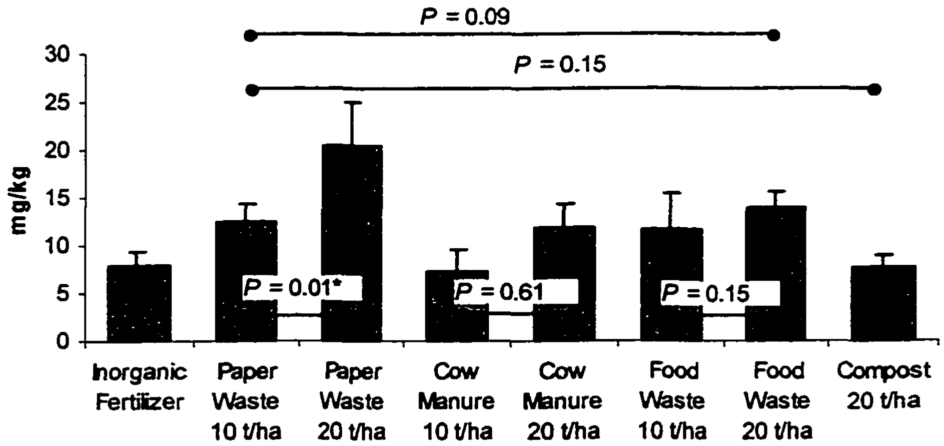
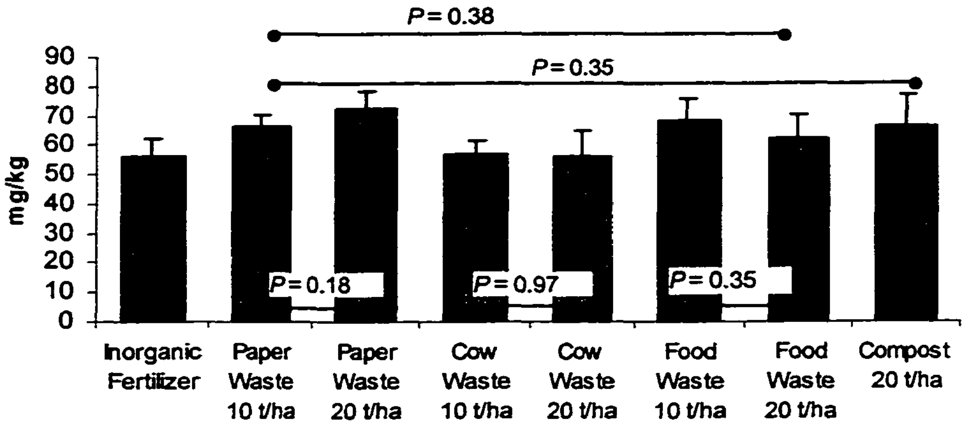
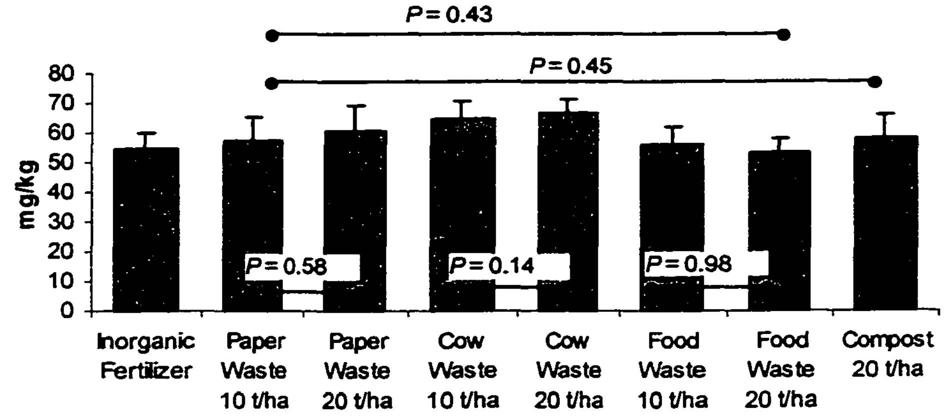


Figure 4.12:. Orthophosphate contents of the tomato plots in 1999. Bars designated by a line (●—●) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted sewage sludge.

a) at Transplanting



b) 30 DAT



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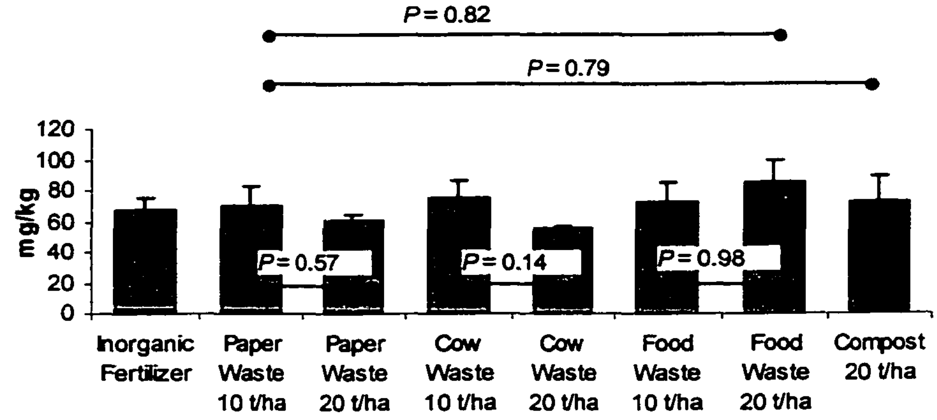
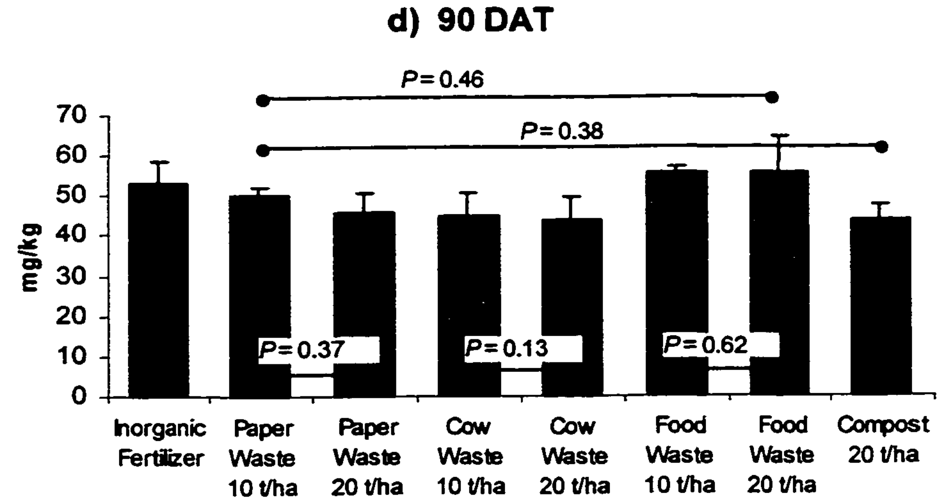


Figure 4.12 (continues)

Figures 4.12 (continued)



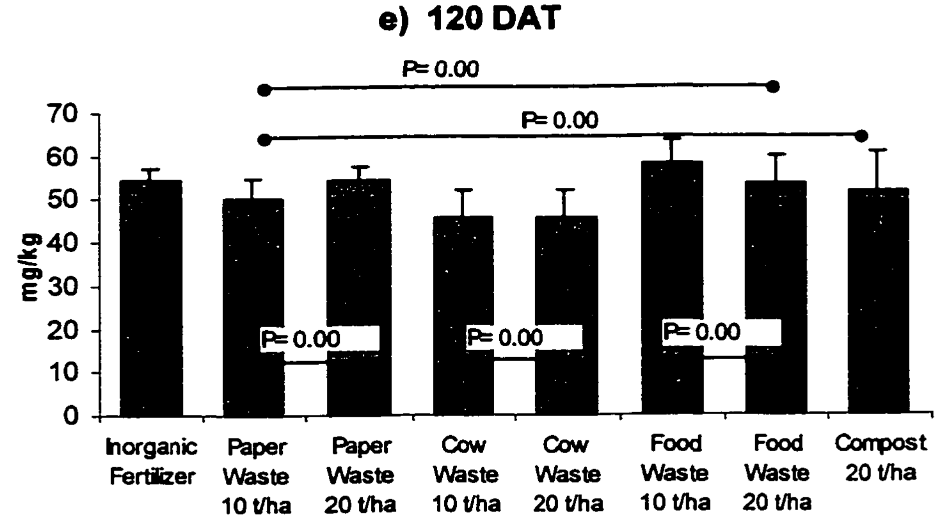
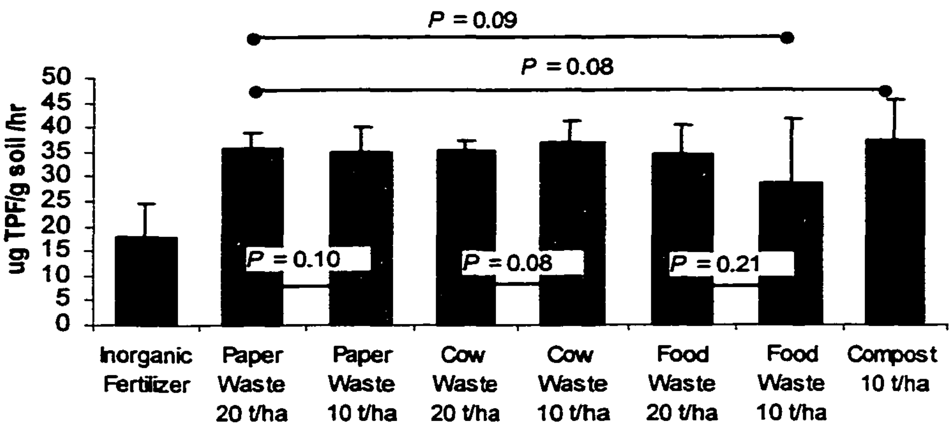
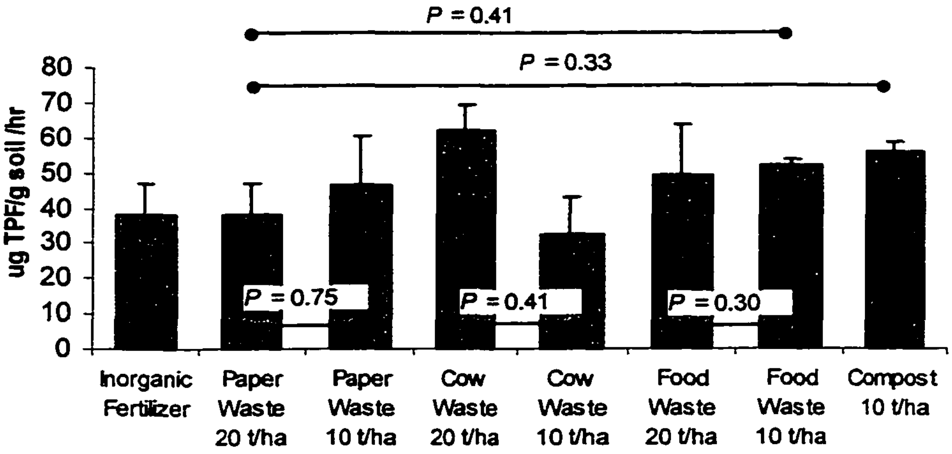


Figure 4.13: Dehydrogenase enzyme activities (DHA) of the tomato plots in 1999. Bars designated by a line (●——●) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted sewage sludge.

a) Transplanting



b) 35 DAT



c) 65 DAT

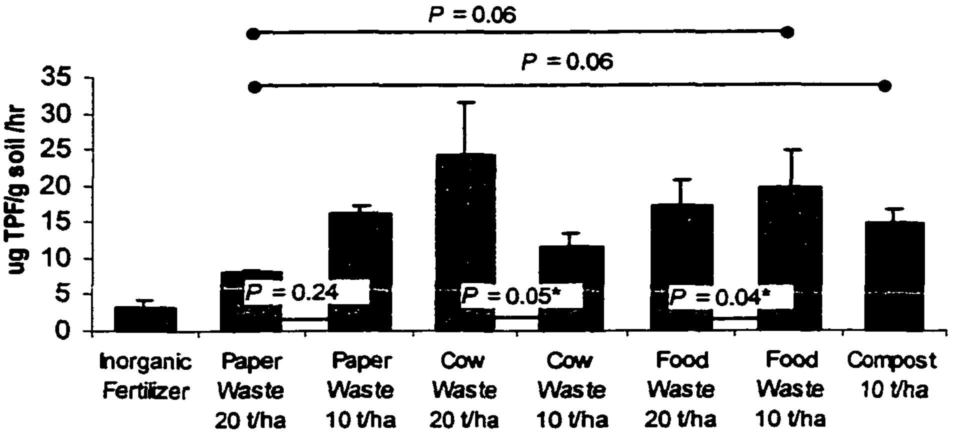
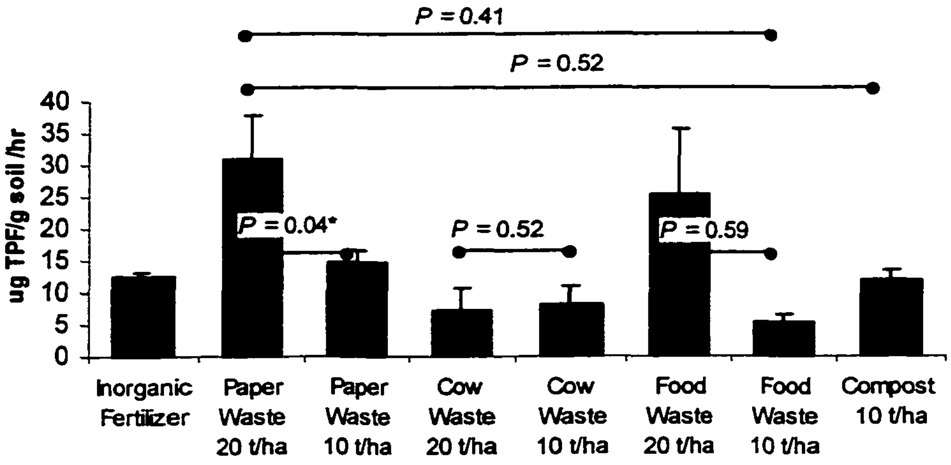


Figure 4.13 (continued)

Figure 4.13 (continued)

d) 90 DAT



e) 120 DAT

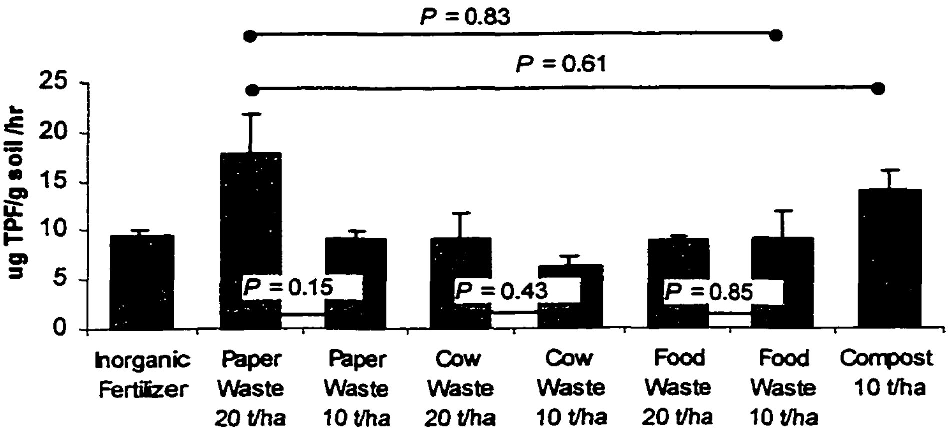


Figure 4.14: Ammonium-nitrogen (NH4-N) content of the tomato plots in 2000. Bars designated by a line (●—●) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted yard waste.

