International Journal of the Physical Sciences Vol. 5(13), pp. 1964-1973, 18 October, 2010
Available online at http://www.academicjournals.org/IJPS
ISSN 1992 - 1950 ©2010 Academic Journals

Review

Potential of vermicompost produced from plant waste on the growth and nutrient status in vegetable production

J. Theunissen, P. A. Ndakidemi* and C. P. Laubscher

Faculty of Applied Science, Cape Peninsula University of Technology, Cape Town Campus, Keizersgracht, P. O. Box 652, Cape Town 8000, South Africa.

Accepted 5 October, 2010

Vermicompost contains plant nutrients including N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu and B, the uptake of which has a positive effect on plant nutrition, photosynthesis, the chlorophyll content of the leaves and improves the nutrient content of the different plant components (roots, shoots and the fruits). The high percentage of humic acids in vermicompost contributes to plant health, as it promotes the synthesis of phenolic compounds such as anthocyanins and flavonoids which may improve the plant quality and act as a deterrent to pests and diseases.

Key words: Phenolic acid, humic acid, earthworms, *Eisenia fetida*, organic, compost, fertilizer, leachate, photosynthesis, chlorophyll.

INTRODUCTION

Intensive crop production including vegetables by using inorganic fertilizers in South Africa has led to increased yield at the expense of environmental degradation. However, environmental degradation due to intensive use of agrochemicals in crop production has created greater interest in the use of vermicompost to supply necessary mineral elements to produce organically grown fruits, vegetables and livestock of a high nutritional value, while recycling all wastes, thus minimizing contamination of soils and waterways (Follet et al., 1981; Matson et al., 1997). Vermicomposts are products of a non-thermophilic biodegradation of organic materials through interactions between earthworms and microorganisms (Aira et al., 2002; Sallaku et al., 2009). Some of these earthworms include *Eisenia fetida*, *Lumbricus rubellus*, *Amyanthes diffrigens* and *Eudrillus engineac* (Nagavalemma et al., 2004). These earthworms improve the soils' physical, chemical and biological conditions for plant growth and nutrient uptake. The accelerated decomposition of plant litter and organic matter by these organisms improve soil fertility by releasing mineral elements in the forms that are available for uptake by plants (Curry, 1987). Vermicompost are materials characterized by high porosity, aeration, drainage, water holding capacity and microbial activity (Edwards and Burrows, 1988; Edwards, 1998; Atiyeh et al., 1999, 2000).

Vermicompost is made up primarily of C, H and O, and contains nutrients such as NO_3, PO_4, Ca, K, Mg, S and micronutrients which exhibit similar effects on plant growth and yield as inorganic fertilizers applied to soil (Singh et al., 2008). Similarly, vermicompost contains a high proportion of humic substances (that is, humic acids, fulvic acids and humin) which provide numerous sites for chemical reaction; microbial components known to enhance plant growth and disease suppression through the activities of bacteria (*Bacillus*), yeasts (*Sporobolomyces* and *Cryptococcus*) and fungi (*Trichoderma*), as well as chemical antagonists such as phenols and amino acids (Nagavalemma et al., 2004).

Soils amended with these products have the ability to

*Corresponding author. E-mail: NdakidemiP@cput.ac.za, Ndakidemi56@yahoo.com. Tel: +27214603196. Fax: +27214603193.

Table 1. Examples of nutrient content in vermicompost, compared with farm yard manure.

Nutrient*	Vermicompost	Farmyard manure
N (%)	1.6	0.5
PO (%)	0.7	0.2
KO (%)	0.8	0.5
Ca (%)	0.5	0.9
Mg (%)	0.2	0.2
Fe (ppm)	175.0	146.5
Cu (ppm)	5.0	2.8
Zn (ppm)	24.5	14.5
Mn (ppm)	96.5	69.0
C:N Ratio	15.5	31.3

*These values are subject to variation depending on the type of organic waste. Source: Punjab State Council for Science and Technology (2010). Available online at: http://agri.and.nic.in/vermi_culture.htm.

retain moisture, improve soil structure and cation exchange capacity, have a higher rate of plant growth hormones and humic acids, higher microbial population and activity, and less root pathogens or soil borne diseases (Hoitink, 1980; Tomati et al., 1988; Alvarez et al., 1995; Domininguez and Edwards, 1997; Subla et al., 1998; Muscolo et al., 1999; Carpenter-Boggs et al., 2000; Atiyeh et al., 2002; Arancon et al., 2003a; Postma et al., 2003; Perner et al., 2006) and overall improvement in plant growth and yield (Kale et al., 1992; Arancon et al., 2003b, 2004).

Various forms of organic matter can be used for vermicomposting, including animal manure, wastes from manufacturing industries e.g. paper, sugar cane or cotton residues, kitchen and agricultural wastes, as well as municipal wastes of organic origin (Alves and Passom, 1997; Atiyeh et al., 1999; Kamergam et al., 1999; Kiehl, 2001). The nutritional value of the vermicompost is however dependent on its origin. Golchin et al. (2006) reported that vermicomposted animal manures tend to have a higher nutritional status, compared with that derived from organic municipal waste. For example, vermicompost produced from cattle and pigs manure as well as food wastes increased the rate of germination, growth and flowering of a range of ornamental and vegetable seedlings compared with vermicompost from other sources (Atiyeh et al., 2000a, b, c). Compared with farm yard manure (Table 1), vermicompost have been reported to have between 40 to 60% higher levels of humic substances and are superior in quality than conventional composts (Dominguez et al., 1997).

Soil is generally considered fertile when it has good physical structure, balanced nutrients and sufficient biotic activity (Mader et al., 2002). The absence or imbalance of any one of these acts as a limiting factor and affects plant growth. A good soil consists of 50 to 70% mineral particles, 30 to 50% pore spaces (containing water and air) and 5 to 15% organic matter (Prasad and Power, 1997). Under normal circumstances, plants are able to access the nutrients required from the soil. However, continuous extensive cropping without adequate nutrients replenishment depletes the soil nutrient levels, particularly N, P, K and Ca (Conradie and Saayman, 1989; Ndakidemi and Semoka, 2006) which are taken in relatively large amounts by the plants compared with micronutrients (Follet et al., 1981; Marschner, 1995). In the soil, plants obtain nutrients from different sources, including the soil reserves, crop residues, vermicompost, synthetic and organic fertilizers. These nutrients are essential for plant growth and development and their deficiency may result in poor plant growth (Matson et al., 1997; Cakmak, 2002; Welch, 2002). Therefore, in a commercial horticultural environment such as those involving the production of vegetables, a continuous supply of both macronutrients (that is, N, P, K, Ca, Mg, S), and micronutrients (Fe, Cu, Zn, Mn, Mo, B) is crucial to a successful harvest.

Nitrogen plays a significant role in photosynthesis, cell division and differentiation, growth and somatic embryogenesis, chlorophyll (Chl) content, rubisco activity, electron transport rate, photosynthetic rate, anthocyanin production and is an important component of proteins required for the metabolic processes that take place during plant growth (Chaplin and Westwood, 1980; Novoa and Loomis, 1981; Mordhorst and Lorz, 1993; Guidi et al., 1998; Jain et al., 1999). Phosphorous also plays a role in increasing water-use efficiency (WUE), a critical factor for plant productivity in drier climates (Vance, 2001; Wittenmayer and Merbach, 2005), improves leaf expansion, axillary bud growth and shoot canopy, improved photosynthetic surface area and carbohydrate utilization (Ahloowalia et al., 2004). Potassium is a nutrient that plays a role in many physiological processes essential for plant growth, including the maintenance for plant water balance and protein synthesis (Fenn, 1940).

