Rev Environ Sci Biotechnol (2015) 14:137–159
DOI 10.1007/s11157-014-9347-1

REVIEW PAPER

Vermicompost as an effective organic fertilizer and biocontrol agent: effect on growth, yield and quality of plants

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Published online: 12 September 2014

Abstract In the present review, vermicompost is described as an excellent soil amendment and a biocontrol agent which make it the best organic fertilizer and more eco-friendly as compared to chemical fertilizers. Vermicompost is an ideal organic manure for better growth and yield of many plants. It can increase the production of crops and prevent them from harmful pests without polluting the environment. Application of vermicompost increased seed germination, stem height, number of leaves, leaf area, leaf dry weight, root length, root number, total yield, number of fruits/plant, chlorophyll content, pH of juice, TSS of juice, micro and macro nutrients, carbohydrate (%) and protein (%) content and improved the quality of the fruits and seeds. Studies suggested that treatments of humic acids, plant growth promoting bacteria and vermicomposts can be used for a sustainable agriculture discouraging the use of chemical fertilizers.

Keywords Vermicompost · Organic fertilizer · Humic acid · Biocontrol agent · Plant growth

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1 Introduction

In India, during the period of 1960s to 1980s, there was a remarkable increase in the agricultural production due to "Green revolution" (Gupta 1996). After green revolution, use of chemical fertilizers increased and India achieved self-sufficiency in agriculture. Use of chemical fertilizers resulted in pollution of soil, water and air. There have been adverse effects on the health of human beings and cattle due to the residues of these agrochemicals in food products (Kumar and Bohra 2006). Harmful effects of chemical fertilizers and pesticides have shifted the interests of researchers towards organic amendments like vermicompost which can increase the production of crops and prevent them from harmful pests without polluting the environment. Vermicompost is not only valuable compost and a biocontrol agent but also an effective way of solid waste management. In terms of improving soil health, vermicomposting is better than other ways of managing solid wastes like traditional composting and landfilling. Landfilling is expensive (Ahlberg et al. 2006) and may lead to leaching of toxic compounds (Senesi et al. 2007). Vermicompost is a finely-divided mature peat-like material which is produced by a non-thermophilic process involving interactions between earthworms and microorganisms (Edwards and Burrows 1988) leading to bioxidation and stabilization of organic material (Aira et al. 2000). Various reports suggested the presence of humic substances in vermicompost. Presence of humic acid fraction in an organic amendment makes it agronomically efficient and ecofriendly (Senesi et al. 2007). Patriquin et al. (1995) supported that organically grown plants being more resistant to pathogens and pests. Soil amendments which can manipulate physicochemical and microbiological environment of soil can be helpful for the suppression of soil borne pathogens (Funk-Jensen and Lumsden 1999; Sahni et al. 2008). As vermicompost is rich in microbial activity and contains antagonistic organisms to control plant pathogens, therefore it is an effective biocontrol agent.

In the present review, vermicompost has been described as an excellent soil amendment and a biocontrol agent through a number of studies along with the reasons which make it the best organic fertilizer and more eco-friendly as compared to chemical fertilizers.

2 Vermicomposting process

Vermicomposting is a non-thermophilic process (Edwards and Burrows 1988) which involves a joint action of earthworms and mesophilic microorganisms (Aira et al. 2000) for the conversion of organic wastes into a valuable end product called vermicompost. India, where a lot of solid organic waste is available in different sectors with no dearth of manpower, the environmentally acceptable vermicomposting technology using earthworms can very well be adopted for converting waste into wealth. Different types of wastes have been treated through a vermitechnology process like dyeing sludge (Bhat et al. 2013), paper mill sludge (Kaur et al. 2010), tannery sludge (Vig et al. 2011), soft drink industry waste (Singh and Kaur 2013), beverage sludge (Singh et al. 2010) etc. Vermiwash is a liquid fertilizer and used as a foliar spray produced by passing water through columns of vermiculture beds (Ismail 1997).

3 Microbiota in vermicompost

A number of bacteria of different species have been reported by different workers in vermicomposts produced by different species of earthworm (Table 1) like *Pseudomonas oxalaticus* (Khambata and Bhat 1953; Pathma and Sakthivel 2012) in *Pherentima* sp., *Rhizobium japonicum* and *Pseudomonas putida* (Madesen and Alexander 1982; Pathma and Sakthivel 2012) in *Lumbricus rubellus*, *Azospirillum*, *Azobacter*, *Nitrobacters*, *Nitrosomonas*, *Ammonifying bacteria and phosphate solubilizers* (Gopal et al. 2009; Pathma and Sakthivel 2012) in *Eudrilus* sp.

4 Vermicompost an ideal organic amendment for plant growth

Vermicompost is ideal organic manure for better growth and yield of many plants due to following reasons:

- Vermicompost has higher nutritional value than traditional composts. This is due to increased rate of mineralization and degree of humification by the action of earthworms (Albanell et al. 1988).
- Vermicompost has high porosity, aeration, drainage, and water-holding capacity (Edwards and Burrows 1988)
- Presence of microbiota particularly fungi, bacteria and actinomycetes makes it suitable for plant growth (Tomati et al. 1987).
- Nutrients such as nitrates, phosphates, and exchangeable calcium and soluble potassium in plant-available forms are present in vermicompost (Orozco et al. 1996).
- Plant growth regulators and other plant growth influencing materials produced by microorganisms are also present in vermicompost (Tomati et al. 1988; Grappelli et al. 1987). Production of cytokinins and auxins was found in organic wastes that were processed by earthworms (Krishnamoorthy and Vajrabhiah 1986)
- Earthworms release certain metabolites, such as vitamin B, vitamin D and similar substances into the soil (Nielson 1965).
- In addition to increased N availability, C, P, K, Ca and Mg availability in the casts are found (Orozco et al. 1996).