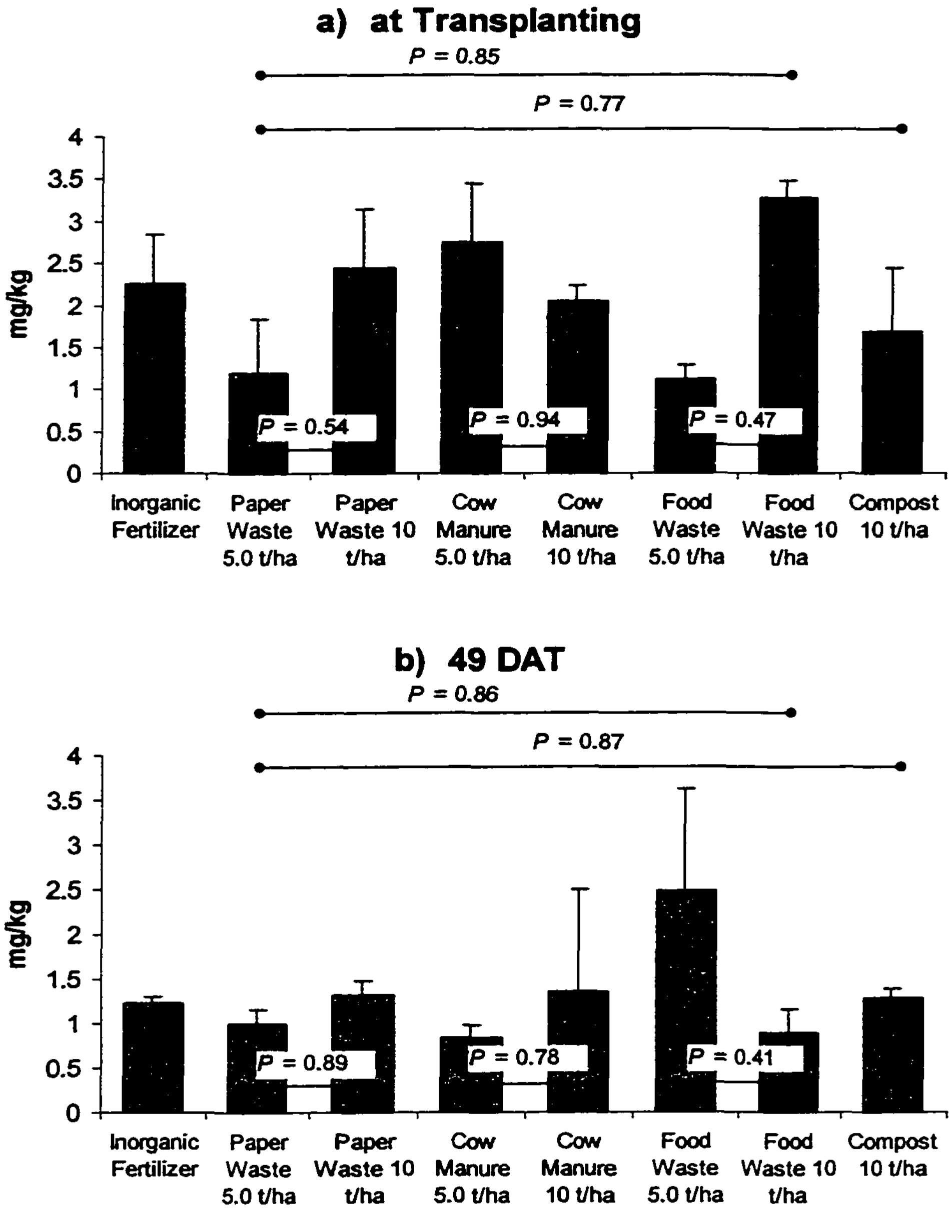
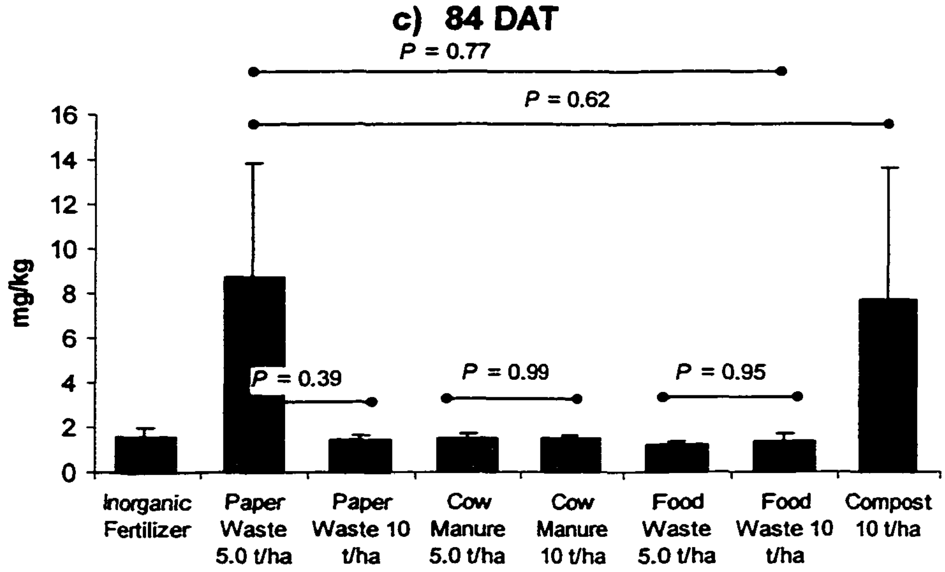
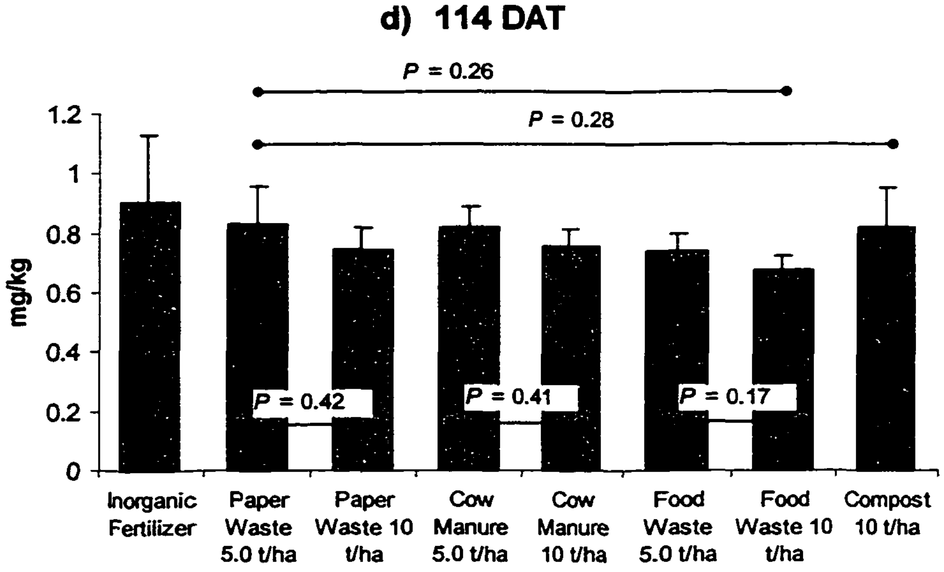


Figure 4.14. (continued)

Figure 4.14 (continued)

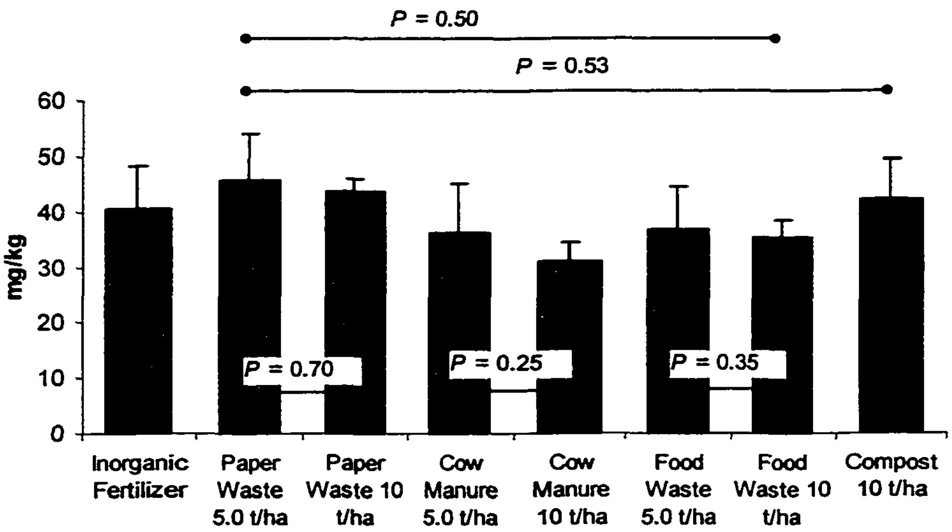


c) 84 DAT



d) 114 DAT

Figure 4.15: Nitrate-nitrogen (NO3-N) contents of the tomato plots in 2000. Bars designated by a line (•——•) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted yard waste.


a) at Transplanting

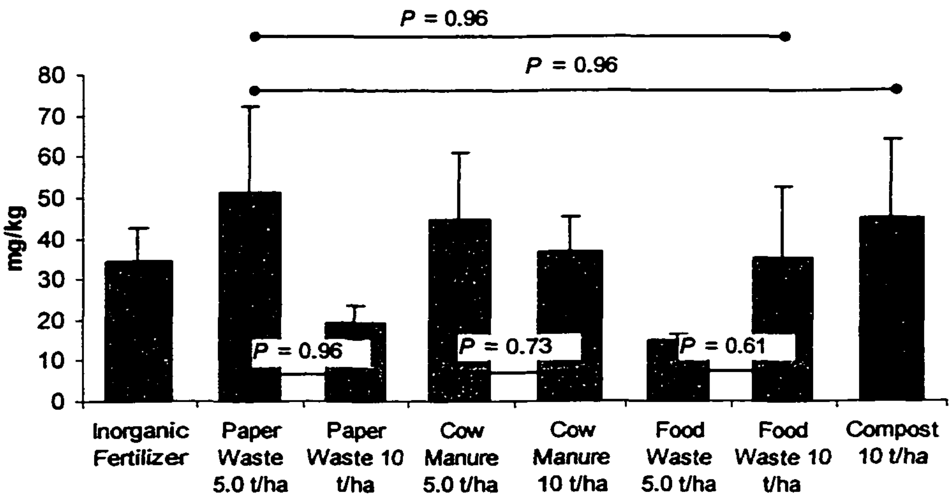
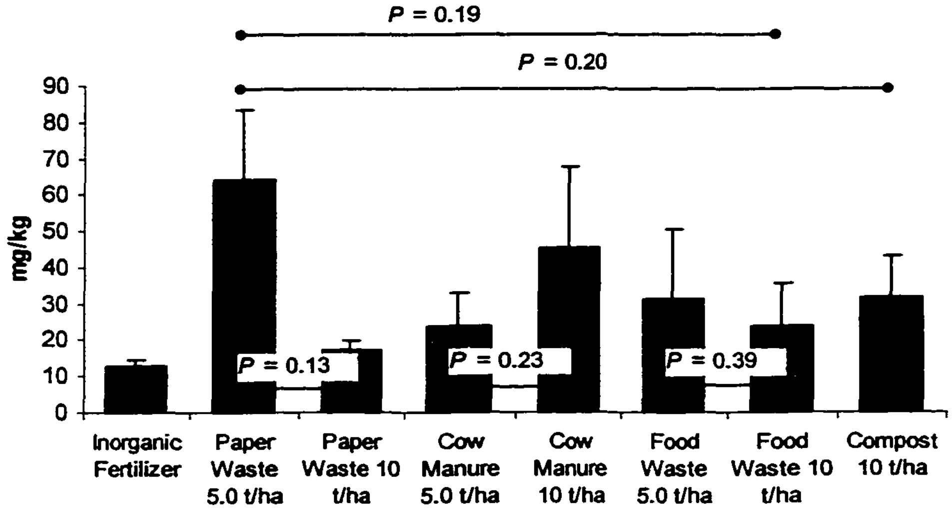

b) 49 DAT

Figure 4.15. (continued)

Figure 4.15 (continued)

c) 84 DAT



d) 114 DAT

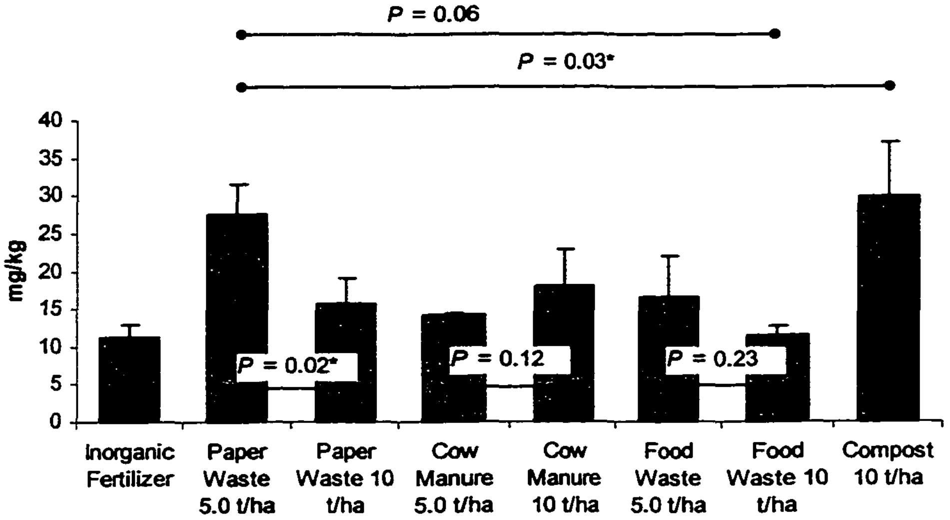
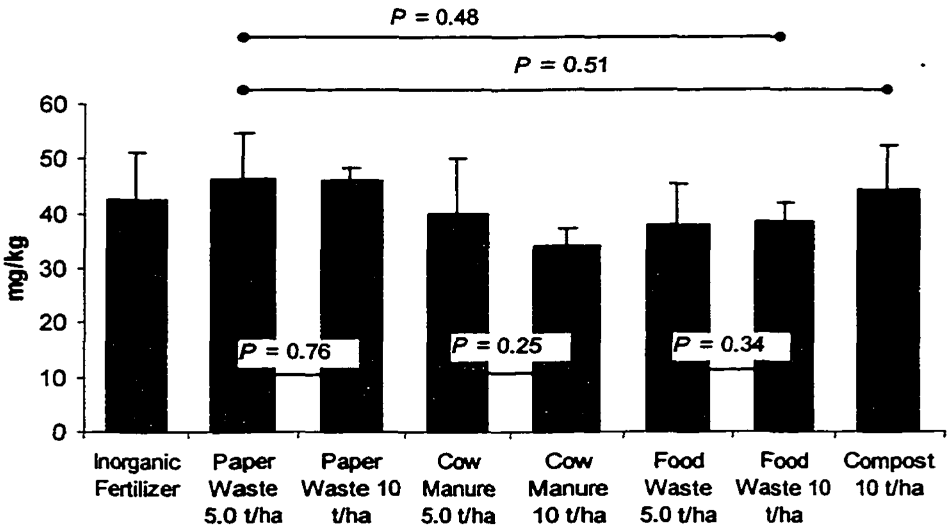


Figure 4.16: Total extractable nitrogen contents of the tomato plots in 2000. Bars designated by a line (●——●) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted yard waste.