The effect of humic substances is more prominent in stimulating root respiration, formation and growth. These results in increased efficiency of the rooting system which in turn improves upper growth; including the shoots, leaves, flowers and fruit (Atiyeh et al., 2002). The use of vermicompost which constitute greater amounts of humic substances has also produced significant improvements in germination rates. It has been hypothesized that the increases in growth, flowering and crop yields are due to earthworms as they increase microbial populations that produce plant growth hormones (Paterson, 2003). These in turn become adsorbed on to the humates produced during the vermicomposting process (Edwards and Arancon, 2004). This review intends to report the potential of vermicompost to improve plant growth and development, nutrient composition and accumulation of metabolites such as phenolic compounds in vegetable crops.

Possible contribution of vermicompost on nutrient composition of plants

In order to produce a good crop, macronutrients available in the soil should be in the range of N (0.1 to 0.5%), P (0.08 to 0.5%), K (1.5 ti 3.0%) (Dutta, 2005). Adequate P is characterized by improved crop quality, increased root growth and earlier crop maturity (Grusak and DellaPenna, 1999). Although macronutrients such as Ca and Mg are used in smaller amounts, they are just as important to profitable crop production as the N, P and K. Exchangeable Ca in soils range 12 to 75% of CEC whereas exchangeable Mg in soils range 4 to 20% of CEC (Eckert and McLean, 1981). Magnesium is involved in numerous physiological and biochemical processes activating more enzymes than any other mineral nutrient, thus, making a significant contribution to plant growth and development (Epstein and Bloom, 2004). Calcium plays an important role in a wide range of physiological and biochemical processes in plants including the adjustments of ethylene responses in plants (Zhang et al., 2002), fruit ripening (Ferguson, 1984), flower senescence and flower abscission (Glenn et al., 1988). Micronutrients such as Fe, Cu, Zn, Mn, Mo and B assist in the formation of chlorophyll, cell division and growth, carbohydrate formation, as well as the maintenance of the plant's enzyme system (Follet et al., 1981). Therefore, the type of organic or inorganic fertilizers used in agriculture with different quantities of macro and micronutrient has a significant effect on the nutrient value of the plants consumed.

It has been confirmed that vermicompost has the capacity to supply both macro and micronutrients in the soil for optimum plant growth (Harris et al., 1990). These plant nutrients are adsorbed on the humic acid molecules and are released slowly and gradually into the soil solution and made available for plant growth and development processes (Senesi, 1992; Arancon et al., 2005; Guiterrez-Miceli, 2007). Numerous reports have indicated that slow and gradual release of N through vermicompost increased the concentration of carotene in a wide range of fruits and vegetables, including carrots (Cserni and Prohaska, 1987; Mozafar, 1993). It was also reported that the increased N, P and K content of the leaves of tomato plants was due to foliar application of a liquid extract from vermicompost (Tejada et al., 2007). Additionally, the significant increase in yield and fruit quality of tomatoes was attributed to improved uptake of N, P and K from vermicompost as well as increased chlorophyll production in the leaves (Tejada et al., 2007). In another study, Tejada and Gonzalez (2006) found that increased macronutrients in the leaves of rice and maize were due to foliar application of vermicompost extracts high in humic substances. Gutierrez-Miceli (2007), found that leachate derived from vermicompost was the most important factor affecting sorghum (*Sorghum bicolor* L.) growth, with a marked effect on the total N, P and K content of the plant. Similarly, Sanchez-Conde and Ortega (1968) reported that plant assimilation of N and P increased when amended with liquid humic acid, while the uptake of K decreased. In agreement with the previous findings, Baldatto et al. (2009) established significant accumulation of N, P, K, Ca and Mg in the roots, shoots and leaves as a result of the application of humic acids derived from vermicompost. The ability of humic substances to interact with both macro and micronutrients was ascribed to their higher contents of oxygen containing functional groups such as carboxyl (COOH), hydroxyl (OH), and carbonyl (C=O) (Senesi, 1992).

Nutrients in vermicompost are present in readily available forms for plant uptake; e.g. NO_3, exchangeable P, K, Ca and Mg (Edwards and Burrows, 1988). Better plant growth and yield of different crops have been reported when vermicompost was combined with artificial fertilizer in a certain ratio. Senthilkumar et al. (2004) found that vermicompost ± NPK fertilizers significantly enhanced *Rose sp* growth, yield and quality over the control, especially when used in combination. Plant available N, P and K were higher in plots supplied with both vermicompost and NPK fertilizers (Senthilkumar et al., 2004). Results from a study conducted by Premuzic et al. (1998) revealed that the fruit of tomato plants grown on vermicompost contained significantly more Ca and vitamin C but less Fe compared with those grown in a hydroponics medium with inorganic fertilization. Plant tissue analysis revealed that total extractable N, P, K and Fe were highest in petunia (*Petunia hybrida* L.) plants grown in the 60% vermicompost medium compared with those grown in the 60% peat medium. However, Cu and Mn concentrations in petunia plants grown in vermicompost media were significantly ($P<0.05$) lower than for those grown in the control medium (Chamani et al., 2008). The yield of pea (*Pisum sativum* L.) was higher with the application of vermicompost at a rate of 10 tha^{-1} along with recommended N, P and K compared with when these fertilizers were applied alone (Reddy et al., 1998). Kumari and Ushakumari (2002) reported that treatment with enriched vermicompost was superior to other treatments for the uptake of N, P, K, Ca and Mg by cowpea (*Vigna unguiculata* L. Walp). In another study, Sainz et al. (1998) reported that addition of vermicompost to soil resulted in increased mineral contents in the substrate and higher concentrations of P, Ca, Mg, Cu, Zn and Mn in shoot tissues of red clover and cucumber. Similarly, combining fertilizer with vermicompost increased the uptake of N, P, K and Mg by rice (*Oryza sativa* L.) and highest N uptake was obtained at 50% of the recommended fertilizer rate applied with 10 tha^{-1} vermicompost (Jadhav et al., 1997). In a field experiment, vermicompost application along with fertilizer N gave higher dry matter (16.2 gplant^{-1}) and grain yield (3.6 tha^{-1}) of wheat (*Triticum aestivum* L.). Similar results were obtained with the application of vermicompost to other field crops such as sorghum (*Sorghum bicolor* L.) and sunflower (*Helianthus annuus* L.) (Devi and Agarwal, 1998; Devi et al., 1998; Patil and Sheelavantar, 2000).

Plants fertilized with vermicompost have shown greater ability to assimilate essential macro and micro nutrients, and resulted into improved root development (Edwards and Burrows, 1988; Werner and Cuevas, 1996; Atiyeh et al., 2001; Arancon et al., 2006). Research efforts should focus on the influence of vermicompost from different sources on nutrient availability and nutritional gains in different vegetables in which aerial, floral, seeds or roots are major components consumed. Furthermore, testing of vermicompost samples for their nutrient constitution before their use is of paramount importance as will provide information on the nutrient quantities and hence justifying their use.