5 Comparison of vermicompost with farmyard manure, chemical fertilizers and biofertilizers

Any material added to the soil to increase its fertility is known as fertilizer. Population of the world is

Table 1 Different types of bacteria in different species of earthworms

Vermicompost earthworm	Names of bacteria	Beneficial traits	References
Eudrilus sp.	Free-living N2 fixers *Azospirillum*, *Azotobacrer*, Autotrophic *Nitrosomonas*, *Nitrobacter*, *Ammonyfying bacteria*, Phosphate solubilizers, Fluorescent pseudomonas	Plant growth promotion by nitrification, phosphate Solubilization and plant disease suppression	Gopal et al. (2009)
Eisenia fetida	Proteibacteria, Bacteroidetes, Verrucomicrobia, Actinobacteria, Firmicutes	Antifungal activity against *Colletotrichum coccodes*, *R. solani*, *P. ultimum*, *P. capsici* and *Fusarium moniliforme*	Yasir et al. (2009a)
Lumbricus terrestris	Florescent pseudomonas, Filamentous actinomycetes	Suppress *Fusarium oxysporum f.* sp. *asparagi* and *Fusarium proliferatum* in asparagus, *Verticillium dahliae* in eggplant and *Fusarium. oxysporum f.* sp. *Lycopersici* Race 1 in tomato	Elmer (2009)
Unspecified	*Eiseniicola composti* YC06271	Antagonistic activity against *F. moniliforme*	Yasir et al. (2009b)
E. fetida	*Bacillus spp. Bacillus. megaterium*, *Bacillus pumillus*, *Bacillus subtilis*	Antimicrobial activity against *Enterococcus faecalis* DSM 2570, *Staphylococcus aureus* DSM 1104	Vaz-Moreira et al. (2008)
Aporrectodea trapezoides *Aporrectodea rosea*	*Pseudomonas corrugata* 214OR	Suppress *Gaeumannomyces graminis* var. *Tritd* in wheat	Doube et al. (1994)
A. trapezoides *Microscolex dubius*	*Rhizobium meliloti* L5-30R	Increased root nodulation and nitrogen fixation in legumes	Stephens et al. (1994)
L. terrestris	*Brodyrhizobium japonicum*	Improved distribution of nodules on soyabean roots	Rouelle (1983)
Unspecified	*Rhizobium trifolii*	Nitrogen fixation and growth of leguminous plants	Buckalew et al. (1982)
Lumbricus rubellus	*Rhizobium japonicum*, *Pseudomonas putida*	Plant growth promotion	Madsen and Alexander (1982)
Pheretima sp.	*Pseudomonas oxalaticus*	Oxalate degradation	Khambata and Bhat (1953)

Source: Pathma and Sakthivel (2012)

increasing day by day and inorganic fertilizers are playing an important role to support this increasing population. About 50 % of world population is being fed by the use of synthetic fertilizers (Erisman et al. 2008). Inorganic fertilizers can be further classified as Nitrogenous fertilizers, Phosphatic fertilizers, Potassic fertilizers, Complex fertilizers and Mixed fertilizers (Kaleem 1996). Uma and Malathi (2009) found that plants of *Amaranthus* sp. in plots receiving vermicompost had higher values of growth, yield and quality parameters as compared to plants in plots receiving chemical fertilizers. Suthar (2009) reported that garlic (*Allium sativum*) plants with vermicompost treatment (at 20 t/ha) had higher values of various growth and yield parameters as compared to values of these parameters in chemical fertilizer treatment. The effect of vermicompost and other fertilizers on growth, yield and nutritional status of tomato was studied by Meenakumari and Shehkar (2012). A total of six treatments i.e. chemical fertilizers alone, farm yard manure alone, vermicompost alone, farm yard manure supplemented with chemical fertilizers, vermicompost supplemented with chemical fertilizers and soil (control) were given. Although vermicompost application showed better results than chemical fertilizers treatment but vermicompost supplemented with chemical fertilizers gave best results. The efficiency of three types of vermicomposts prepared from paper waste, cattle manure and food waste on tomato (*Lycopersicum esculentum*), strawberry (*Fragaria* × *ananassa*) and field pepper (*Capsicum*) were studied by Arancon et al. (2003a, 2004, 2005a). It was found that there was a significant increase in growth and yield parameters like leaf area, plant shoot biomass, number of flowers, number of plant runners and marketable fruits weight by the applications of vermicomposts as compared to inorganic fertilizers. Authors speculated that growth responses were due to the ability of humic acids present in vermicompost to act as plant growth regulators or because the humates may have absorbed hormonal plant growth regulators.

Joshi et al. (2013) studied the effect of vermicompost on growth, yield and quality of wheat and compared it with application of chemical fertilizers. Soil was used as control while three treatments of cattle manure vermicompost i.e. 5, 10 and 20 t/ha and a treatment of chemical fertilizers was given. All the growth, yield and quality parameters increased significantly from control in all the treatments. Higher doses of vermicompost did not vary significantly from lowest dose. Most of the growth, yield and quality parameters had greatest values in treatment with recommended dose of chemical fertilizer. Hence, chemical fertilizers proved to be better than vermicompost in terms of growth, yield and quality in this study.

The growth and yield of garlic (*Allium sativum*) on application of vermicompost and farm yard manure was studied by Suthar (2009). Content of various nutrients like N, P, K, Ca, Cu, Fe and Zn were analyzed for both vermicompost and farm yard manure. Vermicompost was found to have a higher nutrient content as shown in Table 2. Different doses of vermicompost, compost and chemical fertilizers were applied alone and in combinations. It was found that there was excellent plant growth as well as yield in garlic (*Allium stivum*) plants that received vermicompost as main nutrient supplier. Experimental plots with vermicompost at 15 t/ha mixed with 50 % NPK showed 0.6 % higher leaf length, 31.4 % higher shoot length and 28.3 % higher average fruit weight when compared with plots with farm yard manure at 15 t/ha mixed with 100 % NPK. Plots with recommended dose of NPK fertilizers had 28.7 % lower leaf length, 2.5 % lower shoot length, 74.6 % lower root length and 20.1 % lower total plant biomass when compared to plots with vermicompost at 15 t/ha mixed with 50 % NPK. So, vermicompost proved to be better than Farm Yard Manure while combined treatment of vermicompost and chemical fertilizers proved to be best.