a) at Transplanting



b) 49 DAT

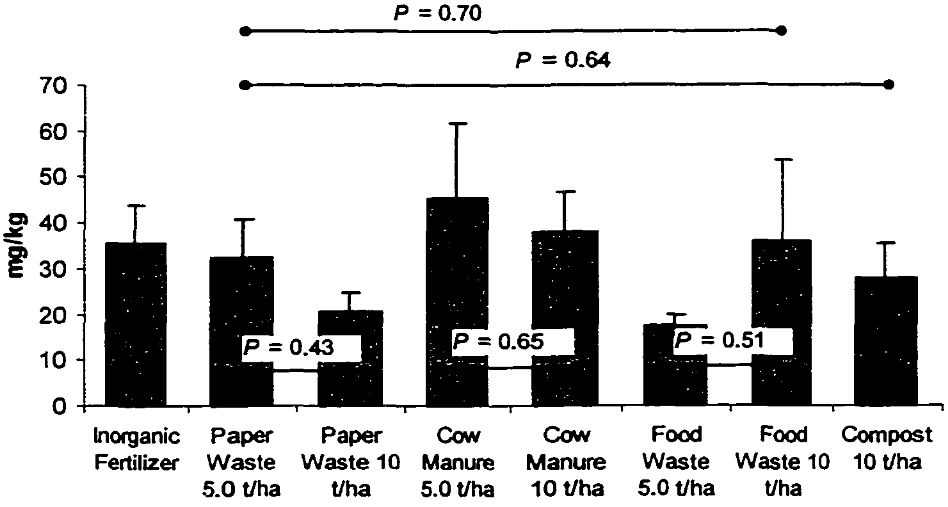
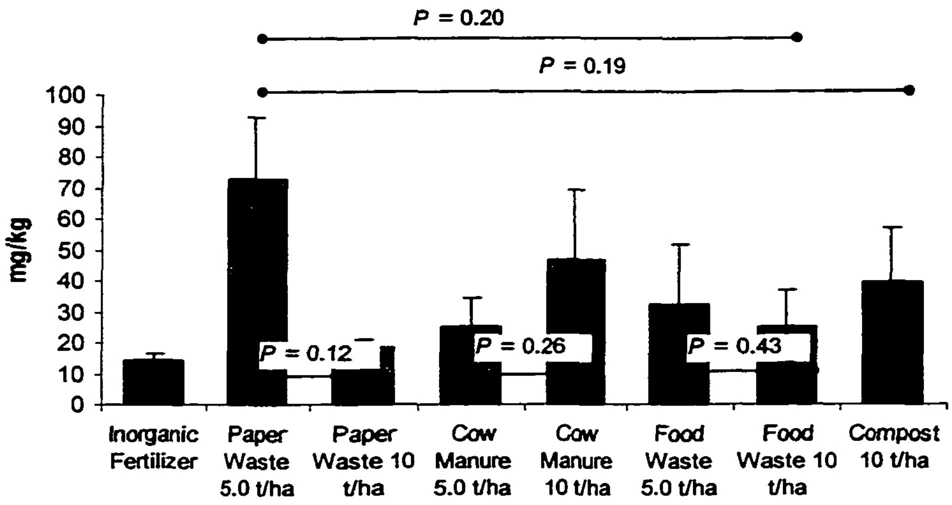


Figure 4.16 (continues)

Figure 4.16 (continued)

c) 84 DAT



d) 114 DAT

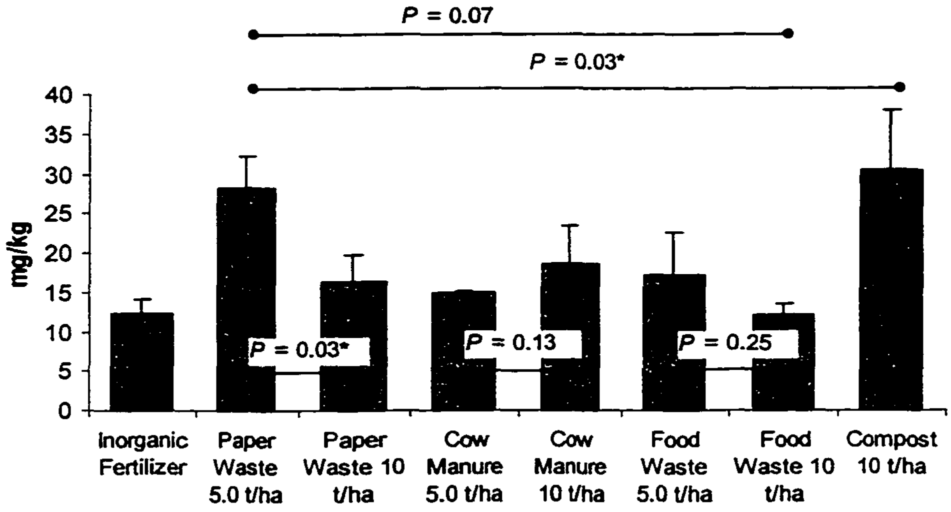
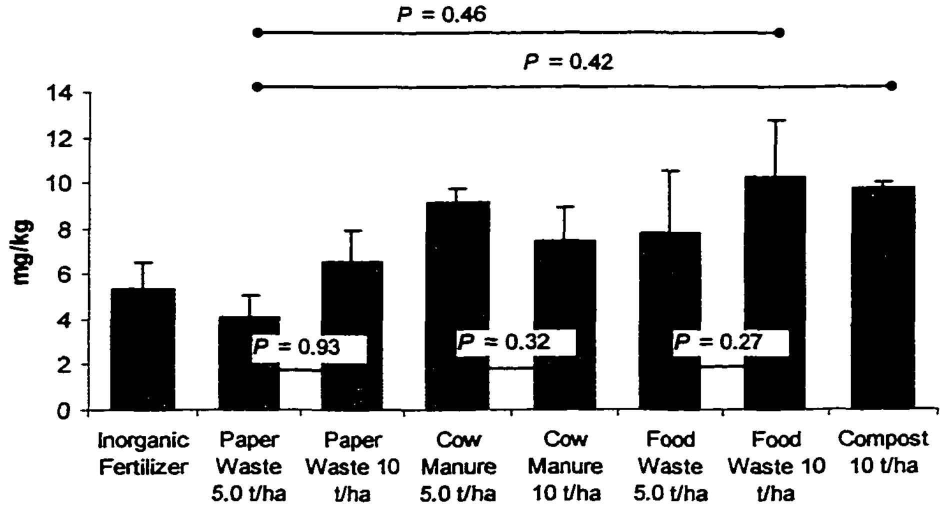
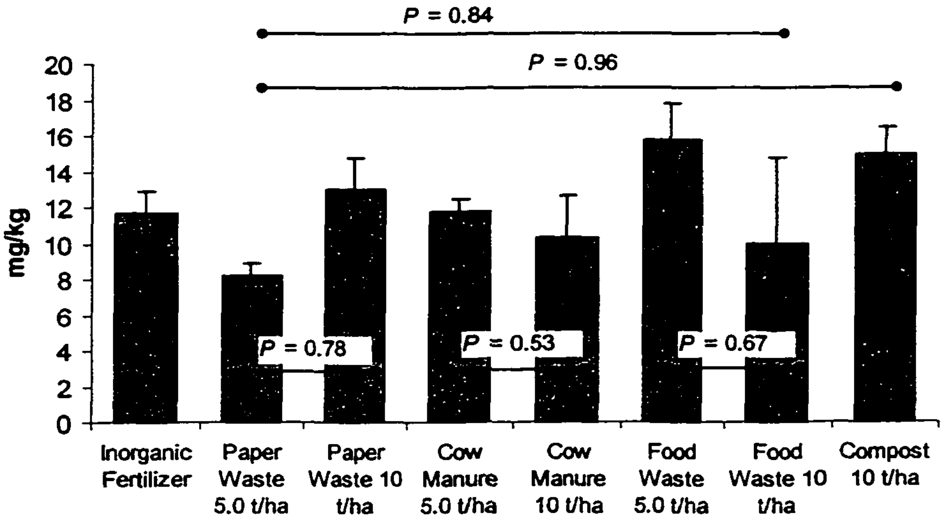


Figure 4.17: Dissolved organic nitrogen (DON) contents of the tomato plots in 2000. Bars designated by a line (●——●) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted yard waste.



a) at Transplanting

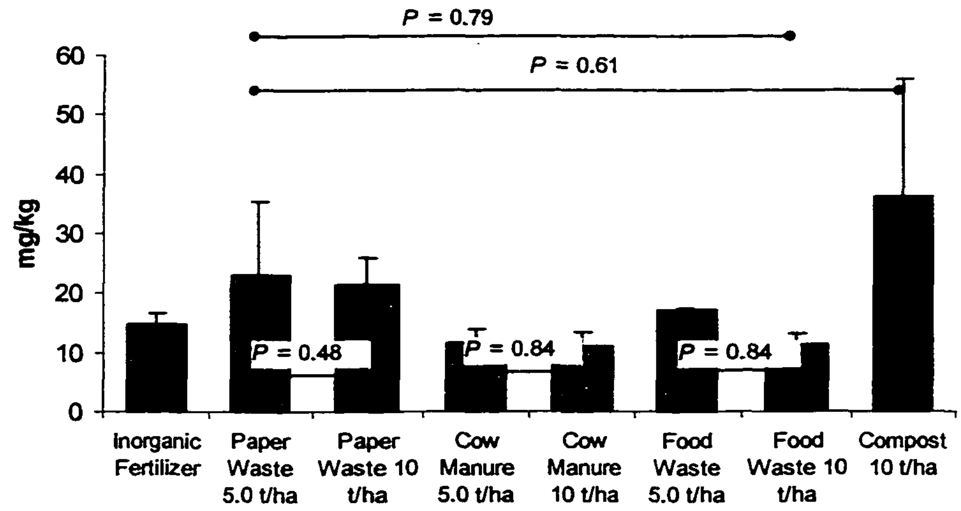


b) 49 DAT

Figure 4.17. (continued)

Figure 4.17 (continued)

c) 84 DAT



d) 114 DAT

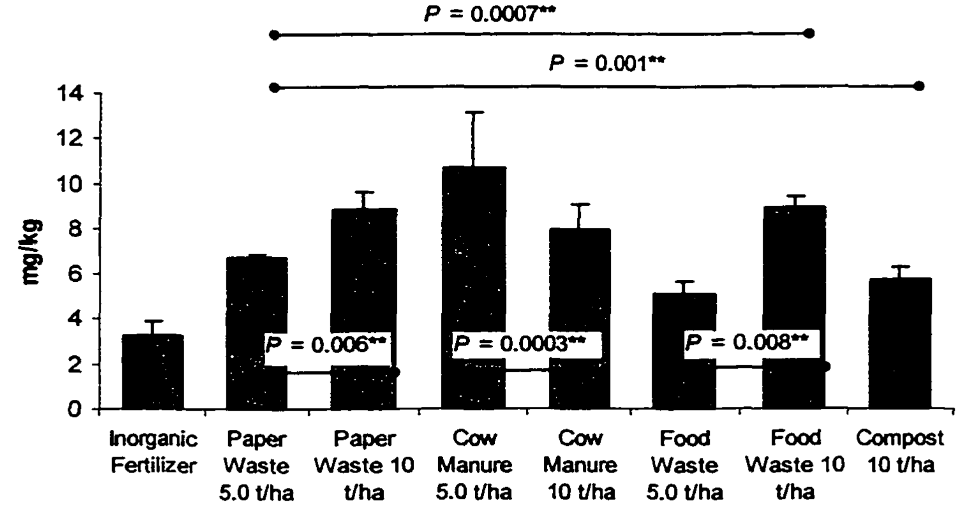
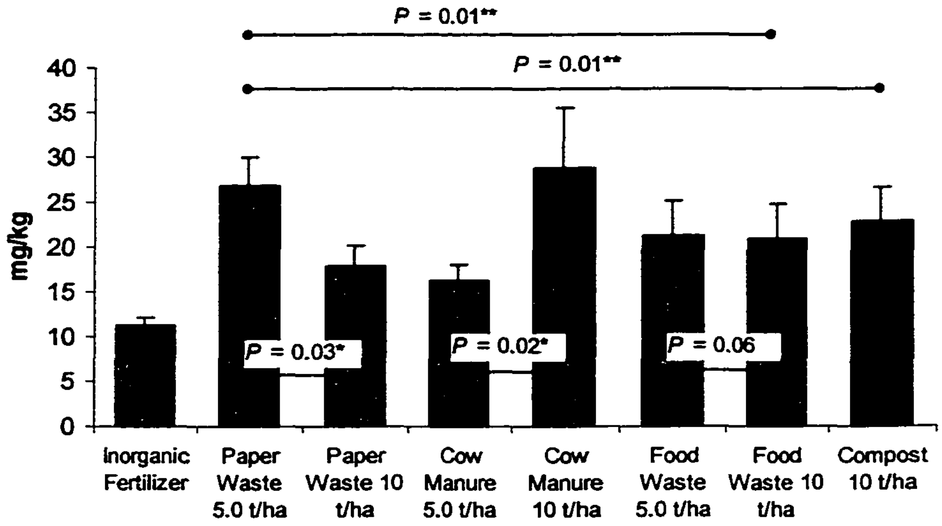
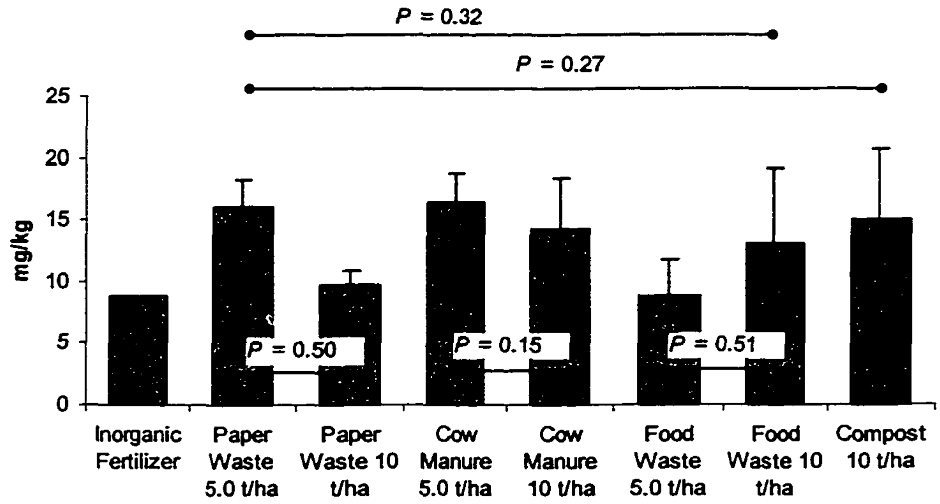


Figure 4.18: Microbial biomass nitrogen contents of the tomato plots in 2000. Bars designated by a line (●——●) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted sewage sludge.