The effect of vermicompost on the composition of phenolic compounds in the plant

Phenolic compounds occur as secondary metabolites in all plant species and they are generally characterized by a benzene ring and one hydroxyl group (Antolovich et al., 2000; Kefeli et al., 2003). These phenolics are divided into several main groups and include flavonoids and anthocyanins. Flavonoids and anthocyanins are known to be synthesized in specific tissues at defined times in response to various environmental factors, such as nutrient stress, pests and diseases, light, UV irradiation, temperature and wounding (Christie et al., 1994, Dixon and Pavia, 1995). The presence of these compounds in many types of edible fruits and vegetables in modern diets provide natural pigmentation and possess a wide range of antioxidant protection and therapeutic benefits to human health, including potent cardio protective, neuroprotective, anti-inflammatory and anti-carcinogenic properties (Miller et al., 1998; Kahkonen et al., 1999, Duthie et al., 2003; Hu, 2003; Heber, 2004; Juranic and Zizak, 2005). However, the value of these compounds relies on the conditions under which the plants are grown. Research evidence has shown that the amounts of phenolic compounds from plants grown under organic conditions are higher than those grown under non-organic conditions (Grusak and DellaPenna, 1999; Dixon, 2001; Asami et al., 2003). In their study, Asami et al. (2003) found that total amounts of phenolic substances were higher in strawberries (*Fragaria ananasa*, var. Chandler) and corn (*Zea mays*) grown organically than those grown with inorganic fertilizers. The levels of total phenolics from the corn samples grown by sustainable methods were 58.5, 40.7 and 58.4% higher than those of conventionally grown samples. The observed higher total phenolic compounds could be due to the increase in environmental stress to the plants as little or no pesticides and synthetic fertilizers were applied to assist in plant growth (Asami et al., 2003).

As the phenolics also provide color, taste and aroma to the fruit (Hattenschwiler and Vitousek, 2000) they are essential in food production, as these are a prerequisite to the marketability of the crop and consumer acceptability.

A consistently higher levels of total phenolics was also observed in plants grown under vermicompost fertilization compared with those grown under Osmocote fertilization and this was attributed to a slow and gradual release of plant-available nutrients from vermicompost or organically grown crops relative to Osmocote or those grown using conventional agricultural practices (Wang and Lin, 2002; Asami et al., 2003; Pant et al., 2009). In some other studies, it was reported that a higher level of antioxidant capacity of a leafy vegetable was partly associated with accumulation of higher levels of phenolic compounds in plant tissue (Dixon and Paiva, 1995; Zhao et al., 2007). The higher levels of total phenolics observed under vermicompost would probably explain why plants grown under vermicompost had fewer attacks by arthropod pests, and better resistance to disease compared with plants that receive inorganic fertilizers (Haukioja et al., 2002; Rao, 2002; Edwards et al., 2004; Vinken et al., 2005; Arancon et al., 2007). Surely, these phytochemicals form part of the natural plant defense system against infection and microbial invasions (Ndakidemi and Dakora, 2003; Makoi and Ndakidemi, 2007; Edwards et al., 2009). Clearly, there is a huge potential in the use of vermicompost as it can play roles not only on the natural plant defense system, but also for human health benefits. However, more understanding is required on the proper rate of vermicompost application with or without inorganic fertilizers for maximum and effective phytochemicals production for plant defense and improved quality of the edible parts. Equally important is the understanding of how vermicompost application should be manipulated to increase the metabolism of phenolic compounds sufficiently enough to improve the color and nutritional quality of the plants and the antioxidant activity of their edible or medicinal products for the benefits of the food industry.

Effect of vermicompost on photosynthesis and chlorophyll production

Photosynthesis is a process which provides the energy necessary for plant growth and reproduction. Chlorophyll represents the principal class of pigments responsible for light absorption and photosynthesis. Photosynthesis however, is a complex process that is sensitive to environmental factors such as macro and micro nutrients (Chapin, 1980; Marschner, 1995). Nutrients such as N, P, K, Mg, Fe and Cu, which are readily available through vermicompost are used in the formation of chlorophyll which is required for light harvesting and subsequent conversion into chemical energy via photoassimilation (Tanaka et al., 1998). For example, N enhances CO_2 fixation (Evans and Terashima, 1988; Tan and Hogan, 1995). Between 6 and 35% of the total Mg is bound to the chlorophyll and plays a major role in photosynthetic CO_2 fixation (Scott and Robson, 1990; Fischer and Bremner, 1993). Iron affects the synthesis of chlorophyll precursor S-aminolevulinic acid, thus, playing an important role in chlorophyll biosynthesis (Pushnik and Miller, 1989). Copper is part of plastocyanin protein responsible for electron transmission during photosynthesis process (Ayala and Sandmann, 1989). Phosphorus and K are also essential in several biochemical activities including photosynthetic CO_2 fixation, respiration, cell division, maintenance of high pH of chloroplast stroma, stomata conductance, water regulation and transport as well as protein synthesis (Humble and Raschke, 1971; Fang et al., 1995). Deficiency of these plant nutrients may deter the formation of chlorophyll resulting in chlorotic leaves (Dutta, 2005). Such chlorotic leaves are not able to harvest and convert light energy into the chemical energy required by the plant for photosynthesis process.

It is well established that inadequate levels of any mineral nutrient in the growth media may limit photosynthesis due to their involvement in chlorophyll formation and carbohydrate synthesis (Dinauer, 1969; Lambers et al., 1998). All of the biochemical processes of photosynthesis depend on nitrogenous compounds which provide the basis for all the reactions that take place inside the chloroplast, including chlorophyll, proteins and enzymes required for the photosynthesis process (Givnish, 1986).

There are different opinions as to whether vermicompost actually increases the chlorophyll content of the leaves. For example, Asiegbu and Oikeh (1995) reported that chemical fertilizers were more efficient in the short term. A study by Alam et al. (2007) on the effect of vermicompost and N, P, K and S fertilizers on the growth and yield of red amaranth (*Amaranthus cruentus*), showed that chemical fertilizers were more efficient in the first four weeks of application suggesting that the vermicompost may have taken at least four weeks to have a more favorable effect on plant growth.

Berova and Karanatsidis (2009) observed increased photosynthetic pigments and leaf gas exchange in red chilli (*Capsicum annum* L.) due to application of vermicompost. In a separate study, Golchin et al. (2006) reported that leaf area index (LAI) and chlorophyll content of the leaves of pistachio (*Pistacia vera* L.) seedlings, as well as the photosynthesis rate were better in vermicompost treatments relative to the treatments without vermicompost. Similarly, apart from the increased leaf area and photosynthetic pigments in a red pepper (*C. annuum* L.) cultivar (Buketen 50), the speed of the net photosynthesis was 33% higher in treatments with vermicompost compared with the control plants (Berova and Karanastidis, 2008). During an experiment on the response of pineapple (*Ananas comosus*) to applications of humic acid derived from vermicompost, Baldatto et al. (2009), found a distinct increase in the levels of photosynthetic pigments and a significant increase in the ratio of chlorophyll *a* and chlorophyll *b* relative to the control. In an experiment involving beans, it was observed that addition of 8.2% w/w vermicompost/soil induced the largest increase in chlorophyll content in the leaves of common bean (*Phaseolus vulgaris* L.) plants (Fernéndez-Luqueño et al., 2010). Results from another study showed that perennial ryegrass (*Lolium perenne* L.) grown in soils amended with 10 to 20% vermicompost increased chlorophyll content compared with plants from un-amended soils (Cheng et al., 2007). It is therefore worth establishing if improvement of soil nutrient via vermicompost of different rates will enhance the chlorophyll production and photosynthetic activity in selected vegetable crops.