Table 2 Comparison of nutrient contents of vermicompost and farm yard manure

Parameters	Vermicompost	Farmyard manure
pH	7.82 ± 0.04	7.81 ± 0.01
TotC (g/kg)	286.5 ± 1.67	266.3 ± 0.51
TotN (g/kg)	23.1 ± 1.0	14.4 ± 0.31
AvailP (g/kg)	9.85 ± 0.10	6.59 ± 0.03
Organic matter (g/kg)	495.5 ± 2.7	461.2 ± 1.31
ExchC/N ratio	12.3 ± 0.13	18.5 ± 0.13
ExchK (g/kg)	15.2 ± 0.19	8.87 ± 0.05
ExchCa (g/kg)	23.8 ± 2.91	15.7 ± 1.31
ExchMg (g/kg)	6.74 ± 0.10	2.59 ± 0.06
ExchNa (g/kg)	6.03 ± 0.06	5.70 ± 0.01
ExchCu (g/kg)	0.97 ± 0.04	0.77 ± 0.01
ExtFe (g/kg)	8.68 ± 0.14	5.59 ± 0.121
ExtMn (g/kg)	13.6 ± 0.18	7.72 ± 0.12
ExtZn (g/kg)	16.9 ± 0.17	8.31 ± 0.10

Source: Suthar (2009)

Singh and Chauhan (2009) applied vermicompost, FYM and chemical fertilizers alone as well as in combination to study their effect on growth and yield of French bean (*Phaseolus vulgaris*) under irrigated conditions. Germination, height of plant, number of leaves per plant, length of leaves, width of leaves, number of pods per plant, length of root, number of nodules, above ground dry mass of plant, below ground dry mass of plant, yield per plot and number of seeds per pod were the parameters to be compared on application of different treatments of these fertilizers. Authors concluded that French bean (*Phaseolus vulgaris*) was most responsive to vermicompost treatment on growth and yield in comparison to farmyard manure, chemical fertilizers and mixed treatments under irrigated conditions. Highest growth and yield in vermicompost treatments was attributed to improvement of physico-chemical properties of soil on vermicompost application. In this study, vermicompost proved to be better not only than farmyard manure but also than chemical fertilizers.

In another study by Thankamani et al. (1996), effect of different organic manures i.e. vermicompost, farmyard manure, saw dust, forest leaf and coir dust compost was studied on clove (*Syzygium aromaticum*) seedlings and black pepper (*Capsicum*) cuttings under nursery conditions. In this study, vermicompost proved to be the best propagating medium for growth characteristics like height, number of branches, length of tap root and dry weight of root of clove (*Syzygium aromaticum*) seedlings and also for growth characteristics i.e. height and number of leaves of black pepper (*Capsicum*) cuttings. Vermicompost proved to be better than farmyard manure in terms of improving soil physico-chemical properties, growth and productivity of plants because of its higher nutrient content than farm yard manure.

In case of Biofertilizers, one or more specific species of micro-organisms are inoculated while vermicompost has a variety of useful micro-organisms already present in it apart from micro and macro nutrients. So, vermicompost is better than biofertilizers in terms of composition. Darzi et al. (2012) studied the effects of application of vermicompost and solubilizing bacterium on the morphological traits and seed yield of anise (*Pimpinella anisum*). Vermicompost was applied as three treatments i.e. 0, 5 and 10 t/ha. Phosphate solubilizing bacterium was applied as three treatments i.e. non-inoculated, seed inoculated and seed inoculated plus spraying on the plant base at stem elongation zone. Plant height, umbel number per plant, biological yield, seed yield and weight of 1000 seeds were recorded for different treatments. Maximum plant height (50.1 cm), umbel number per plant (33.2), biological yield (9,797.2 kg/ha) and seed yield (2,973.2 kg/ha) were recorded in the treatment of vermicompost applied at the rate of 10 t/ha. However, maximum weight of 1,000 seeds (2.21 g) was recorded in the treatment of phosphate solubilizing bacterium applied as seed inoculated with spraying on the plant base at stem elongation zone. Javed and Panwar (2013) studied the effects of vermicompost, bofertilizer and chemical fertilizer alone and in different concentrations on different biochemical parameters of *Glycine max* and *Vigna mungo*. Percentage seed germination, total carbohydrate content, total protein contents and total phenol contents of both crops were recorded in different treatments. Although best results were obtained in the combined treatment of chemical fertilizer, vermicompost and biofertilizer, yet if we compare vermicompost alone with biofertlizer alone and chemical fertilizer alone in this study, we find that seed germination of urad (*Vigna mungo*) was better in vermicompost treatment while seed germination of soybean (*Glycine max*) was better in biofertilizer treatment. Seed germination percentage of both urad (*Vigna mungo*) and soybean (*Glycine max*) was lowest in treatment with chemical fertilizers only. Total protein content of both the crops was more in vermicompost alone as compared to biofertilizers alone. Protein content of urad in treatment with chemical fertilizers alone was greater than the treatments with vermicompost alone and biofertilizers alone. Carbohydrate content of soybean (*Glycine max*) was more in vermicompost alone as compared to treatment with biofertilizers alone while carbohydrate content of urad (*Vigna mungo*) was more in biofertilizer alone as compared to vermicompost alone. Carbohydrate content of urad in treatment with chemical fertilizers alone was greater than the treatments with vermicompost alone and biofertilizers alone. Total phenol content of soybean (*Glycine max*) was better in vermicompost alone than biofertilizers alone while total phenol content of urad (*Vigna mungo*) was more in biofertilizer alone than vermicompost alone. Total phenol content of urad in treatment with chemical fertilizers alone was lower than the treatments with vermicompost alone and biofertilizers alone. Overall, vermicompost had a slightly upper hand over biofertilizer. Vermicompost proved to better than chemical fertilizers in terms of seed germination percentage and total phenol content only.

A 3 year field trial on seven varieties of mustard (*Brassica*) was conducted by Banerjee et al. (2012) to find the effect of different types of fertilizers and plant growth regulator cycocel. During the first year, only chemical fertilizers in recommended doses were applied to all the varieties of mustard (*Brassica*). During second year, two experiments were conducted. In the First experiment, plots without any fertilizer treatment were used as control. One treatment of recommended dose of chemical fertilizers, and four other treatments of mixtures of chemical and biofertilizers in different ratios were given. In second experiment, five treatments of growth regulator cycocel in different doses were given while plots without hormone treatment were used as control. During third year, five treatments of chemical fertilizers, compost, biofertilizers and growth regulator cycocel mixed in different ratios were given and plots without any compost were used as control. Different morpho-physiological traits like leaf area index, leaf area duration, leaf area ratio, crop growth rate, net assimilation rate and harvest index were recorded to compare these parameters in different treatments. It was found that combined treatment of chemical fertilizer, biofertilizer, and compost along with growth regulator enhanced the various morpho-physiological traits significantly attributing to lesser use of chemical fertilizers and thereby lesser environmental pollution.