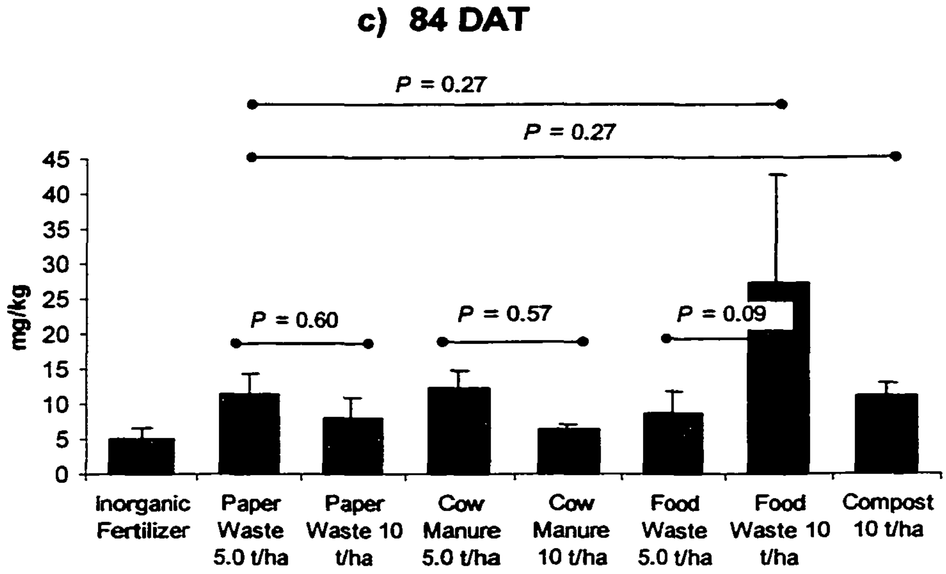


a) at Transplanting



b) 49 DAT

Figure 4.18. (continued)


c) 84 DAT
P = 0.27
P = 0.27
P = 0.60
P = 0.57
P = 0.09
mg/kg
45
40
35
30
25
20
15
10
5
0
Inorganic Fertilizer
Paper Waste 5.0 t/ha
Paper Waste 10 t/ha
Cow Manure 5.0 t/ha
Cow Manure 10 t/ha
Food Waste 5.0 t/ha
Food Waste 10 t/ha
Compost 10 t/ha

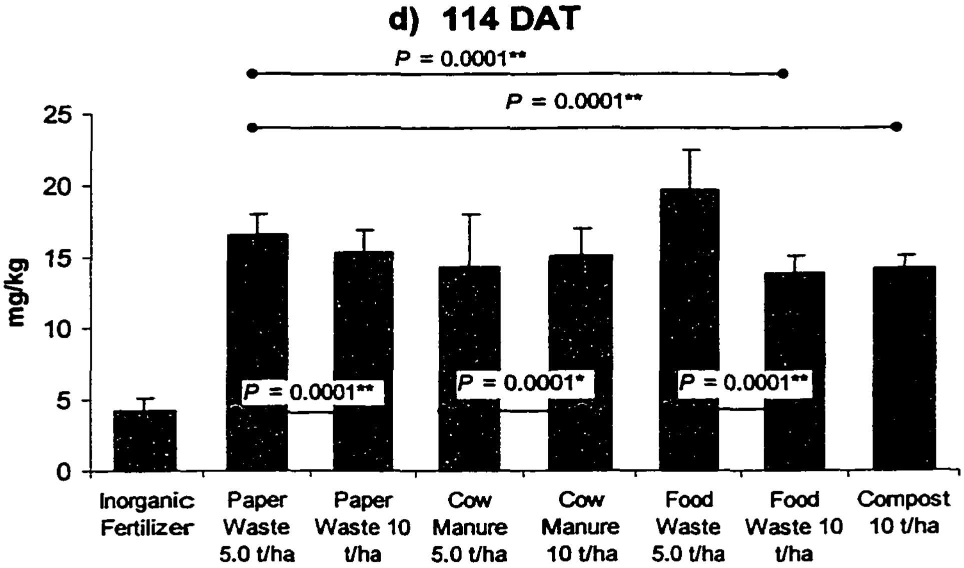
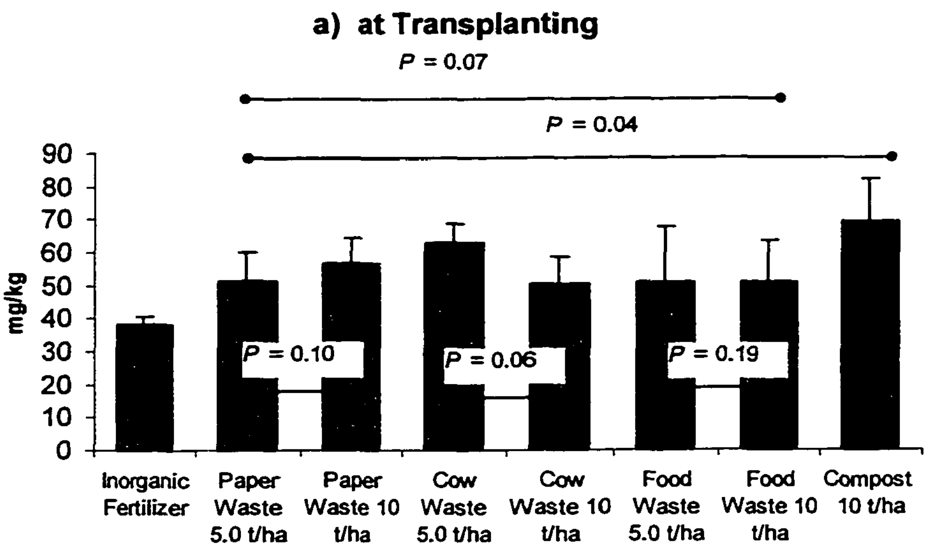
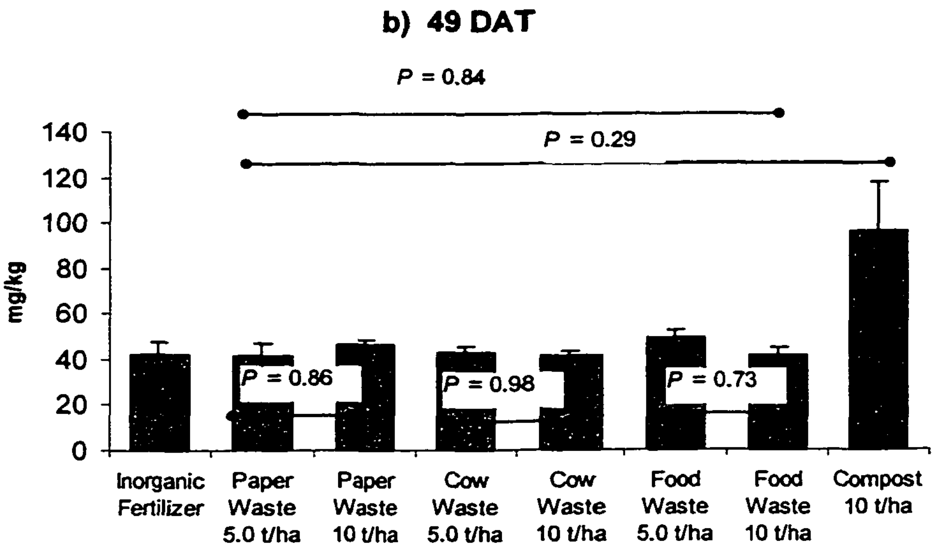

d) 114 DAT
P = 0.0001**
P = 0.0001**
P = 0.0001**
P = 0.0001*
P = 0.0001**
mg/kg
25
20
15
10
5
0
Inorganic Fertilizer
Paper Waste 5.0 t/ha
Paper Waste 10 t/ha
Cow Manure 5.0 t/ha
Cow Manure 10 t/ha
Food Waste 5.0 t/ha
Food Waste 10 t/ha
Compost 10 t/ha

Figure 4.19: Orthophosphate contents of the tomato plots in 2000. Bars designated by a line (•——•) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted yard waste.



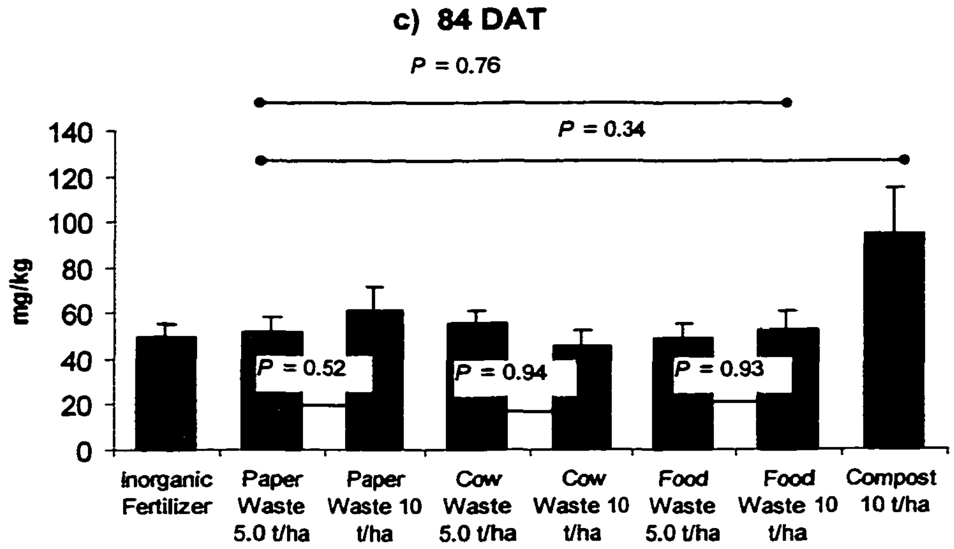
a) at Transplanting



b) 49 DAT

Figure 4.19. (continues)

Figure 4.19 (continued)



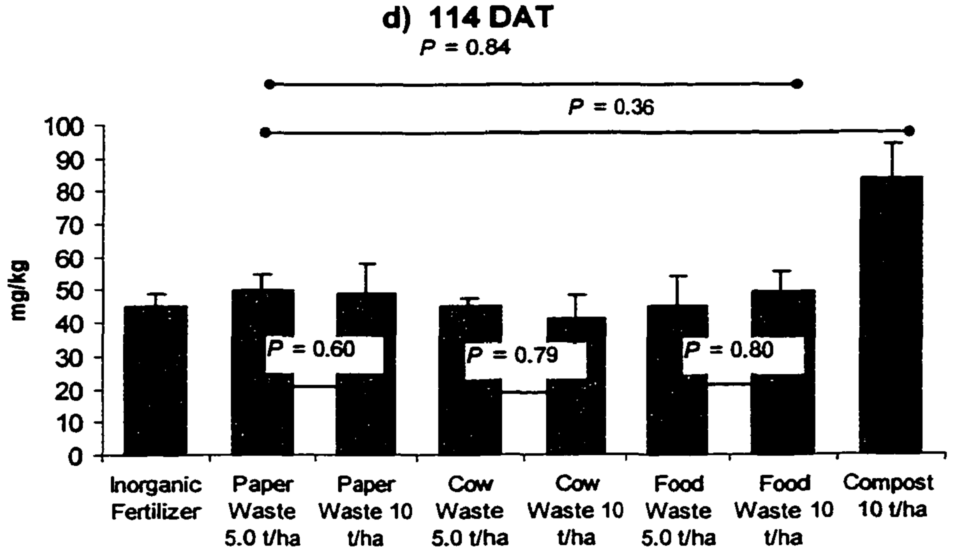
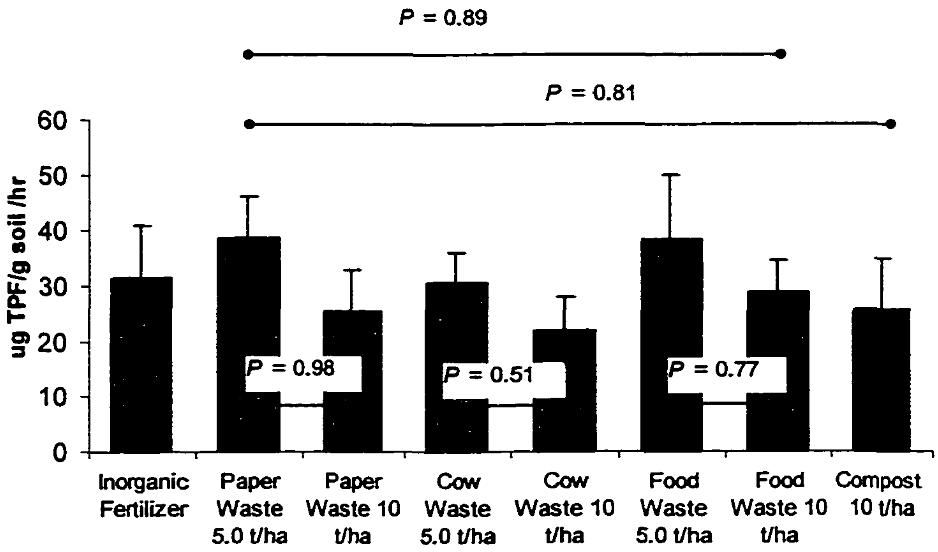


Figure 4.20: Dehydrogenase enzyme activities of the tomato plots in 2000. Bars designated by a line (•——•) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted yard waste.

a) at transplanting



b) 49 DAT

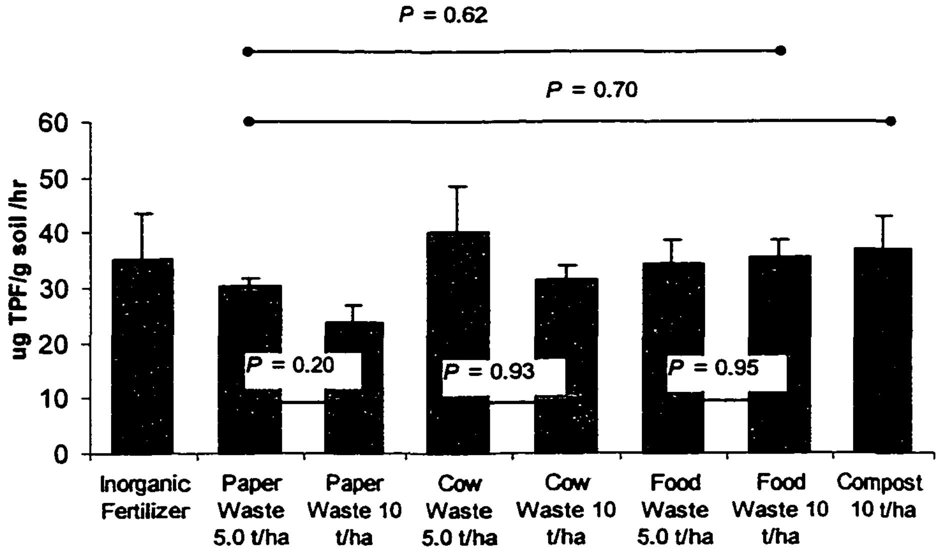
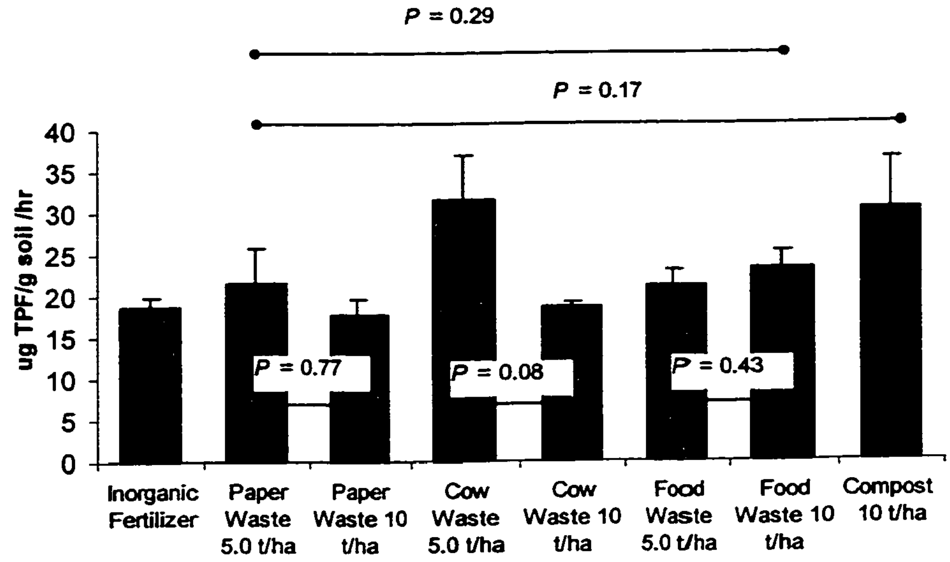