Possible effects of vermicompost on plant growth

Optimum plant growth and development is important for greater final dry matter and yields. In order to achieve this, sufficient amounts of nutrients should be applied to the soil through inorganic and organic sources. Vermicompost for example, an organic source of plant nutrients, contains a higher percentage of nutrients necessary for plant growth in readily available forms (Nagavallemma et al., 2004; Table 1). As a result, vermicompost has a potential for improving plant growth and dry matter yield when added to the soil (Atiyeh et al., 2000; Zaller, 2007). Studies have shown that vermicompost plays a major role in improving growth and yield of different field crops, including vegetables, flowers and fruit crops. For example, the application of vermicompost gave higher germination (93%), growth and yield of mung bean (*Vigna radiate* L.) compared with the control (84%) (Nagavallemma et al., 2004). In a study involving a wide range of vegetable and ornamental seedlings, result showed earlier and better germination in a vermicompost compared with control (Edwards, 1998b; Gutierrez-Miceli et al., 2007).

Furthermore, comparing biodigested slurry and vermicompost, Karmegam et al. (1999) and Karmegam and Daniel (2000) showed that the fresh and dry matter yields of cowpea (*Vigna unguiculata* L.) were greater when soil was amended with vermicompost. Furthermore, the yield of pea (*P. sativum* L.) was also higher when vermicompost was applied at a rate of 10 tha^{-1} along with recommended N, P and K than with these fertilizers applied alone (Reddy et al., 1998). It was also reported that application of different levels of vermicompost to *Chrysanthemum chinensis* resulted in increased fresh weight of flowers, number of flowers per plant (26), flower diameter (6 cm) and yield (0.5 tha^{-1}) with the application of 10 tha^{-1} of vermicompost (Nethra et al., 1999). Vermicompost applied at a rate of 5 tha^{-1} have also been reported to significantly increase yield of tomato (*L. esculentum* L.) (5.8 tha^{-1}) in farmers' fields compared with control (3.5 tha^{-1}) (Nagavallemma et al., 2004). Vadiraj et al. (1998) reported that application of vermicompost produced herbage yields of coriander (*Coriandrum sativum*) cultivars that were comparable to those obtained with chemical fertilizers.

Vermicompost and its components has also shown to benefit plant growth in poor light textured soils which was attributed to high rate of N mineralization as a result of high cation exchange capacity (CEC), slow and gradual release of N with minimum losses due to leaching (Harris et al., 1990). For example, in the poorer sandy soils of the Western Cape (South Africa) where root vegetables such as carrots (*Daucus carota*) are an important agricultural crop, the use of vermicompost could make these soils more productive over a longer period, thus enhancing its potential to support plant growth. Research has revealed that application of vermicompost enhanced plant growth and development, root initiation and root biomass and this was attributed to the organisms essential for maintaining vigorous plant growth capable of withstanding environmental stress (Tomati et al., 1987; Edwards, 1998b; Atiyeh et al., 2002; Bachman and Metzger, 2008).

There is also evidence that humic acids extracted from vermicompost stimulated increase in the number of roots, giving the plant ability to scavenge nutrient from the growing environment for growth and development (Alvarez and Grigera, 2005). For example, humic acids derived from leonardite and peat were found to increase root mass of Kentucky bluegrass (*Poa pratensis* L.) by 73% and root strength by 34% (Ervin et al., 2008). However, the humic acid applications did not increase shoot tiller density or the visual quality of the grass (Ervin et al., 2008). O'Donnel (1972) and Eyheraguibel et al. (2007) established that plants treated with humic substances exhibited an increased number of lateral roots compared with the control. The increased lateral roots in humic treatments relative to the control was ascribed to the presence of the phytohormone auxin in the humic substances, which played a key role in the initiation and emergence of lateral roots as well as regulating lateral root development (Blakely et al., 1982; Laskowski et al., 1995; Casimiro et al., 2001; Bhalerao et al., 2002). In maize (*Z. mays* L.) plants for example, the elongation and proliferation of secondary roots due to the phytohormone auxin in the humic substances resulted in increased total length and root surface area (Canellas et al., 2002). It is worth testing if a similar trend can be repeated in root vegetable crops, in which root organ is the main component consumed. More studies are therefore required to ascertain the physiological contribution and function(s) of humic acid from vermicompost on different vegetable crop components viz: roots, shoots and seeds.

Plant growth and development is affected by the rates of the vermicompost applied to the soil which are in turn affected by agro-climatic conditions of the growing environment (Atiyeh et al., 2000c). For example, vermicompost applied at a rate of 25% improved stem length by 11 mm and diameter by 40 mm in tomato plants compared with the control plants (Atiyeh et al., 2002). Furthermore, vermicompost derived from pig manure applied at a rate of 100% significantly improved leaf numbers, shoot lengths, shoot and root dry mass of tomato seedlings compared with those grown in commercial potting media (MM360) after 21 days (Atiyeh et al., 2002). In experiments involving vermicompost derived from water hyacinth (*Eichhornia crassipes* L.) on the growth and flowering of *Crossandra undulaefolia*, Gajalakshmi and Abbasi (2002) showed that the *C. undulaefolia* plants in soil amended with vermicompost achieved significantly better height, larger number of leaves, more favorable root to shoot ratio and greater biomass per unit time than the control plants. Positive results with vermicompost obtained from a series of experiments on field grown turnips (*Brassica napa* L.) showed that apart from the larger and fully expanded leaves of turnip plants that received vermicompost at a rate of 10 and 20%, they had also an average diameter of 87 and 155 mm, respectively compared with control which had an average diameter of 52 mm (Classen et al., 2007).

It was also reported that soil amended with 30% vermicompost produced the most flowers on the Marigold (*Tagetes erecta* L.) plants in pot culture experiments, and the largest flower diameter was produced in soil amended with 40% vermicompost (Pritam et al., 2010). Their findings indicated that the amount of vermicompost had a significant effect on not only growth and flowering of the Marigold plants, but also on the plant shoot and root biomass, plant height and diameter of the flowers (Pritam et al., 2010). While experimenting on the influence of vermicompost on the growth and fruit yield of strawberry (*Fragaria ananassa* L.), Singh et al. (2008) found that the dose of vermicompost varied according to agro-climatic conditions of the growing environment. Taken together, these results suggest that it would be appropriate to experiment with more than one application rate of vermicompost in the media, on different types of vegetables, in order to attain the optimum rate of vermicompost to be applied for optimum plant growth and yield.