Bhattacharya et al. (2012) studied the effect of vermicomposted flyash in combination with chemical fertilizers on the yield of potato (*Solanum tuberosum*) and soil characteristics after the cultivation of potatoes (*Solanum tuberosum*) in a 2 years field trial. Recommended dose of NPK fertilizers (100 %) was given as control. Three treatments of mixtures of vermicompost and NPK fertilizers were given while one treatment of combination of farm yard manure and Vermicompost (100 %) was applied. Combination of vermicompost and NPK fertilizers (100 %) produced maximum yield. Application of vermicompost increased the nutrient availability of soils and also reduced the solubility of heavy metals (Pb, Cr and Cd). So, application of chemical fertilizers in combination with vermicompost proved to be beneficial for soil fertility and increase in crop yield. It also proved to be eco-friendly by reducing the toxicity of heavy metals. Jeyabal and Kuppuswamy (2001) studied the effect of vermicompost on rice-legume cropping system in both pot and field studies. In pot study, one treatment of chemical fertilizer and 9 treatments of combinations of vermicompost, biofertilizers, biodigested slurry and farm yard manure were given on equal N basis. In field study, one treatment of chemical fertilizer and 6 treatments of different combinations of biodigested slurry, farm yard manure, vermicompost and chemical fertilizers on equal N basis were given. In both studies, it was found that the combined use of vermicompost, chemical fertilizers and biofertilizers lead to higher yields.

Lazcano et al. (2013) compared the effects of inorganic fertilizers and integrated fertilizer regime in which 25 % of nutrients were supplied either by rabbit manure or vermicompost on microbiota and biochemical properties of the soil. Microbiota and biochemical properties of the soil after harvesting the sweet corn (*Zea mays*) grown by applying inorganic fertilizers and integrated fertilizer regimes including compost and vermicompost were analyzed. It was found that application of integrated fertilizer regimes lead to higher microbial biomass and better biochemical properties of soil. Singh et al. (2013) studied the effect of vermicompost obtained from biodegraded distillation waste on the soil properties and essential oil yield of *Pogostemon cablin* (patchouli). In a field trial, five treatments viz. control, bioinoculants enriched vermicompost, bioinoculants enriched compost, vermicompost and recommended dose of chemical fertilizers were given to patchouli plants. In the treatment with bioinoculants enriched vermicompost, oil yield was higher than all the other four treatments. Application of bioinoculants enriched vermicompost also reduced the percentage disease index of the plants. Its application also improved physical and chemical properties of the soil. Hence, in this study, bioinoculated vermicompost obtained from distillation waste proved to be better than chemical fertilizer.

6 Effect of chemical fertilizers in combination with fertilizers other than vermicompost

The effect of applying biofertilizer made from rocks with Acidithiobacillus in combination with diazotrophic bacteria and mycorrhizal fungi on shoot biomass, nodule biomass and grain yield of cowpea (*Vigna unguiculata*) was evaluated by Andrade et al. (2013). Effect of application was investigated for uptake of nutrients and also for soil fertility. Results revealed that application of mixed biofertlizers produced highest grain yield and shoot biomass and also improved soil fertility and uptake of the nutrients by cowpea (*Vigna unguiculata*) plants. Therefore, this study suggested that mixed biofertlizer application can reduce the use of chemical fertilizers in the field and can help in promoting a sustainable agriculture. Impact of mixed application of chemical fertilizers, bio-fertilizers and compost was assessed by Datta et al. (2009) on growth, yield, biochemical and physiological parameters of *Brassica compestris* in field. This study revealed that combined application of chemical fertilizers with biofertilizers and compost can be effective in production of *B. compestris* with a good growth and yield.

Akbari et al. (2011) investigated the effect of treatment of biofertilizers, chemical fertilizer and farmyard manure combined in different proportions on grain yield and quality parameters of sunflower (*Helianthus annuus*). It was found that applying Nitrogen (chemical fertilizer) mixed with farmyard manure and biofertilizers gives better results as compared to application of these fertilizers alone (without any combination with other fertilizer). Parameters like seed protein, grain yield and biological yield were recorded to have higher values on applying these fertilizers as mixtures. It was concluded that application of 50 % N mixed with 50 % farmyard manure and biofertilizers is the most appropriate treatment for growing sunflower crop. Ghaderi-Daneshmand et al. (2012) studied the effect of chemical and biofertilizers (Nitroxin and Biophosphorous) alone as well areas in combination on biological yield, grain weight, number of spikes per square meter, number of grains per spike and harvest Index of wheat crop. Highest values of various traits were recorded in plots receiving combined application of chemical and biofertilizers. It was concluded that applying chemical and biofertilizers in combination can provide us maximum yield and hence, can reduce the adverse effects of chemical fertilizers on environment. In a similar study, Dadkhah (2012) reported that mixed treatment of chemical and biofertilizers had a positive effect on various growth and yield parameters of fennel (*Foeniculum vulgare*) and this mixed treatment can be used as a substitute of using chemical fertilizers alone.

7 Effect of vermicompost on plant growth and yield parameters

Vermicompost improves the growth, yield and quality of plants. A list of various parameters of plants enhanced by vermicompost application is summarized in Table 3.

7.1 Effect on seedling

Vermicompost stimulates the emergence of plants because of the presence of major nutrients and other essential nutrients like P and K (Fernández-Luqueño et al. 2010). Higher germination rate (%) of greenhouse tomato (*Lycopersicum esculentum*) seedlings was observed in Metro-Mix360 (a soil-less nutrient medium) substituted with 40 % vermicompost as compared to metro-mix 360 alone (control) and MM360 substituted with other concentrations of vermicompost (0–100 %) (Atiyeh et al. 2000a). Relative growth rate of cucumber (*Cucumis sativus*) seedlings was found to be significantly higher in vermicompost as compared to commercial peat compost (Sallaku et al. 2009). Vermicompost improves soil structure due to organic matter present in it (Ferreras et al. 2006; Fernández-Luqueño et al. 2010).