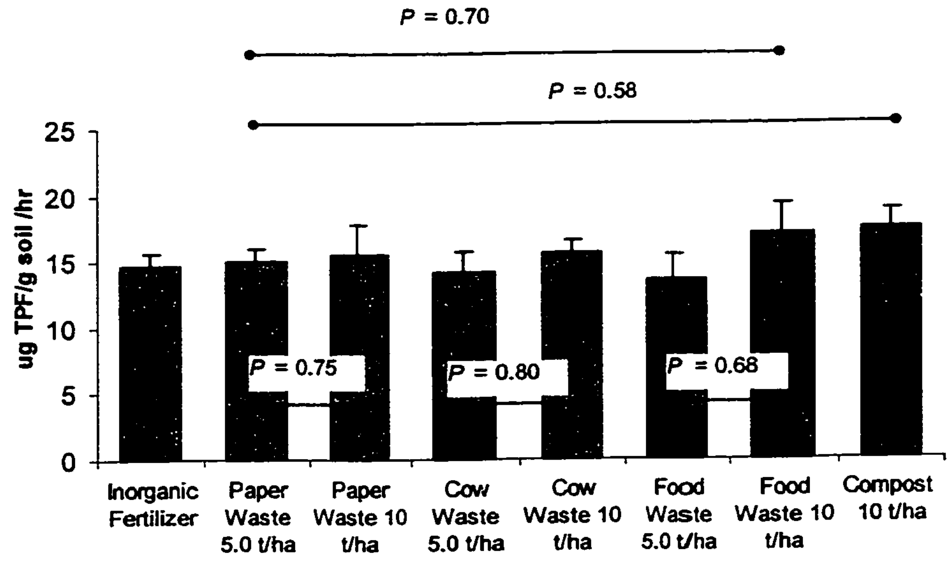
Figure 4.20. (continues)

Figure 4.20 (continued)

c) 84 DAT



d) 114 DAT



4.3.2 DISCUSSION

The biochemical changes of soil in response to vermicompost applications

In both years of the tomato trials, there was a general reduction in the amounts of total extractable nitrogen in soils from all the treatments. These losses of nitrogen from soil in the tomato plots could be explained by several hypotheses. Paul and Clark (1996) in their textbook outlined simplistic pathways in which organic matter undergoes the process termed ammonification – i. e. the process of converting organic N to NH_4^+ by bacteria or fungi. The other known process suggested by Paul and Clark (1996) is mineralization which involves the degradation of proteins, amino sugars and nucleic acids to NH_4^+, the mineral form. Once NH_4^+ has been formed, it has a number of possible fates. It can be taken up by plants in solution and often is a preferred N source. However, in most soils, its positive charge leads to adsorption by clay particles and organic matter and hence decreased plant uptake. It can be utilized for microbial growth and NH_4^+ can be made further available in the soil through the process of nitrification – NH_4^+ is converted to NO_2^- and NO_2^- to NO_3^-. Because plants can readily assimilate NO_3^-, and good plant growth has often considered to be dependent on this process, nitrification has commonly been used as an index to soil fertility. Once, NO_3^- is produced it may undergo reduction by microorganisms to gaseous oxides of N and N_2 – a process called denitrification. It may be taken up by microorganisms and used in the synthesis of amino acids – a process called assimilatory reduction. It may undergo chemudenitrification, in which intermediate oxidation states of N undergo abiotic dismutation yielding gaseous oxides of NO_2 and N_2. NO_3^-, may be leached to deeper layers of the ground water, transported off site by surface run off or accumulate on site, as it does under fallow conditions.

The conversion of N in organic matter from vermicomposts to more labile forms of nitrogen is associated with a decline in amounts of dissolved organic nitrogen (DON) in soil and this occurred in the tomato plots as the growth cycle of the tomatoes progressed. In 1999, all plots contained similar amounts of total extractable nitrogen by the end of the growing cycle of tomatoes. Similar results were obtained in 2000 although, the amounts of total extractable nitrogen were greater compared to those of the previous year, possibly because of accumulation of organic matter by the second year application of vermicomposts. Accumulation of organic matter increased the organic pools of the soils in vermicompost plots as demonstrated by their DON contents, which maintained larger amounts than soil from the inorganic control plots. Larger values of DON increased the potential for further mineralization of nitrogen. More total extractable nitrogen, which was recorded towards the end of the growth cycle of tomatoes, especially in 2000 may be an indication of continuous mineralization of N by microorganisms from vermicomposts. Furthermore, there were positive correlations between the biomass and the total extractable nitrogen ($r > 0.349$ at 0.05 level of significance).

A number of workers have reported increases in soil nitrogen after addition of organic substrates to the soil. Astier et al (1994) reported that manures applied to soil, in combination with inorganic fertilizers, could supply enough available nitrogen for growing commercial crops. In their work, soils treated with compost, combined with vetch, replenished the inorganic nitrogen in the soil after vermicompost applications. Bevacqua and Mellano (1993) and Pascual et al (1999) demonstrated that the addition of municipal sewage sludge compost into the soil increased levels of organic matter and mineral elements.

The retention of more nitrogen in the vermicompost-treated plots compared to that in the inorganic control could also have been due to the increased nutrient-holding capacity of the soil. This condition was also noted in the vermicompost plots in the pepper trial. It has been demonstrated consistently that additions of organic matter into soil increases its water-holding capacity, improve soil tilth, provide food sources for soil microorganisms and increases the cation-exchange-capacity of the soil (Laegreid et al, 1999; Epstein, 1976, Gupta et al. 1986). Overall increases in nutrient holding capacity of soils are attributed by these properties.

Soil microbial biomass in soil from the tomato plots followed a typical response to nutrients available particularly available nitrogen. Amounts of microbial biomass N were correlated positively with the concentrations of total extractable N. In 1999, soil from all plots contained statistically similar amounts of microbial biomass nitrogen, suggesting activation of microorganisms in response to the available nitrogen supplied by vermicomposts and the inorganic fertilizers. Contents of microbial biomass nitrogen, in soil from the inorganic plots, could be merely a response of indigenous microorganisms to the added ammonium-nitrate fertilizers, whereas microbial biomass N in soil from other plots was due to responses of both indigenous microorganisms and microorganisms from the vermicomposts combined. Vaughan and Malcolm (1984) reported that the bulk of soil biomass is inactive, normally because of nutrient limitation, and the addition of an available substrate usually results in a rapid increase in microbial activity and biomass. This could explains the increase in microbial biomass N in soils, between the values of microbial biomass nitrogen in the plots, before any amendments where applied (Table 4.1) and at transplanting when all amendments were applied. Furthermore, the authors stated that microorganisms could maintain a high adenylate energy charge (AEC), which partly explains their ability to make a rapid response to exogenous substrates.

The eventual decline of amounts of microbial biomass in the vermicompost-treated plots, although new microbial populations were added, could be due to inherent qualities of the soil which may not provide favorable conditions for new microbial biomass to thrive. According to Baath et al (1978) and Rovira (1965), newly-formed microbial biomass declines more quickly than the indigenous biomass because of the poor "protective capacity" of the soil. This capacity is influenced strongly by organic matter, CaCO3, predators, pH, and competition for available substrates (Katznelson, 1940). In 1999, levels of organic matter from vermicompost additions may have been insufficient to support sufficient microbial biomass statistically similar with those in soils from the inorganic control plots. However, a second application of vermicomposts in 2000 could have increased the amounts of organic matter that supported more microbial biomass up to the end of the growth cycle of the tomatoes.

The soil microbial biomass is involved with earthworms in the decomposition of organic materials, and thus, the recycling of nutrients in soils. Microbial biomass N constitutes up to 5% of total N (Jenkins on and Ladd, 1981). Therefore, nutrient availability and productivity of soils depends mainly on the size and activity of the microbial biomass (Freidel et al, 1996). Furthermore, the turnover time for N that immobilized in the soil microbial biomass has been reported to be about ten times faster in biomass derived from plant materials (Smith and Paul, 1990). Clearly, the vermicompost applications increased soil microbial biomass and its potential to supply nutrients.

The maintenance of orthophosphate concentrations in soil from the tomato plots could have been due the inherent abundance of P in the experimental tomato site. Labile phosphorus would have behaved in a similar way to extractable nitrogen, whereby concentrations in the soil could have decreased in time because of plant uptake and other forms of losses such as leaching. However, the levels of labile P remained about the same from transplanting up to harvesting, which could be a result of continuous replenishments of P through desorption from clay oxides and/or dissolution from P minerals. Mineralization from soil organic fractions could also have contributed to the P supply, is indicated by the positive correlations between P concentrations, to soil microbial biomass and dehydrogenase activity.

Soil dehydrogenase enzyme activity (DHA) has been considered to be a measurement which can be used as an indication of the total microbial activity (Nannipieri et al., 1990). In my experiments, dehydrogenase activity increased in soils treated with both inorganic fertilizers and vermicomposts, but the latter maintained larger amounts of dehydrogenase activity towards the end of the growing cycle. This condition was also observed in the pepper trials. Furthermore, there were significant positive correlations between microbial DHA and biomass towards the later growth stages of the tomatoes. Many authors have reported that organic fertilization can cause an increases in soil microbiological activity (Bolton et al., 1986, Fraser, et al., 1988; Kirkner et al., 1993; Marinari et al. 2000). Many soil enzyme activities can be correlated with the total organic C in the soil (Frankenberger and Tabatabai 1981). In compost/soil incubation trials, Serra-Wittling et al (1995), reported increases in dehydrogenase activity in soils treated with a range of increasing percentage of composts, in which the highest level of dehydrogenase activity coincided with the mineralization flush. These increases were attributed to intense activity of the microflora in degrading easily-metabolizable compounds, and consequent decreases in microbial activity were attributed to decrease in easily-biodegradable substances. Pascual et al (1999) reported increased dehydrogenase activity after eight years of amending soil with composts. Masciandaro et al (1997) reported increases in dehydrogenase activity following vermicompost applications at 90 t/ha.

There is a general agreement among authors, using a variety of techniques, that only a small portion of the total biomass is active, estimates ranging from 2.4 – 27.4% (Vaughan and Malcolm, 1984). The main restrictions to microbial activity is a lack of organic substrate (Gray, 1976; Lynch, 1982) and the addition of readily available organic substrate usually causes virtually instantaneous increases in respiration (Berrow, Davidson and Burridge, 1982).

Other environmental factors that can decrease microbial biomass and activity have been identified. Conditions such as soil drying, freezing and waterlogging are natural occurrences in many environments and may severely restrict the amount and activity of the microbial biomass (Vaughan and Malcolm, 1984). In my experiments, the marked decreases in dehydrogenase activity in all plots was probably due to dry soil conditions, especially on the last sampling date when irrigation was no longer being applied which caused the soil to dry up. Soil dehydrogenase activity especially in 2000 was correlated positively with the amounts of microbial biomass, which means that as soon as the amounts of microbial biomass declined, then its activity also declined rapidly. Another possible factor influencing decreases in microbial biomass and activity, could be corresponding decreases in the total soil nutrient content of plots, as was indicated by the decreases in the total extractable nitrogen content at the end of the growth cycle of tomatoes. In work involving organic amendment applications to the soil, Ladd and Paul (1973) reported a similar trend whereby dehydrogenase activity increased with microbial cell numbers, reaching a maximum during a period of active metabolism of microbial products, then decreased in parallel with a decline in bacterial numbers. It was also reported that other enzymes such as caseinases followed a similar pattern to dehydrogenase (Nannipieri et al., 1979) and urease (Zantua and Bremmer, 1976). In their work, soil enzymes reached a maximal potential activity, which sometimes took place even before organic amendments or soil pretreatments were introduced. In my experiments, a stabilized level of activity had obviously not been reached before the vermicomposts applications were applied which was indicated by the fluctuations of dehydrogenases on all sampling dates.

4.3.3 RESULTS

Nematode populations and fruit disorders and diseases after vermicompost applications

Fruit diseases

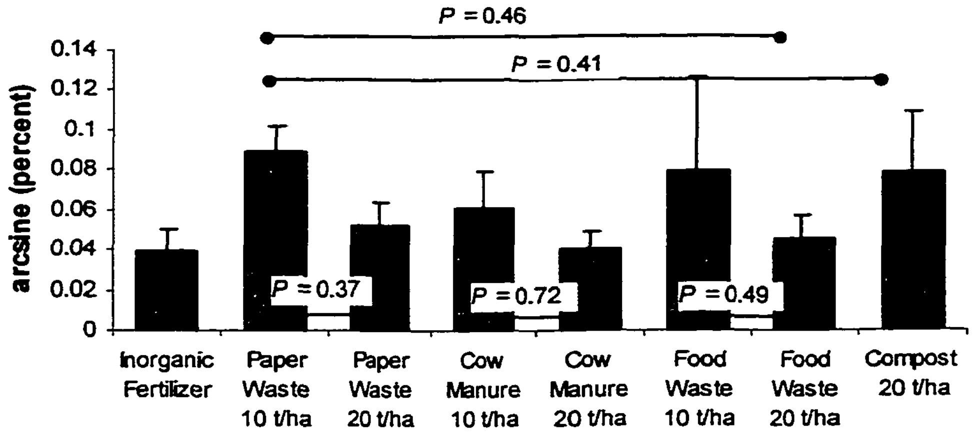
In both years, there are no significant differences on the fruit diseases occurred on tomato fruits except those in 2000 when vermicompost and compost-treated plots produced fruits with significantly greater deformities than those from the inorganic plots (P < 0.05) (Figure 21.a).

Nematodes

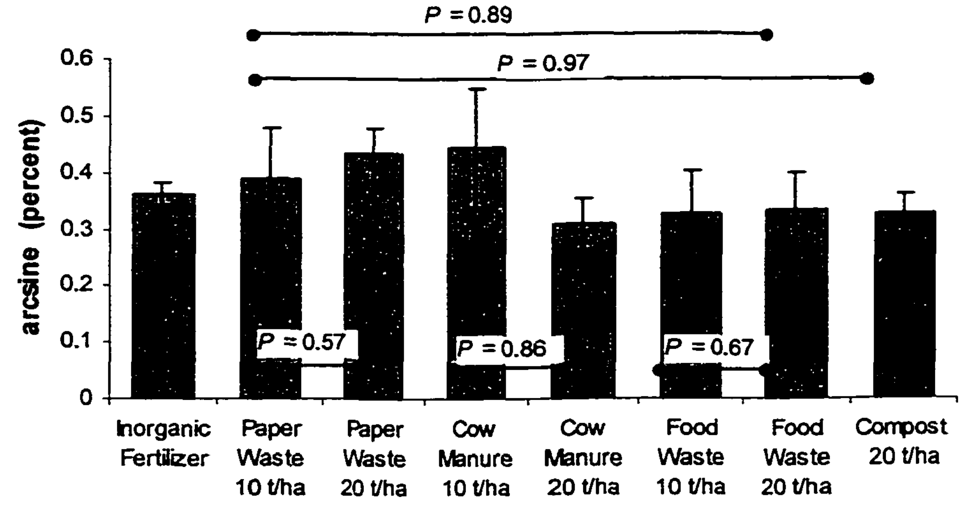
Soils from vermicompost-treated plots contained significantly greater bacterivorous nematodes than those in the inorganic controls (P < 0.01) (Figure 4.22). Soils from cow manure vermicompost-treated plots contained more fungivorous nematodes than soil from the inorganic control plots (P < 0.05), whereas soil from all vermicompost treatments contained significantly fewer plant-parasitic nematodes than soils from the inorganic controls.