Although there have been numerous studies on the positive effects of vermicompost from various sources on general plant growth, fruit setting and root formation (Subler et al., 1998; Atiyeh et al., 2002; Arancon et al., 2005), limited information is available regarding the effect of vermicompost on the root formation of edible root vegetables grown in light-textured soils, where the root portion is of more importance than the shoots, flowers and seeds. Therefore, there is a need to determine the effect of vermicompost on root vegetable crops grown on sandy, well-drained soil.

Conclusion

Organic vegetable production is controlled by essential macro and micronutrients and other growth promoting substances present in the growth media. These may be supplied from inorganic and organic sources. With the global trend moving towards the production of organic food crops, organic waste material processed by the naturally occurring earthworm *Eisenia fetida* may be used to produce vermicompost which will supply nutrients and other soil stimulants for plant growth and improve soil quality. Plant growth and quality are enhanced through improved soil quality. It is therefore worthwhile to establish the ideal rate of application of vermicompost in order to achieve this objective.

ACKNOWLEDGEMENT

This study was supported by Cape Peninsula University of Technology through University Research Fund (RP 03).

REFERENCES

Ahloowalia BS, Maluszynski M, Nichterlin K (2004). Global impact of mutation derived varieties. Euphytica, 135: 187-204.

Aira M, Monroy F, Dominguez J, Mato S (2002). How earthworm density affects microbial biomass and activity in pig manure. Eur. J. Soil Biol. 38: 7-10.

Alam M, Jahan M, Ali M, Islam M, Khandaker S (2007). Effect of vermicompost and NPKS fertilizers on growth, yield and yield components of Red Amaranth. Aust. J. Basic Appl. Sci., 1(4): 706-716.

Alvarez MAB, Gagne S, Antoun H (1995). Effect of compost on rhizosphere microflora of the tomato and on the incidence of plant growth-promoting rhizobacteria. App. Environ. Microbiol., 61: 194-199.

Alvarez R, Grigera S (2005). Analysis of soil fertility and managements on yields of wheat and corn in the rolling pampa of Argentina. J. Agron.Crop Sci., 191: 321-329.

Alves WL, Passoni AA (1997). Compost and vermicompost of urban solid waste in *Licania tomentosa* (Benth) seedlings production to arborization. Pesqui. Agropecu. Bras., 32(10): 1053-1058.

Antolovich M, Prenzler P, Robards K, Ryan D (2000). Sample preparation of phenolic compounds in fruits. Analyst, 125: 989-1009.

Arancon NQ, Edwards CA, Bierman P (2006). Influence of vermicomposts on field strawberries: Effect on soil microbiological and chemical properties. Bioresour. Technol., 97: 831- 840.

Arancon N, Edwards C, Yardim E, Oliver T, Byrne R, Keeney G (2007). Supression of two-spotted spider mite *(Tetranychus urticae),* mealy bug *(Pseudococcus* sp) and aphid *(Myzus persicae)* populations and damage by vermicomposts. Crop Prot., 26: 29-39.

Arancon N, Lee S, Edwards C, Atiyeh R (2003a). Effects of humic acids derived from cattle, food and paper-waste vermicomposts on the growth of greenhouse plants. Pedobiologia, 47(5): 741-744.

Arancon NQ, Edwards CA, Bierman P, Metzger JD, Lucht C (2005). Effects of vermicomposts produced from cattle manure, food waste and paper waste on the growth and yield of peppers in the field. Pedobiologia, 49(4): 297-306.

Arancon NQ, Edwards CA, Bierman P, Welch C, Metzger JD (2004). The influence of vermicompost applications to strawberries: Part 1. Effects on growth and yield. Biores. Technol., 93: 145-153.

Arancon NQ, Lee S, Edwards CA, Atiyeh RM (2003b). Effects of humic acids and aqueous extracts derived from cattle, food and paper-waste vermicomposts on growth of greenhouse plants. Pedobiologia (Jena), 47: 744-781.

Asami D, Hang Y, Barnett D, Mitchelle A (2003). Comparison of the total phenolic and ascorbic content of freeze-dried and air dried marionberry, strawberry, and corn grown using conventional, organic and sustainable agricultural practices. J. Agric. Food Chem., 51: 1237-1241.

Asiegbu J, Oikeh S (1995). Evaluation of chemical composition of manures from different organic wastes and their potential for supply of nutrients to tomato in a tropical Ultisol. Biol. Agricric. Hortic., 12: 47-60.

Atiyeh R, Lee S, Edwards C, Arancon Q, Metzger J (2002). The influence of humic acids derived from earthworm processed organic wastes on plant growth. Bioresour. Technol., 84(1): 7-14.

Atiyeh RM, Arancon NQ, Edwards CA, Metzger JD (2000a): Influence of earthworm-processed pig manure on the growth and yield of greenhouse tomatoes. Bioresour. Technol., 75: 175-180.

Atiyeh RM, Edwards CA, Subler S, Metzger J (2000b). Earthworm-processed organic wastes as components of horticultural potting media for growing marigold and vegetable seedlings. Compost Sci. Util., 82: 15-223.

Atiyeh RM, Edwards CA, Subler S, Metzger JD (2001). Pig manure vermicompost as a component of a horticultural bedding plant medium: Effects on physicochemical properties and plant growth. Bioresour. Technol., 78(1): 11-20.

Atiyeh RM, Subler S, Edwards CA, Bachman G, Metzger JD, Shuster W (2000c): Effects of vermicomposts and composts on plant growth in horticultural container media and soil. Pedobiologia (Jena), 44: 579-590.

Atiyeh RM, Subler S, Edwards CA, Metzger J (1999). Growth of tomato plants in horticultural potting media amended with vermicompost. Pedobiologia, 43: 724-728.

Ayala MB, Sandmann G (1989). Activities of Cu-containing protein in Cu-depleted pea leaves. Physiol. Plantar., 72: 801-806.

Bachman GR, Metzger JD (2008). Growth of bedding plants in commercial potting substrate amended with vermicompost. Bioresour. Technol. 99: 3155-3161.

Baldatto LSB, Baldatto MA, Giro VB, Canellas LP, Olivares FL, Bressan-Smith R (2009). Performance of 'Victoria' pineapple in response to humic acid application during acclimatization. Braz. J. Soil Sci., 33(4): Section 4.

Berova M, Karanatsdis G (2009). Influence of bio-fertilizer, produced by *Lumbricus rubellus* on growth, leaf gas exchange and photosynthetic content of pepper plants (*Capsicum annuum* L.). Acta Hort., 830: 447-452.

Berova M, Karanatsidis G (2008). Physiological response and yield of pepper plants *(Capsicum annum* L.) to organic fertilization. J. Central Eur. Agric., 9(4): 715-722.

Bhalerao RP, Eklof J, Ljung K, Marchant A, Bennett M, Sandberg G (2002). Shoot-derived auxin is essential for early lateral root emergence in *Arabidopsis* seedlings. Plant J., 29(8): 325-332.

Blakely LN, Durham M, Evans TA, Blakely RM (1982). Experimental studies on lateral root-formation in radish seedling roots: I. General methods, developmental stages, and spontaneous formation of lateral roots. Bot. Gaz., 143: 341-352.

Cakmak I (2002). Plant nutrition research: priorities to meet human needs for food in sustainable ways. Plant Soil, 247: 3-24.