7.2 Effect on plant

Growth and development of plants is due to the presence of humic acids (Arancon et al. 2005a) and micro and macronutrients (Atiyeh et al. 2002; Fernández-Luqueño et al. 2010) in vermicompost. The maximum increase in plant height of *Matricaria chamomilla* was observed when vermicompost was applied at the rate of 20 t/ha (Hadi et al. 2011). Plant height of maize (*Zea mays*) plant increased significantly as compared to control when grown in peat moss amended with vermicompost supplemented with different concentrations of mycorrhizas (*Glomus fasciculatum* and *Glomus claroideum*) and diazotrophic bacteria (Gutiérrez-Miceli et al. 2008). Highest plant height of potato (*Solanum tuberosum*) was observed when vermicompost mixed with 100 % NPKS (chemical fertilizers) was applied to the soil (Alam et al. 2007). Vermicompost prepared from perithecium weed increased plant height of *Abelmoschus esculentus* as compared to control (sole soil) and soil amended with recommended dose of chemical fertilizers (Vijaya and Seethalakshmi 2011). There was an increase in plant height of Crossandra (*Crossandra undulaefolia*) in pots treated with water hyacinth vermicompost as compared to the control pots and pots treated with water hyacinth compost (Gajalakshmi and Abbasi 2002). Vermicompost application at 6 t/ha improved the plant height of eggplant (*Solanum melongena*) as compared to control (without vermicompost) (Moraditochaee et al. 2011).

Peyvast et al. (2008) applied vermicompost prepared from cattle dung in greenhouse as four different treatments i.e. 0, 10, 20 and 30 % to investigate its effect on spinach (*Spinacia oleracea*) Treatment with 0 % vermicontrol served as control. Highest plant height (14.56 cm) was observed in treatment with 10 % vermicompost while lowest plant height was observed in control (13.70 cm). Plant heights of 14.30 and 14.16 cm were recorded in treatments with 20 and

Table 3 List of parameters of various plants enhanced by vermicompost application

S. no	Crops	Parameters enhanced	References
1	Lilies (*Lilium*)	Plant height, chlorophyll content	Mirakalaei et al. (2013)
		Stem weight, root weight, root length	
2	*Setaria* grass	Root volume, Mg, Ca and K content	Sabrina et al. (2013)
3	Urad (*Vigna mungo*)	Germination percentage (urad), Phenol content of leaves	Javed and Panwar (2013)
	and soybean (*Glycine max*)		
4	*Pogostemon cablin*	Oil yield	Singh et al. (2013)
5	Wheat (*Triticum aestivum*)	Mean plant height mean stem diameter, number of leaves per plant, number of spikes/plant, spike length/plant, number of spikelets/spikes per plant, yield/acre, protein content, fat content, carbohydrate content, dietary fibers content, ash content	Joshi et al. (2013)
		Moisture content	
6	Potato (*Solanum tuberosum*)	Net yield	Bhattacharya et al. (2012)
7	Mustard (*Brassica*)	Leaf area, leaf area ratio, Crop growth rate, net assimilation, harvest index	Banerjee et al. (2012)
8	Anise (*Pimpinella anisum*)	Plant height, umbel number per plant, biological yield, seed yield, 1,000 seed weight	Darzi et al. (2012)
9	Tomato (*Lycopersicum esculentum*)	Fresh weight of leaves, dry weight of leaves, dry weight of fruits, number of branches	Meenakumari and Shehkar (2012)
10	Marigold (*Tagetes*)	Plant weight, plant dry weight, P content, flower yield, number of flowers	Paul and Bhattacharaya (2012)
11	Lettuce (*Lactuca sativa*)	Number of leaves, leaf fresh weight, leaf dry weight, chlorophyll content and yield	Papathanasiou et al. (2012)
12	*Lilium*	Number of leaves, leaf dry biomass, stem diameter, stem weight, root length, root number, stem height, Fe content, Ca content, Zn content, K content flowering time, number of flowers	Moghadam et al. (2012)
13	Marigold plant (*Tagetes*)	Ca content, K content, size of flower	Shadanpour et al. (2011)
14	Geranium (*Pelargonium species*)	Plant weight, Cu content, Mn content, Fe content, Zn content, K content, N content, oil yield	Chand et al. (2011)
15	Pea (*Pisum sativum*)	Number of leaves, root weight, root length	Khan and Ishaq (2011)
16	French bean (*Phaseolus vulgaris*)	Number of branches, shoot length	Singh et al. (2011)
17	*Chrysanthemum morifolium*	Plant height, plant spread, number of branches, flower stalk length, flower diameter flower yield, number of flowers/plant	Verma et al. (2011)
18	*Abelmoschus esculentus*	Plant height, carbohydrate (%) content, protein (%) content, fruits/plant, total yield	Vijaya and Seethalakshmi (2011)
19	Eggplant(*Solanum melongena*)	Plant height, fruit yield, fruit length, number of fruits/plant	Moraditochaee et al. (2011)
20	*Matricaria chamomilla*	Plant height, oil yield, flower head diameter, fresh and dry flower yield, number of flowers/plant	Hadi et al. (2011)
21	Okra (*Abelmoschus esculentus*)	Number of leaves, stem circumference, fat content, protein (%) content, marketable yield	Ansari and Kumar Sukhraj (2010)