Figure 4.21 Fruit disorders in tomatoes in 1999. Bars designated by a line (●—●) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted sewage sludge.

a) Deformed



b) Insect feeding



c) Blossom end rot

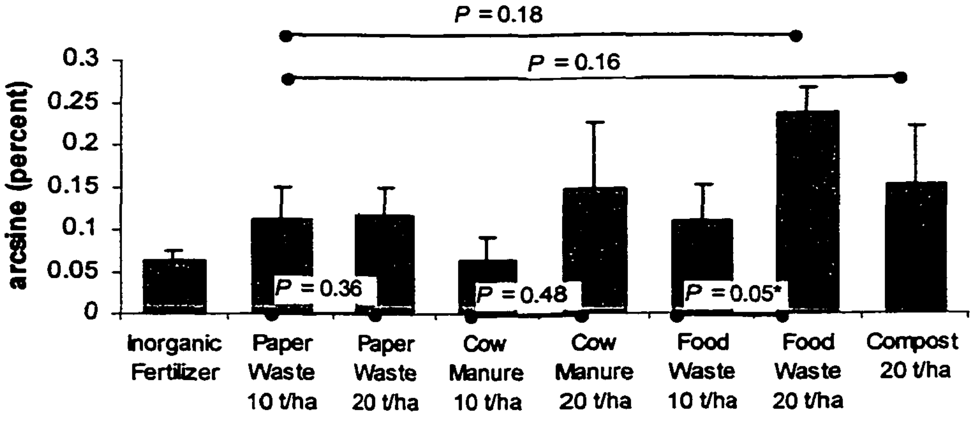
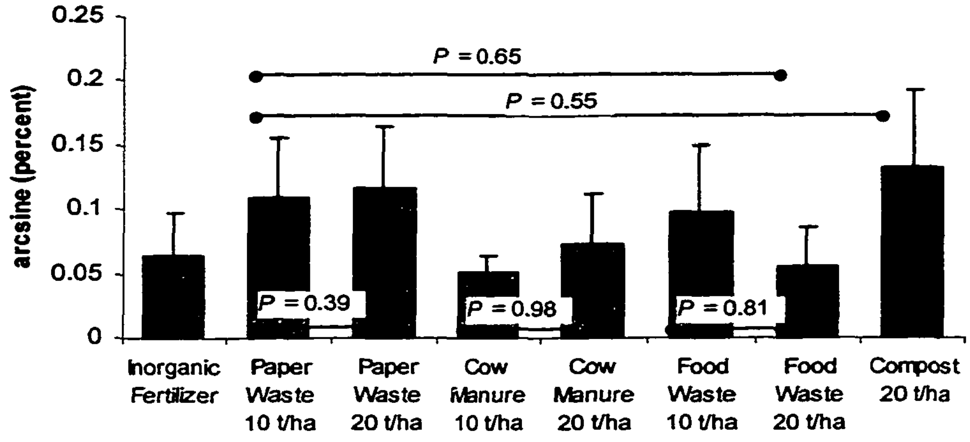


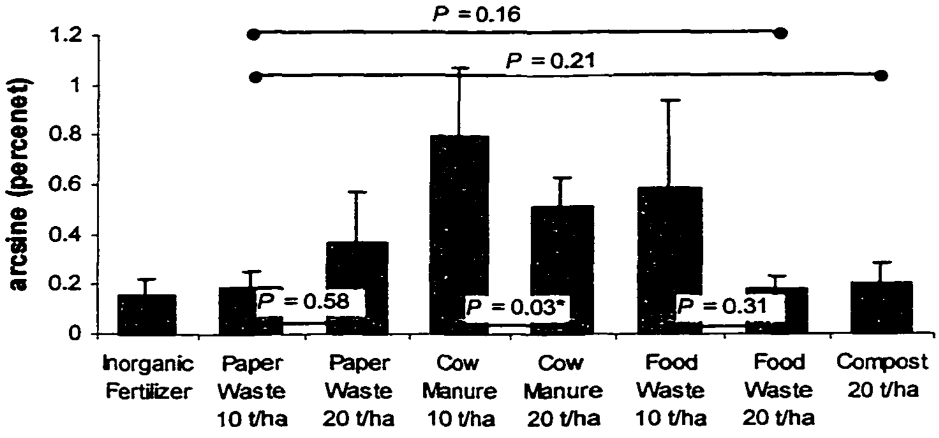
Figure 4.21. (continued)

Figure 4.21 (continued)

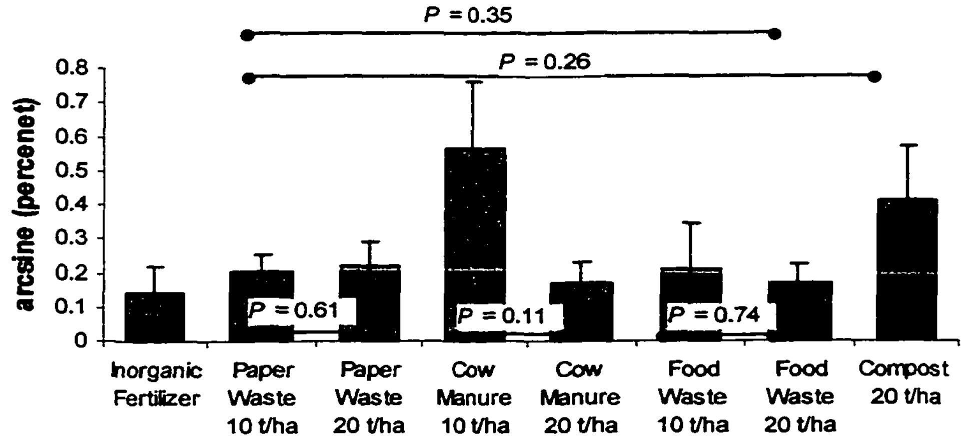
d) Other fruit rots



e) Concentric cracks



f) Radial cracks



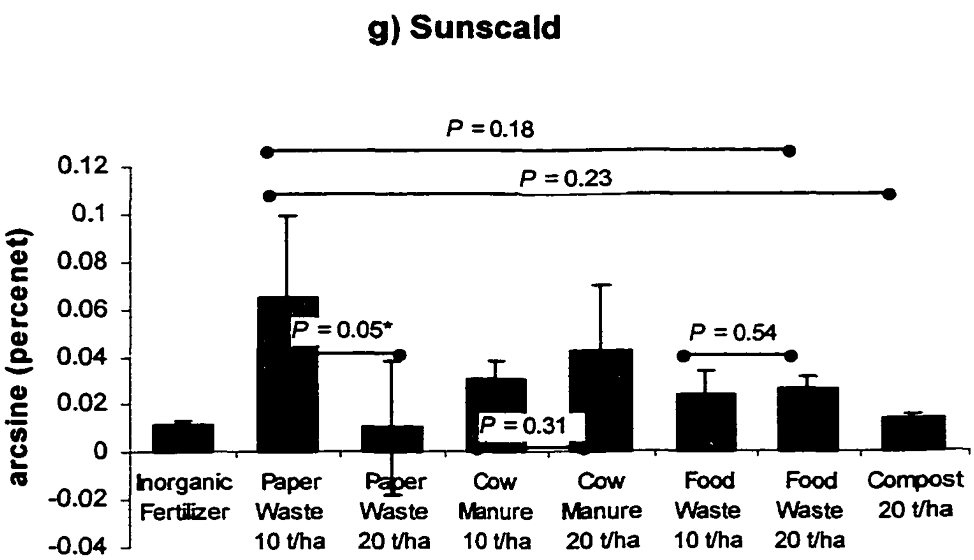
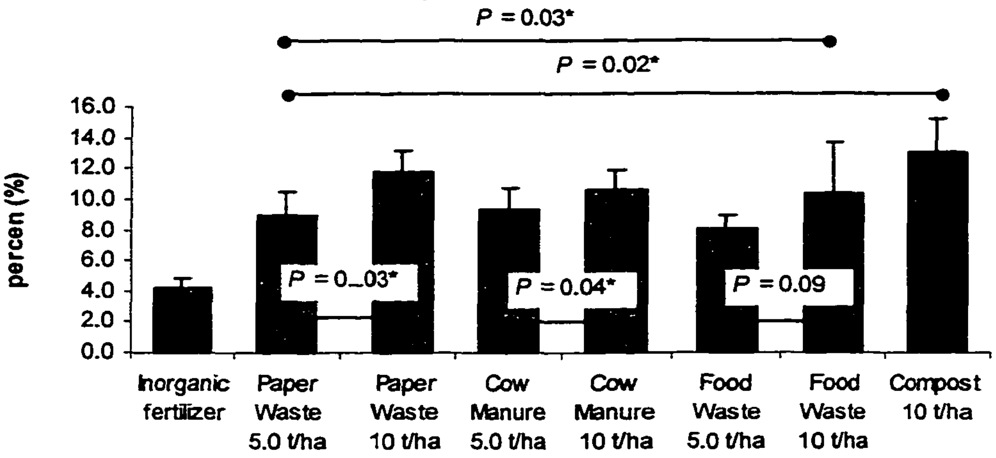
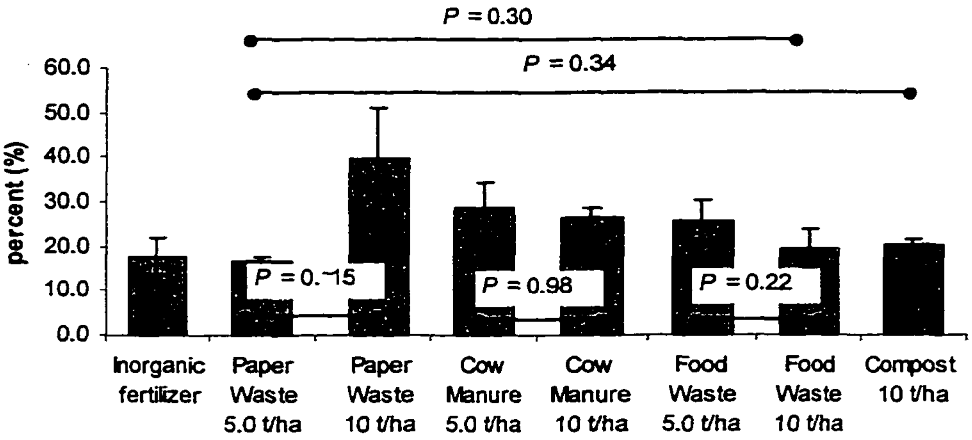

g) Sunscald
P = 0.18
P = 0.23
P = 0.05*
P = 0.31
P = 0.54
arcsine (percenet)
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
Inorganic Fertilizer
Paper Waste 10 t/ha
Paper Waste 20 t/ha
Cow Manure 10 t/ha
Cow Manure 20 t/ha
Food Waste 10 t/ha
Food Waste 20 t/ha
Compost 20 t/ha

Figure 4.22 Fruit disorders in tomatoes in 2000. Bars designated by a line (●—●) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted yard waste.

a) Deformed



b) Blossom end rot



c) Other fruit rots

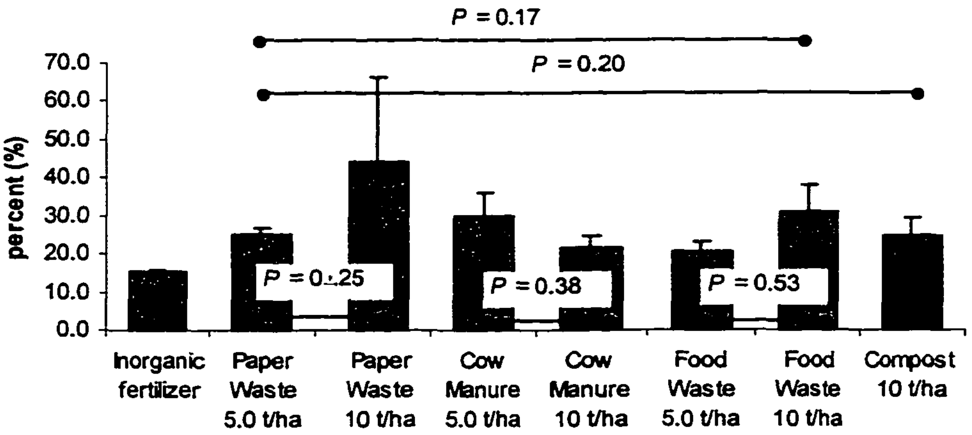
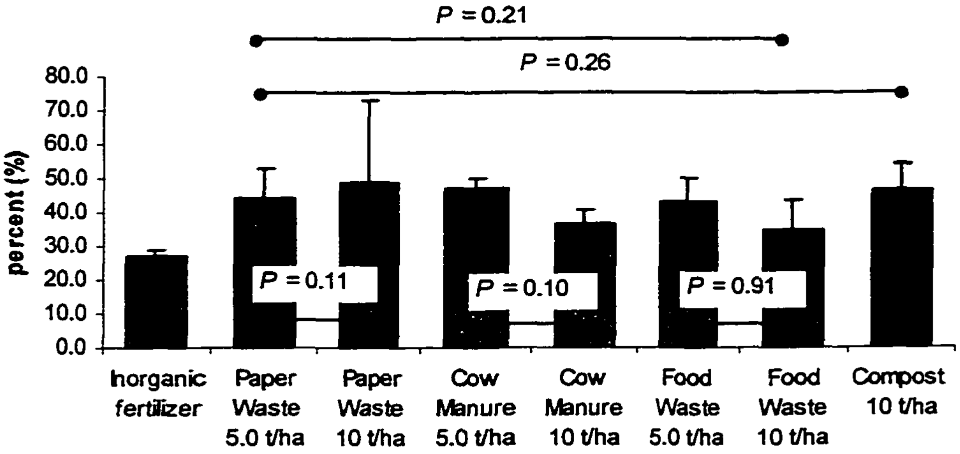


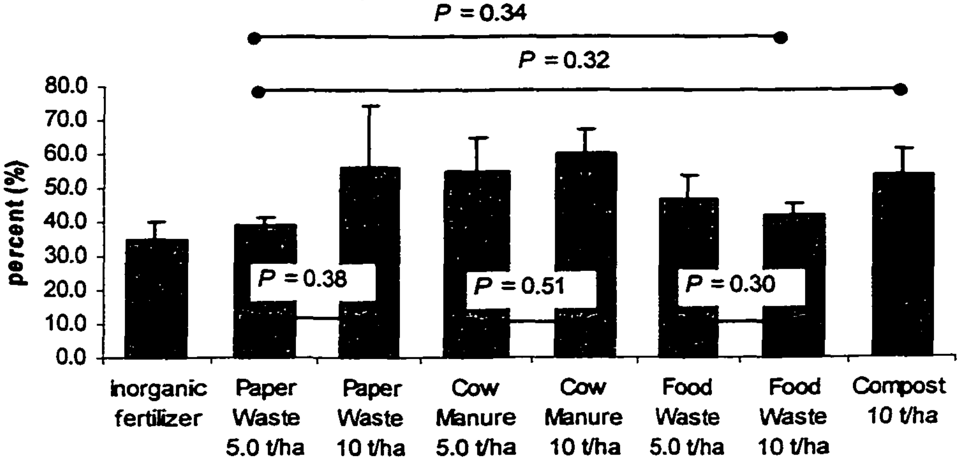
Figure 4.22. (continues)

Figure 4.22 (continued)