Canellas L, Olivares F, Okorokova-Facanha A, Facanha A (2002). Humic acids isolated from earthworm compost enhance root elongation, lateral root emergence and plasma membrane H+-ATPhase activity in maize root. Plant Physiol., 130: 1951-1957.

Carpenter-Boggs L, Kennedy AC, Reganold JP (2000). Organic and biodynamic management: Effects on soil biology. Soil Sci. Soc. Amer. J., 64: 1651-1659.

Casimiro I, Marchant A, Bhalerao RP, Beeckman T, D'Hooge S, Swarup

R, Graham N, Inzé D, Sandberg G, Casero PJ (2001). Auxin transport promotes *Arabidopsis* lateral root initiation. Plant Cell, 13: 843-852.
Chamani E, Joyce DC, Reihanytabar A (2008). Vermicompost effects on the growth and flowering of *Petunia hybrida* 'Dream Neon Rose' American-Eurasian J. Agric. Environ. Sci., 3(3): 506-512.
Chapin FS (1980). The mineral nutrition of wild plants. Ann. Rev. Ecol. Systematics, 11: 233-260.
Chaplin MH, Westwood MN (1980). Relationship of nutritional factors to fruit set. J. Plant Nutri., 4(2): 477-505.
Cheng HF, Xu WP, Liu JL, Zhao QJ, He YQ, Chen G (2007). Application of composted sewage sludge (CSS) as a soil amendment for turfgrass growth. Ecol. Eng., 29: 96-104.
Christie PJ, Alfenito MR, Walbot V (1994). Impact of low-temperature stress on general phenylpropanoid and anthocyanin pathways: Enhancement of transcript abundance and anthocyanin pigmentation in maize seedlings. Planta, 194: 541-549.
Classen JJ, Rice JM, Sherman R (2007). The effects of vermicompost on field turnips and rainfall runoff. Compost Sci. Utilisation, 15(1): 34-39.
Conradie WJ, Saayman D (1989). Effects of long-term nitrogen, phosphorus, and potassium fertilization on Chenin blanc vines. II. Leaf analyses and grape composition. Am. J. Enol. Vitic. 40(2): 91-98.
Cserni I, Prohaska K (1987). The effect of N supply on the nitrate, sugar and carotene content of carrots. Acta Hort., 220: 303-307.
Curry JP (1987). The invertebrate fauna of grassland and its influence on productivity. 1. The composition of the fauna. Grass For. Sci., 42: 103-120.
Devi D, Agarwal SK (1998). Performance of sunflower hybrids as influenced by organic manure and fertilizer. J. Oilseeds Res., 15(2): 272-279.
Devi D, Agarwal SK, Dayal D (1998). Response of sunflower [*Helianthus annuus* (L.)] to organic manures and fertilizers. Indian J. Agron., 43(3): 469-473.
Dinauer R (ed) (1969). Physiological aspects of crop yield. American society of Agronomy. Madison, pp. 20-24.
Dixon RA (2001). Natural products and plant disease resistance. Nature, 411: 843-847.
Dixon RA, Paiva NL (1995). Stress-induced phenylpropanoid metabolism. Plant Cell, 7: 1085-1097.
Dominguez J, Edwards CA, Subler S (1997). A comparison of vermicomposting and composting. BioCycle, 38: 57-59.
Domininguez J, Edwards C (1997). A comparison of vermicomposting and composting. BioCycle 38(4): 57.
Duthie GG, Peter T. Gardner PT, Kyle JAM (2003). Plant polyphenols: are they the new magic bullet? Proc. Nutr. Soc., 62: 599-603.
Dutta AC (2005). Botany for degree students. Oxford. New Dehli, pp. 220-233.
Eckert DL, McLean EO (1981). Basic cation saturation ratios as a basis for fertilizing and liming agronomic crops. I. Growth chamber studies. Agron. J., 75: 795-799.
Edwards CA (1998). The use of earthworm in the breakdown and management of organic waste. In: Earthworm Ecology. ACA Press LLC, Boca Raton, FL, pp. 327-354.
Edwards CA (1998b). The Use of Earthworms in the Breakdown and Management of Organic Wastes. *In* Edwards CA (Ed.), Earthworm Ecology, CRC Press LLC, Florida, USA, pp. 327-354.
Edwards CA, Arancon N (2004). Vermicomposts suppress plant pests and disease attacks. BioCycle, 45(3): 51-54.
Edwards CA, Arancon NQ, Vasko-Bennet M, Askar A, Keeney G, Little B (2009). Suppression of green peach aphid *(Myzus persicae*) (Sulz.), citrus mealybug *(Planococcus citri)* (Risso), and two spotted spider mite *(Tetranychus urticae)* (Koch.) attacks on tomatoes and cucumbers by aqueous extracts from vermicomposts. Crop Prot., 30: 1-14.
Edwards CA, Burrows I (1988). The potential of earthworm composts as plant growth media. In: Edwards CA and Neuhauser E (Eds.). Earthworms in Waste and Environmental Management. SPB Academic Press. The Hague, The Netherlands, pp: 21-32.
Edwards CA, Domininguez J, Arancon Q (2004). The influence of vermicomposts on plant growth and pest incidence. Soil Zoology for Sustainable Development in the 21st Century. Shakir Hanna SH, Mikhail WZA, (eds), pp. 398-420.
Epstein E, Bloom AJ (2004). Mineral Nutrition of Plants: Principles and Perspectives, second ed. Sinauer Associates, Sunderland, MA, ISBN 0-87893-172-4.
Ervin E, Zhang X, Roberts J (2008). Improving root development with foliar humic acid applications during Kentucky bluegrass so establishment on sand. Acta Hort., 783: 317-322.
Evans JR, Terashima I (1988). Photosynthetic characteristics of spinarch leaves grown with different nitrogen treatments. Plant Cell Physiol., 29: 157-165.
Eyheraguibel B, Silvestre J, Morard P (2007). Effects of humic substances derived from organic waste enhancement on the growth and mineral nutrition of maize. Bio. Tech., 99(10): 4206-4212.
Fang Z, Mi F, Berkowitz GA (1995). Molecular and physiological analysis of a thykaloid K+ channel protein. Plant Physiol., 108: 1725-1734.
Fenn WO (1940). The role of potassium in physiological processes. Physiol. Rev., 20: 377-415.
Ferguson IB (1984). Calcium in plant senescence and fruit ripening. Plant Cell Environ., 7: 477-489.
Fernández-Luqueño F, Reyes-Varela V, Martínez-Suárez C, Salomón-Hernández G, Yáñez-Meneses J, Ceballos-Ramírez JM, Dendooven L (2010). Effect of different nitrogen sources on plant characteristics and yield of common bean (*Phaseolus vulgaris* L.). Biores. Technol., 101: 396-403.
Fischer ES, Bremner E (1993). Influence of Mg deficiency on rates of leaf expansion, starch and suchrose accumulation, net assimilation in *Phaseolus vulgaris*. Physiol. Plantar, 89: 271-276.
Follet RH, Murphy LS, Donahue RL (1981). Fertilizers and soil amendments. Prentice-Hall. Engelwood Cliffs, pp. 393-422.
Gajalakshmi S, Abbasi S (2002). Effect of the application of water hyacinth compost/vermicompost on the growth and flowering of *Crossandra undulaefolia,* and on several vegetables. Bioresour. Technol., 85: 197-199.
Givnish TJ (ed) (1986). On the economy of plant form and function. Proceedings of the sixth Maria Moors Cabot Symposium, "Evolutionary constraints on primary productivity: Adaptive patterns of energy capture in plants", Harvard Forest, 1983. Cambridge University Press. Cambridge.
Glenn GM, Reddy ASN, Poovaiah BW (1988). Effect of calcium on cell wall structure protein phosphorylation and protein profile in senescing apples. Plant Cell Physiol., 29: 565-572.
Golchin A, Nadi M, Mozaffari V (2006). The effects of vermicomposts produced from various organic solid wastes on growth of pistachio seedlings. Acta Hort., 726: 301-306.
Grusak MA, DellaPenna D (1999). Improving the nutrient composition of plants to enhance human nutrition and health. Plant Mol. Biol. 50: 133-161.
Guidi L, Lorefice G, Pardossi A, Malorgio F, Tognoni F, Soldatini GF (1998). Growth and photosynthesis of *Lycopersicon esculentum* (L.) plants as affected by nitrogen deficiency. Biol. Plant, 40: 235-244.
Gutiérrez-Miceli FA, Santiago-Borraz J, Molina JAM, Nafate CC, Abud-Archila M, Llaven MAO, Rincón-Rosales R, Dendooven L (2007). Vermicompost as a soil supplement to improve growth, yield and fruit quality of tomato (*Lycopersicum esculentum*). Bioresour. Technol., 98(15): 2781-2786.
Harris GD, Platt WL, Price BC (1990). Vermicomposting in a rural community. Biocycle, 10(2): 48-51.
Hattenschwiler S, Vitousek PM (2000). The role of polyphenols in terrestrial ecosystem nutrient cycling. Tr. Ecol. Evolution, 15: 238-243.
Haukoija E, Ossipov V, Lempa K (2002). The interactive effects of leaf maturation and phenolics on consumption and growth of a geometrid moth. Entomol. Exp. Appl., 104(1): 125-136.
Heber D (2004). Phytochemicals beyond antioxidation, J. Nutr. 134: 3175S–3176S.
Hoitink HAJ (1980). Composted bark, a lightweight growth medium with fungicidal properties. Plant Dis., 64: 142-147.
Hu FB (2003). Plant based foods and prevention of cardiovascular diseases: An overview. Am.J. Clin. Nutri., 78: 5445-5515.
Humble GD, Raschke K (1971). Stomatal opening quantitatively related to potassium transport. Plant Physiol., 48: 447-453.