Table 3 continued

S. no	Crops	Parameters enhanced	References
22	Groundnut (*Arachis hypogaea*)	Number of leaves, leaf area, plant weight, plant dry weight, root length, shoot length, N content, Mg content, Ca content, K content, P content, no. of seeds/plant	Mycin et al. (2010)
23	French bean (*Phaseolus vulgaris*)	Germination, height of plant, number of leaves per plant, length of leaves, width of leaves, number of pods per plant, length of root, number of nodules, above ground dry plant biomass, below ground dry plant biomass, yield per plot, number of seeds per pod	Singh and Chauhan (2009)
24	Cucumber (*Cucumis sativus*)	Seedling growth rate	Sallaku et al. (2009)
25	Garlic (*Allium sativum*)	Plant dry weight, root length, shoot length, number of cloves/fruit, leaf length	Suthar (2009)
26	Tomato (*Lycopersicum esculentum*)	Number of leaves, plant weight	Lazcano et al. (2009)
27	*Amaranthus* sp.	Number of leaves, average leaf length, plant height, number of branches, root length, shoot length, chlorophyll *a* and *b* content, average number of flowers, carotenoid content, sugar content, K content, N content, P content, yield	Uma and Malathi (2009)
28	Cucumber (*Cucumis sativus*)	Number of leaves, leaf dry weight, chlorophyll content, stem height, pH of juice, TSS of juice, total yield, Number of fruits/plant	Azarmi et al. (2009)
29	Pak choi (*Brassica rapa*)	Number of leaves, leaf area, plant height, stem weight, plant weigh, Cu content, Mn content, Fe content, Zn content, B content	Pant et al. (2009)
30	Maize (*Zea mays*)	Number of leaves, plant height, stem diameter, root volume, Mycorrhizal colonization, P content in leaves	Gutiérrez-Miceli et al. (2008)
31	Spinach (*Spinacia oleracea*)	Plant height, Leaf size, N content, TSS of fruit, Leaf fresh weight, Leaf dry weight	Peyvast et al. (2008)
32	Strawberry (*Fragaria × ananassa*)	Plant spread, plant dry weight, leaf area, ascorbic acid content, pH of fruit, TSS of fruit, total yield, number of fruits/plant	Singh et al. (2008)
33	*Andrographis paniculata*	Shoot length, protein (%) content Chlorophyll *a* and *b*	Vijaya et al. (2008)
34	*Sorghum*	Mycorrhizal colonization	Hameeda et al. (2007)
35	Lettuce (*Lactuca sativa*)	Plant weight, plant dry weight	Ali et al. (2007)
36	Potato (*Solanum tuberosum*)	Plant height, yield	Alam et al. (2007)
37	Peppers (*Capsicum*)	Leaf areas, plant shoot biomass, marketable fruit yield	Arancon et al. (2005a)
38	Sorghum (*Sorghum bicolor*)	Number of leaves, leaf area Plant height, root length	Reddy and Ohkura (2004)
39	Strawberry (*Fragaria × ananassa*)	Leaf area, plant shoot, biomass Number of flowers, number of plant runners, marketable fruits weight	Arancon et al. (2004)
40	Tomato (*Lycopersicum esculentum*), pepper (*Capsicum*) and strawberry (*Fragaria × ananassa*)	Dry shoot weight, marketable yields	Arancon et al. (2003a, b)

Table 3 continued

S. no	Crops	Parameters enhanced	References
41	*Crossandra undulaefolia*	Number of leaves, plant height Number of flowers/plant, root length, shoot/root ratio, harvest index, length of inflorescence	Gajalakshmi and Abbasi (2002)
42	Tomato (*Lycopersicum esculentum*)	Marketable yield, higher seedling height, germination rate (%)	Atiyeh et al. (2000a, b)
43	Clove (*Syzygium aromaticum*) and black pepper (*Piper nigrum*)	Plant height, number of branches Length of tap root, dry weight of roots	Thankamani et al. (1996)

30 % vermicompost respectively. Although all the treatments with vermicompost increased plant height significantly as compared to control, no significant difference was observed between three vermicompost treatments. Application of vermicompost in combination with *Azospirillum*, Phosphate solubilising bacteria and 50 % recommended dose of chemical fertilizers increased the plant height, plant spread, number of branches of *Chrysanthemum morifolium* plant as compared to other treatments consisting of combinations of *Azospirillum*, phosphate solubilizing bacteria, farm yard manure, vermicompost and recommended dose of chemical fertilizers in different ratios (Verma et al. 2011). Average plant height of *Amaranthus* species increased when vermicompost was applied. The average plant height and number of branches had a higher value than control and treatment with chemical fertilizers application after 30 days of germination (Uma and Malathi 2009). Ansari and Kumar Sukhraj (2010) compared the effects of vermicompost, cattle dung, vermiwash, vermicompost and vermiwash in combination and chemical fertilizers on okra (*Abelmoschus esculentus*) in a pot study. Pots with sole soil were used as control. Plant height was found to be maximum (45.83 cm) in combined treatment of vermicompost and vermiwash. It was found to be 36.00, 44.33, 42.33 and 39.33 cm in treatments with cattle dung, chemical fertilizers, vermiwash and vermicompost respectively. Plant height in all the treatments was higher than control (31.67 cm). Hence, combined application of vermicompost and vermiwash proved to be most effective for growth of okra.

A mixture of 75 % vermicompost produced by *Perionyx excavatus* and 25 % soil increased plant height of sorghum when compared to control, soil amended with normal compost and soil amended with different concentrations of vermicompost produced by two other species viz. *Octonochaeta rosea* and *Octochaetona phillotti*. It was even higher than the plant height in soil amended with chemical fertilizers (urea and superphosphate) (Reddy and Ohkura 2004). Non-aerated vermicompost tea application increased plant height of pak choi (*Brassica rapa*) as compared to control, aerated vermicompost tea and vermicompost tea with microbial enhancer (Pant et al. 2009). Plant height of pea (*Pisum sativum*) was found to be greater in vermicompost as compared to soil and pit compost (Khan and Ishaq 2011). Plant height of lilies (*Lilium longiflorum*) was greater in vermicompost treatment as compared to control and treatments of bagasses compost and fish fertilizer (Mirakalaei et al. 2013).

Singh et al. (2011) reported that Combined treatment of vermicompost at the rate of 3.75 t/ha with 25 % rate of NPK fertilizers lead to an increase in number of primary branches of french bean (*Phaseolus vulgaris*). Maximum enhancement in plant fresh weight and dry weight of groundnut (*Arachis hypogaea*) was recorded by the application of vermicompost at the rate of 4 t/ha as compared to control and other vermicompost treatments (1, 2, 3 t/ha) (Mycin et al. 2010).

Paul and Bhattacharya (2012) applied vermicompost at the rate of 5 and 2.5 t/ha on African marigold (*Tagetes*). Other treatments included cattle dung manure and cattle dung manure plus 50 % NPK. Maximum plant fresh weight and dry weight were observed in treatment of vermicompost at the rate of 5 t/ha. Fresh weight and dry weight of lettuce (*Lactuca sativa*) plants significantly increased in 50:50 and 20:80 mixtures of feed stock compost and vermicompost mixtures as compared to feedstock derived compost alone (Ali et al. 2007). Aerial biomass of tomato (*Lycopersicum esculentum*) plants increased when peat was substituted with vermicompost (10–20 %) as compared to pure peat based substrate

(Lazcano et al. 2009). Chand et al. (2011) reported that when vermicompost was applied at the rate of 2.5 g/kg with 50 % recommended dose of NPK fertilizers on geranium (*Pelargonium species*), maximum plant dry matter was obtained which was higher than other eight treatments consisting of different concentrations of vermicompost, biofertilizers and NPK fertilizers.