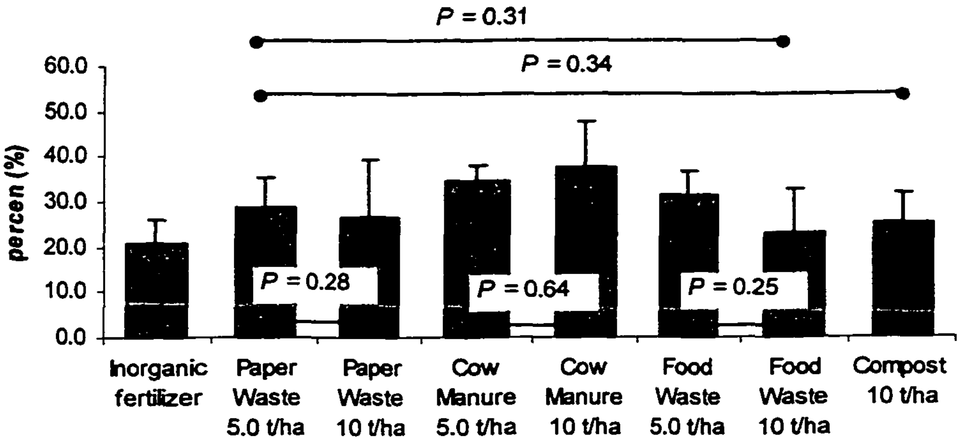
d) Sunscald



e) Radial cracks



f) Concentric cracks



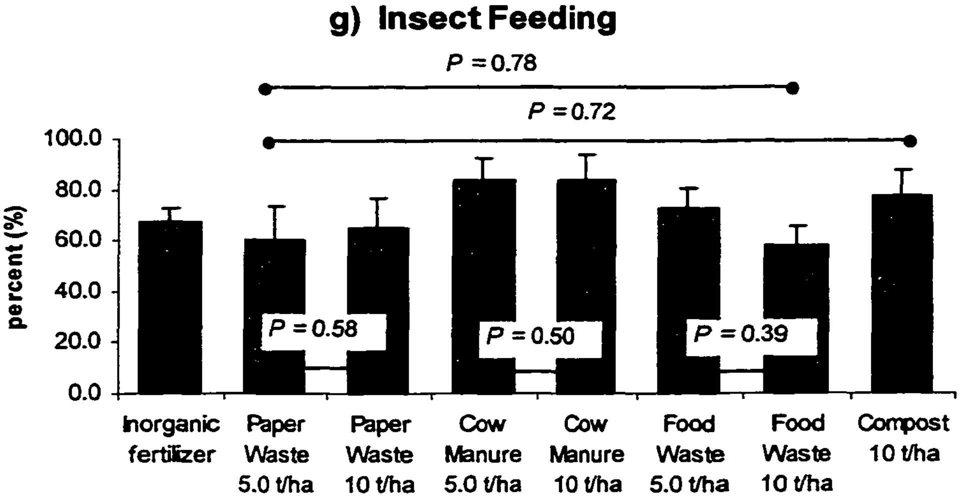
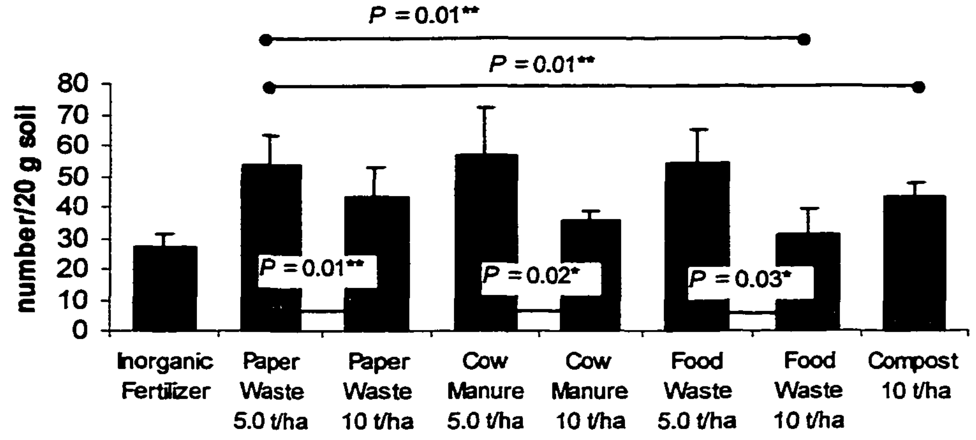
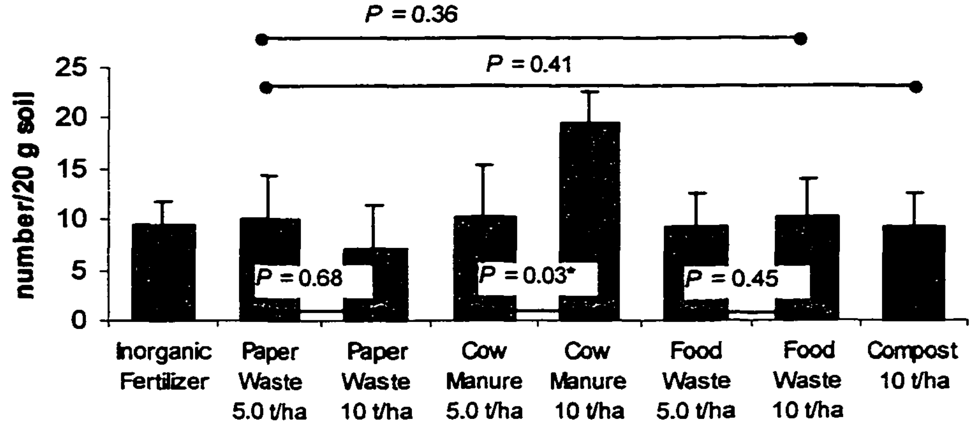

g) Insect Feeding
P = 0.78
P = 0.72
100.0
80.0
60.0
40.0
20.0
0.0
percent (%)
P = 0.58
P = 0.50
P = 0.39
Inorganic fertilizer
Paper Waste 5.0 t/ha
Paper Waste 10 t/ha
Cow Manure 5.0 t/ha
Cow Manure 10 t/ha
Food Waste 5.0 t/ha
Food Waste 10 t/ha
Compost 10 t/ha

Figure 4.23: Nematode populations in tomato plots in 2000. Bars designated by a line (•—•) are grouped means and *P* values above the line are results of orthogonal contrasts between grouped means versus the inorganic control. Inorganic fertilizer-labeled bars represent the control plots, paper waste, cow waste/manure, and food waste-labeled bars are the vermicompost treatments and compost-labeled bars are plots that were treated with composted yard waste.

a) Bacterivores



b) Fungivores



c) Plant Parasites

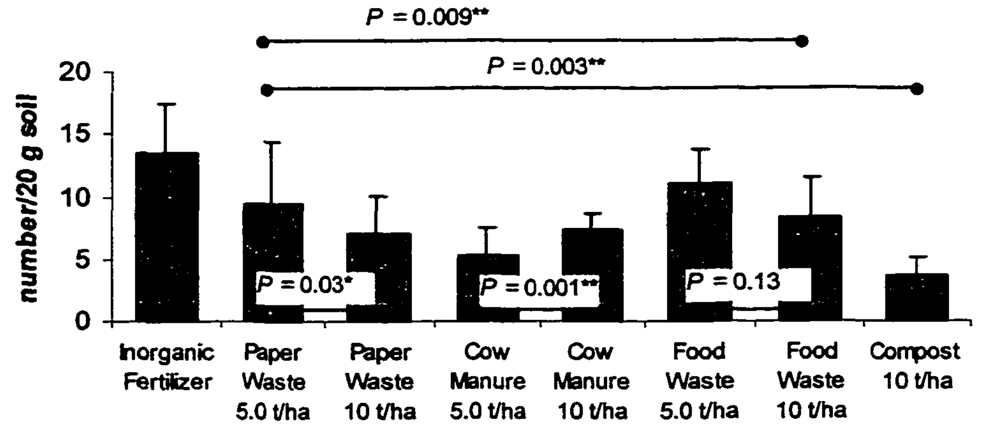


Figure 4.23

4.3.3 DISCUSSION

Nematode populations and fruit disorders and diseases after vermicompost applications

Fruit disorders and diseases

Three main components can contribute to disease incidence or pest attack development - the availability the host, the presence of the causal organisms and the environment. For an attack to take place successfully, the host must be susceptible, the causal organism must be virulent and the environment must be favorable. Understanding of the relationships of these three components has been the central to the success of most disease and pest management. The application of pesticides is based on the principle that modifications of the environment, through the application of chemicals that deter and kill causal organisms, can prevent or even deter further disease development. However, increasing recognition of the potential adverse effects of chemical pesticides on the environment have sounded alarms that perhaps pesticides are less than perfect solutions to pest control problems (Luna and House, 1990). Stern et al. (1959) introduced the new paradigm of integrated pest management in the control of pests that integrates economics chemicals and ecology. The authors called for an approach to pest control based on an understanding of pest and crop ecology and "integration" of a variety of biological, cultural, as well as chemical controls into an economically and ecologically sound pest management strategy. This strategy has been the central theme in the evolution of Integrated Pest Management (IPM) programs worldwide.

There had been attempts to modify or to improve "host" crops to minimize disease development. These attempts had been made through genetic improvement to make crops tolerant or resistant to pests and diseases. In some circumstances, crop resistance to disease and pest attack may be induced by merely improving plant quality such as by improvements in plant nutrition. Knowledge of host nutrition, and pest dynamics and ecology provides an excellent basis for developing a well-balanced nutrition program and is the best tool for integrating other cultural practices, especially irrigation and pest control (El-Zik and Frisbie 1985). Dependent upon the pest species and the crop, the level and type of fertilization used can have a stimulatory or a suppressive effect on pest populations. Excess fertilization, especially with nitrogen, can promote succulent and excessive vegetation growth that encourages a micro-environment favorable for the development of diseases such as V*erticilllium wilt* and A*nthracnose* (*Colletotrichum gossypii*) of cotton, fire blight *(Erwinia amylovora*) of pear, rust (*Puccinia* spp.) of wheat and leaf spot (*Coniella musaiaensis*) of kenaf (*Hibiscus cannabinus*) (Elzik and Frisbie, 1985; Adeoti, 1987; Agrios 1988). Conversely, lower N fertilization has decreased disease incidence and severity of soil-borne pathogens of banana (*Fusarium oxysporum* f.sp. *cubense*), bean (*F. solani* f.sp. *phaseolo*), avocado (*P. cinnamoni*), and tomato and sugar beet (S. rolfsii) Henis and Katan, 1975). Recent laboratory work at the Soil Ecology laboratory of the Ohio State University (unpublished data) showed that vermicompost used as growth media for vegetable seedlings did not only supply nutrients but also suppressed *Rhizoctonia* and P*ythium* diseases, suggesting that vermicomposts possess qualities that are suppressive to plant diseases. The mechanism of suppression has been suggested to be microbial in nature because disease suppression declined when vermicompost was sterilized.

In my field tomato trials, most of the fruit disorders that were evaluated did not differ significantly between the vermicompost-treated plots and the inorganic controls, or between the kinds of vermicomposts. There were two types of fruit cracking that were evaluated among the non-marketable yields – concentric and radial cracking. Fruit cracking is physiological in nature. Fruit cracking occurs when there is a rapid net influx of water and solutes into the fruit at the same time that ripening or other factors reduce the strength and elasticity of the tomato skin (Peet, 1992). According to Peet (1992), some of the anatomic characteristics, most frequently associated with fruit cracking are large fruit size, low skin tensile strength or low skin extensibility at the turning to the pink stage of ripeness, thin skin, thin pericarp and shallow cutin penetration. None of these characteristics seemed to be influenced by vermicompost applications to improve tolerance to cracking because no significant differences occurred between the treatments.

Blossom-end rot (BER) has several causes. Calcium deficiency, coupled with moisture stress, are the most common causes (Pill et al., 1978). High availability of ammonium (NH_4) as the N source can increase the occurrence of BER significantly. Jones (1999) reported that as the ratio of NH_4-N to NO_3-N decreases from 1:100 to about 25:75 (increase on NH4-N), the incidence of BER increased significantly. The narrow ratios of NH4-N to NO_3-N, of about 1:10 in the tomato plots during fruiting, could have increased the incidence of BER. However, because there were no significant differences in the NH_4-N and NO3-N ratios at the fruiting stage, it is not surprising that BER incidence among treatments did not also differ significantly.

It is possible that Ca was deficient in all plots and that the amounts of Ca contained in the vermicomposts were insufficient to prevent BER. However, a number of other physical stresses when combined with other types of physiological stresses can result in BER-attacked fruit. There was a significant positive correlation between amounts of cracking and BER suggesting that cracking could have triggered BER attacked-fruits.

Sunscald occurs on green (most sensitive) and ripening (less sensitive) fruit from exposure to direct sunlight for long periods (Jones, 1999). None of the treatments provided sufficient sun protection for the fruits as was indicated by the similarities in their shoot biomass. Consequently, there were no significant differences in the percentages of fruits damaged by sunscalding. It is also noteworthy that the percentages of fruits damaged by sun-scalding was positively correlated with BER suggesting that solar injury added physiological stress to tomatoes that contributed to the BER incidence, in addition to cracking. Similarly, there were no significant differences in fruits rots which maybe caused by other organisms such as anthracnose and other bacteria among the treatments.

There were no significant differences in amounts or types of insect feeding among the treatments suggesting that vermicompost as a source of nutrition did not change the quality of the tomato plants enough to induce resistance or susceptibility to insect pests. There were also no correlations between the fresh shoot weight of tomatoes and insect feeding that would confirm succulence as a factor that increased the tendency of arthropod to be attracted and feed on tomatoes..

It is likely that fruit physiological disorders such as BER, sunscald, and cracking triggered insect feeding and rots caused by microorganisms. There were significant positive correlations that exist between those physiological disorders and insect feeding and other fruit rotting. For instance, cracking can make the fruit more vulnerable to insect feeding as the soft internal parts of fruits become exposed. Fruit cracks can serve as convenient entrances for rot-causing microorganisms.

While numbers of fruit disorders did not appear to differ significantly among the treatments, it is also possible that effects brought about by plant nutrition on fruit disorders especially herbivory could have been masked by the application of pesticides to tomatoes at the onset of fruiting and up to the harvesting stage.

Nematode populations

There is considerable interest in understanding the roles of the soil fauna in the regulation of the below-ground processes of decomposition and nutrient cycling. One of the most abundant and functionally important of the many taxonomic groups of fauna in soils are nematodes (Bardgett and Cook, 1998). Nematodes have been used as soil ecological indicators because they are very responsive to changes in the soil resulting from various agricultural practices (Wasilewska, 1989; Hendrix et al., 1986; Hyvonen and Persson, 1990; Bongers, 1991). These land practices affect the species richness, trophic structure, and successional status of nematode communities (Neher, 2001).

Nematodes populations in the tomato plots followed similar trends to those in the strawberries and peppers experiments except that in the tomato plots, bacterivous nematodes were significantly more numerous in soils treated with vermicomposts that in soils from inorganic control plots. Similarly, the addition of inorganic fertilizers increased the number of plant parasitic nematodes in tomato significantly compared with those in vermicompost-treated plots. Yardim and Edwards (1998) reported various factors that increase numbers of plant-parasitic nematodes in soils and these have been discussed in the previous chapter 2 in details. According to Yardim and Edwards, agrochemicals could have had stimulatory effects on the egg hatching and survival patterns of plant-parasitic nematodes. Many other workers have similar results but none of these researches mentioned any direct influence of soil amendments such as inorganic fertilizers on the increases of plant parasitic nematode populations.

There is a possibility that microbial biomass composition affects trophic diversity of nematodes directly. In a grassland ecosystem, Bardgett and Chan (1999) reported that the addition of exogenous substrates increased the amounts of microbial biomass particularly bacteria. It is possible that the increase in the amounts of bacterial biomass in my plots increased the numbers of the bacteria-feeding nematodes. The vermicomposts applied to the tomato plots sustained large numbers of bacteria and therefore could have increased the number of the bacteria-feeding nematodes, which subsequently dominated other trophic levels in the vermicompost-treated plots. This was confirmed by the positive correlations between microbial biomass and the number of bacterivores in the tomato plots. Vermicompost contain large numbers of bacteria and fungi as well as organic matter; so their applications could have caused considerable increases in the number of microbial-feeding nematodes. Inorganic fertilizers that were applied may have provided a microenvironment that favored the increase in the populations of plant-parasitic nematodes. The mechanisms involved could be the low availability of organic materials to provide food for nematodes in other trophic levels and allowed plant parasitic nematodes to dominate in the inorganic controls.