Jadhav AD, Talashilkar SC, Pawar AG (1997). Influence of the conjunctive use of FYM, vermicompost and urea on growth and nutrient uptake in rice. J. Maharashtra Agric. Univ., 22(2): 249-250.
Jain V, Pal M, Lakkineni KC, Abrol YP (1999). Photosynthetic characteristics in two wheat genotypes as affected by nitrogen nutrition. Biol. Plant, 42: 217-222.
Juranić Z, Žižak Ž (2005). Biological activities of berries: From antioxidant capacity to anti-cancer effects. BioFactors, 23: 207-211.
Kähkönen MP, Hopia AI, Vuorela HJ, Rauha J, Pihlaja K, Kujala ST, Heinonen M (1999). Antioxidant activity of plant extracts containing phenolic compounds. J. Agric. Food Chem., 47: 3954 -3962.
Kale RD, Mallesh BC, Kubra B, Bagyaraj DJ (1992). Influence of vermicompost application on the available macronutrients and selected microbial populations in a paddy field. Soil Biol. Biochem., 24: 1317-1320.
Karmegam N, Alagermalai K, Daniel T (1999). Effect of vermicompost on the growth and yield of greengram (*Phaseolus aureus* Rob.). Trop. Agric., 76(2): 143-146.
Karmegam N, Daniel T (2000). Effect of biodigested slurry and vermicompost on the growth and yield of cowpea [*Vigna unguiculata* (L.)]. Environ. Ecol., 18(2): 367-370.
Kefeli VI, Kalevitch MV, Borsari B (2003). Phenolic cycle in plants and environment. J. Cell Mol. Biol., 2: 13-18.
Kiehl JC (2001). Produc¸a˜o de composto orgaˆnico e vermicomposto. Informe Agropecua´rio, Belo Horizonte, 22(212): 40-52.
Kumari MS, Ushakumari K (2002). Effect of vermicompost enriched with rock phosphate on the yield and uptake of nutrients in cowpea *(Vigna unguinculata* L. Walp). J. Trop. Agric., 40: 27-30.
Lambers H, Chapin FS, Pons TL (1998). Plant physiological ecology. Springer. New York, pp. 58-59.
Laskowski MJ, Williams ME, Nusbaum HC, Sussex IM (1995). Formation of lateral-root-meristems is a 2-stage process. Development, 121: 3303-3310.
Mader P, Fliebach A, Dubois D, Gunst L, Fried P, Niggli U (2002). Soil Fertility and biodiversity in organic farming. Sci., 296: 1694-2020.
Makoi JHJR, Ndakidemi PA (2007). Biological, ecological and agronomic significance of plant phenolic compounds in rhizosphere of the symbiotic legumes. Afr. J. Biotechnol., 6(12): 1358-1368.
Marschner H (1995). Mineral Nutrition of higher plants. Academic Press, San Diego.
Matson PA, Parton WJ, Power AJ, Swift MJ (1997). Agricultural intensification and ecosystem properties. Science, 277: 504-509.
Miller FJ Jr, Gutterman DD, Rios CD, Heistad DD, Davidson BL (1998). Superoxide production in vascular smooth muscle contributes to oxidative stress and impaired relaxation in atherosclerosis. Circ. Res., 82: 1298-1305.
Mordhorst AP, Lorz H (1993). Embryogenesis and development of isolated barley (*Hordeum vulgare* L.) microspores are influenced by the amount and composition of nitrogen sources in culture media. Plant Physiol., 142: 485-492.
Mozafar A (1993). Nitrogen fertilizers and the amount of vitamins in plants: A review. J. Plant Nutr., 16: 2479-2506.
Muscolo A, Bovalo F, Gionfriddo F, Nardi F (1999). Earthworm humic matter produces auxin-like effects on *Daucus carota* cell growth and nitrate metabolism. Soil Biol. Biochem., 31: 1303-1311.
Nagavallemma KP, Wani SP, Lacroix S, Padmaja VV, Vineela C, Babu Rao M, Sahrawat KL (2004). Vermicomposting: Recycling wastes into valuable organic fertilizer. Global Theme on Agrecosystems Report no. 8. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics, p. 20.
Ndakidemi PA, Dakora FD (2003). Legume seed flavonoids and nitrogenous metabolites as signals and protectants in early seedling development. Funct. Plant Biol., 30: 729 -745.
Ndakidemi PA, Semoka JMR (2006). Soil fertility survey in western Usambara Mountains, northern Tanzania. Pedosphere, 16(2): 237-244.
Nethra NN, Jayaprasad KV, Kale RD (1999). China aster [*Callistephus chinensis* (L)] cultivation using vermicompost as organic amendment. Crop Res. Hisar., 17(2): 209-215.
Novoa R, Loomis RS (1981). Nitrogen and plant production. Plant Soil, 58(1-3):177-204.
O'Donnell R (1972). The auxin-like effects of humic preparations from leonardite. Soil Sci., 116: 106-112.
Pant AP, Radovich TJK, Hue NV, Talcott ST, Krenek KA (2009). Vermicompost extracts influence growth, mineral nutrients, phytonutrients and antioxidant activity in pak choi (*Brassica rapa* cv. Bonsai, Chinensis group) grown under vermicompost and chemical fertilizer. J. Sci. Food Agric., 89: 2383-2392.
Paterson E (2003). Importance of rhizodeposition in the coupling of plant and microbial productivity. Eur. J. Soil Sci., 54(4): 741-750.
Patil SL, Sheelavantar MN (2000). Effect of moisture conservation practices, organic sources and nitrogen levels on yield, water use and root development of rabi sorghum [*Sorghum bicolor* (L.)] in the vertisols of semiarid tropics. Ann. Agric. Res., 21(21): 32-36.
Perner H, Schwarz D, George E (2006). Effect of mycorrhizal inoculation and compost supply on growth and nutrient uptake of young leek plants growth on peat-based substrates. Horti. Sci., 41: 628-632.
Postma J, Montanari M, van den Boogert PHJF (2003). Microbial enrichment to enhance disease suppressive activity of compost. Eur. J. Soil Biol., 39: 157-163.
Prasad R, Power JF (1997). Soil fertility management for sustainable agriculture. CRC Press, Boca Raton.
Premuzic Z, Bargiela M, Garcia A, Rendina A, Iorio A (1998). Calcium, iron, potassium, phosphorus and vitamin C content of organic and hydroponic tomatoes. Hort. Sci., 33: 255-257.
Pritam S, Garg VK, Kaushik CP (2010). Growth and yield response of marigold to potting media containing vermicompost produced from different wastes. Environmentalist, 30: 123-130.
Punjab State Council for Science and Technology (2010). Available online at: http://agri.and.nic.in/vermi_culture.htm. 23 October 2010.
Pushnik JC, Miller EW (1989). Iron regulation of chloroplast photosynthetic function: Mediation of PS I development. J. Plant Nutr., 12: 407-421.
Rao K (2002). Induced host plant resistance in the management of sucking insect pests of groundnut. Ann. Plant Protec. Sci. 10: 45-50.
Reddy R, Reddy MAN, Reddy YTN, Reddy NS, Anjanappa N, Reddy R (1998). Effect of organic and inorganic sources of NPK on growth and yield of pea [*Pisum sativum* (L)]. Legume Res., 21(1): 57-60.
Sainz MJ, Taboada-Castro MT, Vilariño A (1998). Growth, mineral nutrition and mycorrhizal colonization of red clover and cucumber plants grown in a soil amended with composted urban wastes. Plant Soil, 205: 85-92.
Sallaku G, Babaj I, Kaciu S, Balliu A (2009). The influence of vermicompost on plant growth characteristics of cucumber (*Cucumis sativus* L.) seedlings under saline conditions. J. Food Agric. Environ., 7(3-4): 869-872.
Sanchez-Conde M, Ortega C (1968). Effect of humc acid on development and the mineral nutrition of the pepper plant. Control de la ferilizacion de las plantas cultivadas, 2: 745-755.
Scott BJ, Robson AD (1990). Changes in the content and form of magnesium in the first trifoliate leaf subterranean clover under altered or constant root supply. Aust. J. Agric. Res., 41: 511-519.
Senesi N, Saiz-Jimenez C, Miano TM (1992). Spectroscopic characterization of metal-humic acid-like complexes of earthwormcomposted organic wastes. Sci. total Environ., 117/118: 111-120.
Senthilkumar S, Sriramachandrasekharan MV, Haripriya K (2004). Effect of vermicompost and fertilizer on the growth and yield of rose. J. Interacademicia, 8: 207-210.
Singh R, Sarma R, Satyendra K, Gupta R, Patil R (2008). Vermicompost substitution influences growth, physiological disorders, fruit yield and quality of strawberry *(Fragaria x ananassa (Duch.)*.Biorecour. Technol., 99: 8502-8511.
Subler S, Edwards CA, Metzger JD (1998). Comparing vermicomposts and composts. Biocycle, 39: 63-66.
Tan W, Hogan DG (1995). Limitation to net photosynthesis as affected by nitrogen status in jackpine (*Pinus banksiana* Lamb.) seedlings. J. Exp. Bot., 46: 407-413.
Tanaka A, Ito H, Tanaka R, Tanaka NK, Yoshida K, Okada K (1998). Chlorophyll *a* oxygenase (CAO) is involved in chlorophyll *b* formation from chlorophyll *a*. – Proc. Nat. Acad. Sci. USA, 95: 12719-12723.
Tejada M, Gonzalez J (2006). Effect of foliar application of beet vinasse