Singh et al. (2008) used vermicompost prepared from vegetable waste mixed with cow dung and applied it as four treatments (at the rates of 2.5, 5.0, 7.5 and 10 t/ha) on strawberry (*Fragaria* × *ananassa*) in the field. Treatment with recommended dose of inorganic fertilizers was used as control. Plant spread and plant dry weight was found to be higher in vermicompost treatments as compared to inorganic fertilizer treatment. After 180 days of planting, plant spread was observed to be 12.7 cm in inorganic fertilizer treatment while it was found to be 12.5, 13.0, 13.9 and 13.8 cm in treatments with vermicompost applied at the rates of 2.5, 5.0, 7.5 and 10 t/ha respectively. Increase in plant spread in all vermicompost treatment was statistically significant as compared to inorganic fertilizer treatment. Similarly, plant dry weight was significantly higher in all treatments of vermicompost as compared to control (inorganic fertilizer). Highest value of plant dry weight was 28.8 g per plant in treatment of vermicompost at the rate of 7.5 t/ha while lowest value of plant dry weight (24.1 g) was recorded in inorganic fertilizers treatment. Growth of plants on adding high concentrations of vermicompost may get inhibited because of an increase in salts (especially Na) concentrations (Fernández-Luqueño et al. 2010). Amendment of soil with vermicompost leads to increase in water holding capacity, nutrients and minor elements concentrations, which in turn lead to a better plant development (Atiyeh et al. 2002). Growth of plants is different in different vermicompost treatments because growth promoting substances are released at different rates in different treatments (Singh et al. 2008; Azarmi et al. 2009). Raw material used to prepare vermicompost, microorganisms and amount of nutrients affect the efficiency of vermicompost as a plant growth enhancer (Jack and Thies 2006; Hameeda et al. 2007).

7.3 Effect on roots

Hormone like activity of vermicompost leads to an increase in root biomass, root initiation and better growth and development of plants (Bachman and Metzger 2007; Mycin et al. 2010). Application of Phosphorous-enriched vermicompost increased root volume of *Setaria* grass as compared to control and other treatments with different combinations of gafsa phosphate, earthworms, Arbuscular mycorhhiza fungi and empty fruit bunch (Sabrina et al. 2013). Increases in root fresh weight and root length of *Lilium longiflorum*, root length, dry and fresh root weight of pea (*Pisum sativum*), dry root weight of maize (*Zea mays*), root length of crossandra (*C. undulaefolia*) were reported by Mirakalaei et al. (2013), Khan and Ishaq (2011), Gutiérrez-Miceli et al. (2008) and Gajalakshmi and Abbasi (2002) respectively. A mixture of 75 % vermicompost produced by *Perionyx excavatus* and 25 % soil increased root length more as compared to control, soil amended with normal compost and soil amended with different concentrations of vermicompost produced by two other species viz. *O. rosea* and *O. philloti*. Root number and Root length of *Lilium* plant increased on applying 30 % vermicompost. This increase was higher as compared to control and other vermicompost treatments (10–20 %) (Moghadam et al. 2012). There were increases in root biomass of sorghum (*Sorghum bicolor*), root length of *Andrographis paniculata*, fresh and dry biomass of spinach (*Spinacia oleracea*), root biomass, number of root tips of tomato (*Lycopersicum esculentum*) plants, average root length of *Amaranthus* species, root length of groundnut (*Arachis hypogaea*), root length of pea (*Pisum sativum*), number of nodules/plant, root fresh biomass and root dry biomass of french bean (*Phaseolus vulgaris*) and root biomass of lettuce (*Lactuca sativa*) cultivars on vermicompost applications as reported by Reddy and Ohkura (2004), Vijaya et al. (2008), Peyvast et al. (2008), Lazcano et al. (2009), Uma and Malathi (2009), Mycin et al. (2010), Khan and Ishaq (2011), Singh et al. (2011) and Papathanasiou et al. (2012) respectively. Complex of exchangeable auxin groups with humic acids enhanced root elongation, lateral emergence of maize (*Zea mays*) roots (Arancon et al. 2008; Mycin et al. 2010). Humic acids increase root growth and plant biomass (Vaughan and Malcom 1985; Nardi et al. 2002).

7.4 Effect on shoot

Application of 60 % vermicompost with 30 % sand and 10 % soil increased the shoot fresh weight and shoot dry weight of marigold (*Tagetes*) plant as compared to control and all other treatments of different proportions of peat, perlite, sand, soil, compost and vermicompost (Shadanpour et al. 2011). Higher shoot dry weight of greenhouse tomato (*Lycopersicum esculentum*) was observed in Metro-Mix360 substituted with 40 % vermicompost as compared to metro-mix 360 alone (control) and MM360 substituted with other concentrations of vermicompost (0–100 %) (Atiyeh et al. 2000a). Azarmi et al. (2009) investigated the effect of vermicompost @ 10, 20 and 30 t/ha) on two cultivars (sultan and storm) of cucumber (*Cucumis sativus*). Plots without any treatment were used as control. Stem dry weight was found to be maximum in plots with 30 t/ha of vermicompost. Stem dry weights were recorded to be 30.99 g/plant and 36.03 (in plots with 30 t/ha treatment) for sultan and storm cultivars respectively. Lowest values of stem dry weight (23.31 and 27.25 g) were observed in control plots. In 10 t/ha treatment plots, stem dry weights were found to be 27.17 and 30.25 g for sultan and storm cultivars respectively. Similarly, 28.57 and 34.15 g were the stem dry weights for sultan and storm cultivars in 20 t/ha treatment. Results showed that application of vermicompost at a rate of 30 t/ha lead to highest stem dry weights. Increase in shoot length, shoot fresh and dry biomass of french bean (*Phaseolus vulgaris*) has been reported by Singh et al. (2011). Increases in shoot lengths of *Andrographis paniculata*, *Amaranthus* species, garlic (*Allium sativum*) and groundnut (*Arachis hypogaea*) were reported by Vijaya et al. (2008), Uma and Malathi (2009), Suthar (2009) and Mycin et al. (2010) respectively. Shoot/root ratio of crossandra (*C. undulaefolia*), stem diameter of maize (*Zea mays*) (Gutiérrez-Miceli et al. 2008), stem height, fresh and dry weights of stem and stem diameter of *Lilium* plant (Moghadam et al. 2012) and stem circumference of okra (*Abelmoschus esculentus*) (Ansari and Kumar Sukhraj 2010) increased on applying vermicompost.