Bardgett et al (1999) reported, that in grassland ecosystems, plant feeding nematodes (plant parasitic) triggered increases in soil microbial biomass. Those conditions resulted from of increased translocation of photoassimilates to the roots resulting from nematode root feeding, consequently enhancing microbial biomass. However, in annual crop such as tomatoes, soil microbial biomass did not show any significant correlations with numbers of plant parasitic nematodes. This could be due to the dominance of plant parasitic nematodes in the tomato rhizosphere. Bardgett et al (1999) reported decreases in yield in areas dominated by plant parasitic nematodes but these also seemed to affect the tomato yields although not significantly compared to those tomato yields in the vermicompost-treated plots.

A number of works discussed in Chapter 2 reported the contributions of nematodes to the overall mineralization of soil nutrients. Increases in the microbial biomass and nematode populations in the tomato plots indicated significant contributions to mineralization because of the significant positive correlations that occurred between numbers of microbial-feeding nematodes and amounts of total extractable N.

CHAPTER 5

CONCLUSIONS

Field applications of vermicomposts increased the growth, flowering and yields of strawberries, and they had considerable effects on peppers but their effects on improving tomato growth and yields tended to be less. Increases in the growth of plants in response to vermicompost applications included greater leaf areas, greater shoot weights, more plant suckers, more flowers, greater marketable fruit yields and lower non-marketable fruit yields. Plant growth increases in response to vermicomposts became evident at early growth stages of the crops and continued through fruiting.

The positive responses of the test crops to vermicomposts tended not to be dependent as also occurred in greenhouse trials. Strawberries grew fastest and yielded best after the 10t/ha rate of food waste vermicompost applications on Site A and in response to both applications rates of 10 t/ha and 5 t/ha on Site B. Peppers yielded most fruit weights in response to 10 t/ha of vermicomposts compared to the 20 t/ha rate of vermicompost applications in 1999 and responded well to both 10 t/ha and 5 t/ha rates of vermicomposts in 2000. Tomatoes yielded best in response to applications of 10 t/ha vermicomposts than to 20 t/ha rates of vermicompost applications in 1999 and yielded similarly in response to both 10 t/ha and 5 t/ha rates of vermicompost application in

2000. It seems likely from my experimental results that even lower application rates of vermicomposts could still be effective in promoting plant growth and this would clearly be very attractive economically..

Clearly, the positive responses of the test crops to vermicompost applications cannot be explained in terms of the availability of macronutrients, because all of the vermicompost treatments were supplemented with inorganic fertilizer to equalize macronutrient availability at the transplanting date.

A number of other factors might have increased crops growth and yields, such as the availability of micronutrients in vermicomposts, enhancements in microbial biomass and activity in soil in response to vermicompost applications, the presence of plant growth-regulating substances produced by microbial activity in vermicomposts and disease suppression or to changes in the trophic structure of nematode populations which suppress plant parasitic species as a result of vermicompost treatments.

The vermicomposts contained sufficient micronutrients to have had some influences on increased growth and yields of the test crops. However, a lack of micronutrient deficiency symptoms on the experimental crops in the inorganic control plots, is a circumstantial evidence that there were no important direct influences of micronutrients from vermicomposts on growth and yield of the test crops.

Vermicomposts contain very rich and diverse microbial populations. Their applications to soils could have added to the indigenous soil microorganism populations, resulting in much larger, richer and diverse soil microbial populations. This could have increased the ability and efficiency of plants to utilize the available nutrients in the soil, through continuous mineralization of nutrients from the organic matter reserves of the vermicomposts, and the release of these nutrients from microbial cells as they die and degenerate. Some microorganisms can form synergistic relationships in plant rhizospheres, by acting as root extensions, thereby increasing the capacity of plants to utilize soil moisture and nutrients, and at the same time they benefit from plant root exudates. Other byproducts of microbial activities known to promote plant growth, include producing antibiotics, disease antagonists and plant growth influencing substances such as hormones and humates. Research reports have shown that some microorganisms, such as the *pseudomonads* are antagonistic to plant pathogens and by this mechanism simply microbial competition can induce resistance to plant diseases, as was demonstrated in my experiments by the suppression of *Verticillium wilt* on strawberries. We have also demonstrated suppression of *Pythium* and *Rhizoctonia* on cucumbers and radishes in the laboratory.

The production of plant growth hormones, such as indole acetic acid (IAA), gibberellins and cytokinins are some of the byproducts of the microbial activities promoted by earthworms may have well also have directly influenced plant growth and yields. The action of earthworms and microorganisms, in fragmenting organic substrates during vermicomposting, has been shown to produce plant growth-influencing substances. Many workers have reported on the presence of humates and plant growth hormones such as auxins, gibberillic acids and cytokinins in vermicomposts. Bioassays in our laboratory have demonstrated the presence of plant-growth-influencing substances (PGIs), in the forms of hormones in liquid extracts from vermicomposts and humic acids obtained in base extracts from vermicomposts. When these extracts were applied in relatively small amounts, plant produced significant positive effects on growth and these positive effects were very similar to those of plant growth-hormone treatments on plants. The presence of such PGIs were confirmed in greenhouse trials, when plants that were grown in commercial soilless growth media such as MM360 and substituted at different rates with vermicomposts, germinated, flowered and fruited better than in the in the control media despite full nutrient applications in all treatments. In my field experiments, the presence of such PGIs could explain the increases in growth and yield that occurred even at the lowest rate of vermicompost applications (5 t/ha).

Another factor that could have contributed to the increased growth and yields by vermicomposts are the changes in the trophic diversity of nematodes in soils that received vermicompost treatments, compared with inorganic amended soils. Vermicomposts increased the numbers of bacterial and fungal-feeding nematodes and decreased the numbers of plant-parasitic nematodes significantly. This could be due to a corresponding increase in microbial biomass and diversity in the soils after vermicompost applications. Increases in the populations of bacteria and fungi in the vermicompost plots could have increased the numbers of their nematode consumers. The decreased populations of plant-parasitic nematodes in soils treated with vermicomposts might possibly have been due to competition among the other components of the nematode may community and the larger microbial biomass available. It is possible that the increase the in populations of plant parasitic nematodes have caused decreases in growth and yield in plants that were grown in soils that were treated with inorganic fertilizer only compared with vermicomposts.

Vermicomposts as organic soil amendments would have considerable influence on physical properties which make soils more favorable for plant growth. Our laboratory has reported consistently on improvements of the physical properties of the soil and plant growth media that had been amended with vermicomposts. These include more aggregates, lower bulk densities, greater porosities and increased organic matter contents. Such properties could improve the overall qualities of soil for plant growth in terms of nutrient-holding capacity, water-holding capacity, porosity and aeration thereby making the amended soil more suitable for the plants to produce roots and to support more vegetative growth and eventually fruit yields. There could have been many overall improvements in the physical properties of soils after the applications to vermicomposts in the field plots that promoted plant growth and yields.

It seems likely that the increases in microbial biomass in the soil resulting from additions of vermicomposts, increased the overall activity of microorganisms, sustained nutrient cycling, improved soil physical properties, enhanced the production of additional metabolites as plant growth regulators, increased numbers of bacterial and fungal feeding nematodes and decreased plant parasitic nematodes. The positive changes in the chemical, physical properties of the soil as well as these biological effects eventually supported vigorous growth and produced greater yields of crops

The three types of vermicomposts increased the growth and yields of specific crops differently. For instance, strawberries in soils amended with food waste grew and yielded significantly better than plants treated with paper waste vermicomposts although the abilities of both paper and food waste vermicomposts to suppress wilt disease did not differ statistically. Cow manure and paper waste vermicompost applications to peppers seemed to increase growth and yields more than those of food waste vermicomposts. Future research must include investigating the possibilities of producing and standardizing vermicomposts in terms of elemental, microbial and PGI contents. This may involve mixing different types of vermicomposts or mixing different types of organic materials to produce vermicomposts so as to attain their full potentials in improving the growth and yields of a wider range of kinds of crops.

The positive effects of vermicomposts on plant growth and yields and on improvements in soil properties make them potentially very good soil amendments. The nutrients and PGIs they contain would decrease the costs of inorganic fertilizers needed. Vermicompost applications could also potentially reduce the costs of plant protection chemicals such as fungicides and nematicides because they can suppress plant diseases. Unlike other organic amendments, such as manures and traditional composts, vermicomposts may be applied at very low and economic application rates because they have been proven to increase crop growth and yields at such low applications rates thereby minimizing costs of hauling and spreading.

There is a growing global movement towards organic agriculture in response to some of the adverse environmental effects of the use of inorganic fertilizers and organic materials, such as animal manures, human wastes, yard wastes and municipal sewage wastes. The process of vermicomposting not only recycles organic wastes, minimizes losses of nutrients through volatilization and leaching and eliminates odors from organic wastes compared to conventional thermophilic composting and turns a waste material into a resource. Vermicomposting has already been reported to be adaptable to a range of using different species of earthworms climates and environmental factors in many parts of the world, using local organic waste sources and earthworm species. This makes vermicomposts potentially good for soil organic amendments for cereals, small fruits, vegetables, fruit trees and other perennial crops.

The commercial values of vermicomposts vary considerably with their sources, ranging through animal manures, biosolids, horticultural and food wastes and industrial organic wastes and they are currently sold from about 50 to 300 U.S. dollars a ton. Food waste vermicomposts can cost about 200 dollars per ton, and cow manure vermicompost cost about 100 dollars per ton, and paper waste vermicomposts 50 dollars per ton. Such costs are critical factors influencing the overall profitability of any crop production using vermicomposts as amendments. Cost and return calculations of producing strawberries and peppers with vermicomposts can help to determine the economic practicability of using vermicomposts rather than full inorganic fertilization. The production costs that I calculated were based on a usual yearly growing cycle of each crop and that percentage increases in crop yields, as a result of vermicompost applications, with the cost of vermicomposts factored in. Economic calculations showed that the application of paper waste vermicomposts at the rate of 2.5 T/A (dry weight) would be more profitable than applying food waste vermicomposts at the same rate to strawberries (Appendix A), although plants treated with food waste vermicompost produced greater yields compared to plants that received paper waste vermicomposts. Such cost and return calculations for bell peppers also indicated that the use of cow manure and paper waste vermicomposts, based on my cost estimates are more profitable than the use of food waste vermicomposts applied at the same rate (Appendix B). Paper waste vermicomposts applications were more profitable due to their relatively low price compared to that of cow manure and food waste vermicomposts although yields of peppers grown with paper waste vermicompost amendments increased less than those grown with cow manure vermicompost additions. Prices of vermicomposts are therefore another important factor to consider in deciding the most appropriate vermicompost for a particular crop. As vermicomposting gains in popularity it seems likely that production costs will decrease.

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APPENDIX A

Comparison of economic cost and return of strawberry production using full inorganic fertilization and using vermicomposts as organic amendments

	Full Inorganic	Food Waste	Paper Waste
		21.5 % in.	16% in.
Operating Costs			
Plants	120	120	120
Seed-Cover Crop	1	1	1
Fertilizer	76	35.72	31.92
Vermicompost		500	125
Services-Soil and Tissue Tests	60	60	60
Chemicals	171	171	171
Fuel and Machine Operating	250	250	250
Repairs	57	57	57
Straw	88	88	88
Marketing, Promotion	162	162	162
Overhead	145	145	145
Labour	365	390	390
Total Operating Costs	1495	1979.72	1600.92
Fixed Cost			
Land Investment	104	104	104
machinery Investment	125	125	125
Machinery Depreciation	169	169	169
Irrigation Eqpt. Investment	75	75	75
Irrigation Eqpt. Depreciation	35	35	35
Total Fixed Cost	508	508	508
TOTAL COST	2003	2487.72	2108.92
YIELD 3000 lbs @ $1/lb	3000	3645	3480
NET RETURNS	**997**	**1157.28**	**1371.08**

Yield increases of 21.5% and 16% resulting from the applications of food waste and paper waste vermicomposts, respectively, were factored in the calculations.

* See Appendix C for additional assumptions.

APPENDIX B

Comparison of economic cost and return of pepper production using full inorganic fertilization and using vermicomposts as organic amendments

						COST PER ACRE			
		Materials		Hand Labor		IF	FW	CW	PW
Operation	Cost	Type	Cost	Hours	$		21% IN.	39% IN.	31% IN.
LAND PREPARATION									
Subsoil	38.8					38.75	38.75	38.75	38.75
Disc 2x	11.5					23	23	23	23
Land plane	12					12	12	12	12
Borders, cross check									
and break borders	17.8					17.75	17.75	17.75	17.75
Flood irrigate		water 1 ac/ft	14.6			14.56	14.56	14.56	14.56
Fertilizer double-spread	8	500 lb. 11-52-0	63.8			71.75	880	936	155
Disc 2x	11.5					23	23	23	23
Triplane	11					11	11	11	11
List beds	13.5					13.5	13.5	13.5	13.5
TOTAL LAND PREPARATION						**225.31**	**1033.6**	**1089.6**	**308.56**
GROWING PERIOD									
Drip system and tape		Drip system	700	20	155	855	855	855	855
Install plastic mulch	55	Plastic mulch	110			165	165	165	165
Metam sodium via drip		Metam sodium	100	4	31	131	131	131	131
Transplanting		17 M plants	850	40	310	1160	1160	1160	1160
Fertilizer (via drip)		400 lb. N @ .35	140			140	26.25	8.82	52.5
Drip maintenance		350 lb. Phosphorus	91			91	0	0	0
Irrigate 20x		Chemicals	30			30	30	30	30
		Water 4 ac/ft	58.2	16	124	182.24	182.24	182.24	182.24
insect control 7x & 3x drip	9	Insecticides	280			343	343	343	343
Remove drip tape and plastic				20	155	155	155	155	155
Disc out beds	11.5					11.5	11.5	11.5	11.5
TOTAL GROWING PERIOD						**3263.74**	**3059**	**3041.6**	**3085.2**
GROWING PERIOD AND LAND PREPARATION COSTS						3489.05	4092.6	4131.1	3393.8
Land Rent (net acres)						225	225	225	225
Cash Overhead	17 % of preharvest costs and land rest					631.39	631.39	631.39	631.39
TOTAL PREHARVEST COSTS						**4345.44**	**4948.9**	**4987.5**	**4250.2**
Harvest cost									
Pick, haul, pack, cool, and sell		1300carton/acre @	4.40 per carton			5720	6921.2	7950.8	7493.2
TOTAL OF ALL COSTS						10065.44	11870	12938	11743
Yield 1300 cartons/acre @ 10.00/30 lb cartoon						13000	15730	18070	17030
NET RETURNS						**2934.56**	**3859.9**	**5131.7**	**5286.6**

* IF: Inorganic Fertilizer, CW: Cow manure, PW: Paper waste and FW: Food waste vermicomposts. See Appendix C for additional assumptions.

APPENDIX C

APPENDIX C

Assumptions of N supplied by vermicomposts

Pepper (95 kg N/ha)= 80 lbs/acre				Actual	Equivalent	Fertilizer
	% Dry	%	Actual Dry Wt. Per	N Supplied	fertilizer replaced	Replaced out of
	Wt	N	2.5 Tons Wet weight	lbs	%	235 lbs req'd
			lbs			
Food Waste	0.57	0.013	2850	11.115	32.69	13.91
paper waste	0.81	0.01	4050	12.15	35.74	15.21
Cow Manure	0.27	0.015	1350	6.075	17.87	7.60
Strawberry (85 kg N/ha) = 70 lbs/acre					Equivalent	Fertilizer
	% Dry	%	Actual Dry Wt. Per	Actual N supplied	fertilizer replaced	Replaced out of
	Wt	N	2.5 Tons Wet weight	lbs	%	205 lbs req'd
			lbs			
Food Waste	0.57	0.013	2850	11.115	32.69	15.87
paper waste	0.81	0.01	4050	12.15	35.74	17.35

The recommended N fertilization for peppers is 95 kg/ha (80 lbs per acre) an 85 kg/ha (70 lbs/acre) for strawberries.

Actual N supplied by the vermicomposts was computed as 30% of the total N content which is the available N for the year.