on maize yield. Biological Agric. Hort., 24: 197-214.
Tejada M, Gonzalez J, Hernandez M, Garcia C (2007). Agricultural use of leachates obtained from two different vermicomposting processes. Bioresour. Technol., 99(14): 6228-6232.
Tomati U, Grappelli A, Galli E (1987). The presence of growth regulators in earthworm-worked wastes. On Earthworms. Proceedings of International Symposioum on Earthworms. Selected Symposia and Monographs. Unione Zoologica Italiana, 2. Mucchi, Modena, pp. 423-435.
Tomati U, Grappelli A, Galli E (1988). The hormone-like effect of earthworm casts on plant growth. Biol. Fert. Soils, 5: 288-294.
Vadiraj BA, Siddagangaiah D, Potty SN (1998). Response of coriander (*Coriandrum sativum* L.) cultivars to graded levels of vermicompost. J. Spices Aromatic Crops, 7(2): 141-143.
Vance CP (2001). Symbiotic nitrogen fixation and phosphorus acquisition. Plant Nutrition in a world of declining renewable resources. Plant Physiol., 127: 390-397.
Vinken R, Schaeffer A, Ji R (2005). Abiotic association of soil-borne monomeric phenols with humic acids. Organic Geochem., 360: 583-593.
Wang SY, Lin S (2002). Compost as soil supplement enhanced plant growth and fruit quality of strawberry. J. Plant Nutr., 25: 1143-2259.
Welch RM (2002). The impact of mineral nutrients in food crops on global human health. Plant Soil, 247: 83-90.
Werner M, Cuevas R (1996). Vermiculture in Cuba. Biocycle, 37(6): 61-62.
Wittenmayer L, Merbach W (2005). Plant responses to drought and phosphorus deficiency: contribution of phytohormones in root-related processes.J. Plant Nutr. Soil Sci., 168(4): 531-540.
Zaller JG (2007). Vermicompost in seedling potting media can affect germination, biomass allocation, yields and fruit quality of three tomato varieties. Eur. J. Soil Biol., 43: 332-336.
Zhang FS, Yamasaki S, Nanzyo M (2002). Waste ashes for use in agricultural production I. Liming effect, contents of plant nutrients and chemical characteristics of some metals. Sci. Total Environ., 284:215-225.
Zhao X, Iwamoto T, Carey EE (2007). Antioxidant capacity of leafy vegetables as affected by high tunnel environment, fertilization and growth stage. J. Sci. Food Agric., 87:2692-2699.