7.5 Effect on leaves and chlorophyll

Plant-available form of nitrogen (nitrate) is grater in vermicompost. Available N is greater in vermicompost than conventionally composted manure (Taleshi et al. 2011). N fertilization increased growth and leaf area index of plant which in turn increases absorption of light leading to more dry matter and yield (Nanda et al. 1995; Ravi et al. 2008). Azarmi et al. (2009) reported that leaf dry weight, chlorophyll content and number of leaves of cucumber (*Cucumis sativus*) increased on vermicompost applications. Leaf number and leaf area of pak choi (*Brassica rapa*) (Pant et al. 2009), number of leaves and leaf area of sorghum (*Sorghum bicolor*) (Reddy and Ohkura 2004), number of leaves of crossandra (*C. undulaefolia*) (Gajalakshmi and Abbasi 2002), leaf number and leaf dry mass of *Lilium* plant (Moghadam et al. 2012), number of leaves of tomato (*Lycopersicum esculentum*) (Lazcano et al. 2009), average number of leaves, leaf length, chlorophyll *a* and *b* contents of *Amaranthus* species (Uma and Malathi 2009), number of leaves/plant of okra (*Abelmoschus esculentus*) (Ansari and Kumar Sukhraj 2010), number of leaves and leaf area of groundnut (*Arachis hypogaea*) (Mycin et al. 2010), number of leaves of pea (*Pisum sativum*) (Khan and Ishaq 2011), number of leaves of maize (*Zea mays*) plant (Gutiérrez-Miceli et al. 2008), leaf size, leaf fresh and dry weights of spinach (*Spinacia oleracea*) plant (Peyvast et al. 2008), number of leaves of cucumber (*Cucumis sativus*) (Azarmi et al. 2009), leaf area of strawberry (*Fragaria* × *ananassa*) (Singh et al. 2008), leaf length of garlic (*Allium sativum*) (Suthar 2009), leaf dry weight of cucumber (*Cucumis sativus*) (Azarmi et al. 2009), chlorophyll *a* and chlorophyll *b* content of *Andrographis paniculata* (Vijaya et al. 2008), Chlorophyll content of two cultivars (sultan and storm) of cucumber (*Cucumis sativus*) (Azarmi et al. 2009), Chorophyll content of leaves of *Lilium longiflorum* (Mirakalaei et al. 2013) increased on applying vermicompost. Papathanasiou et al. (2012) compared two treatments (10 and 20 %) of vermicompost with inorganic fertilizer using sole soil as control in a pot study during two crop seasons (winter and spring) on lettuce (*Lactuca sativa*). During winter season, highest average leaf number (23.67) was recorded in 10 % vermicompost treatment. Highest leaf dry weight (11.67 g) was observed in 20 % vermicompost treatment. During spring season, 20 % vermicompost treatment leads to highest leaf dry weight (15.35 g). Use of maize (*Zea mays*) plants as forage depends upon number of leaves and the wet weight of maize (*Zea mays*) plants (Atiyeh et al. 2002).

7.6 Effect on flowers

Increase in N levels, microbial activity on adding vermicompost leads to greater root expansion, which in turn leads to greater uptake of nutrients, water and rate of photosynthesis, ultimately leading to better flowering and heading (Taleshi et al. 2011). Vermicompost applications increased number of flowers and flower yield of african marigold (*Tagetes*) (Paul and Bhattacharya 2012), number of flowers/plants and length of inflorescence of crossandra (*C. undulaefolia*) (Gajalakshmi and Abbasi 2002), number of flowers/plant, flower diameter, flower stalk length and flower yield of *Chrysanthemum morifolium* and *Matricaria chamomilla* (Verma et al. 2011; Hadi et al. 2011). Moghadam et al. (2012) observed early flowering and increased number of flower of *Lilium* plant on application of vermicompost. Early flowering and higher fruit yields on adding vermicompost may be due to better growth of plants on vermicompost additions (Brown 1995; Atiyeh et al. 2000b, 2001; Arancon et al. 2004, 2006; Singh et al. 2008).

7.7 Effect on fruits

Plants receiving vermicompost might have received nutrition in a balanced and sustained way than those receiving inorganic fertilizers only (Arancon et al. 2004; Singh et al. 2008) and it might have helped the plants in producing albino and malformed fruits in lesser number (Singh et al. 2008). Increases have been reported in number of fruits/plant of strawberry (*Fragaria × ananassa*) (Singh et al. 2008), number of fruit/plant of two cultivars (sultan and storm) of Cucumber (*Cucumis sativus*) (Azarmi et al. 2009), number of fruits/plant and fruit length of eggplant (*Solanum melongena* L.) (Moraditochaee et al. 2011), number of cloves/fruit of garlic (*Allium sativum*) (Suthar 2009) on applying vermicompost. Better growth of plants under different doses of vermicompost might have favoured the production of firmer, better coloured and quality fruit (Singh et al. 2008). Number of pods/plant and seeds/plant of groundnut (*Arachis hypogaea*) increased by vermicompost applications (Mycin et al. 2010).

7.8 Effect on yield

There was increase in marketable yield of fruits of okra (*Abelmoschus esculentus*) (Ansari and Kumar Sukhraj 2010), total yield of strawberry (*Fragaria × ananassa*) (Singh et al. 2008), fruit yield of eggplant (*Solanum melongena*) (Moraditochaee et al. 2011), yield of *potato* (*Solanum tuberosum*) (Alam et al. 2007), total yield of two cultivars (sultan and storm) of cucumber (*Cucumis sativus*) (Azarmi et al. 2009), fruits/plants and total yield of *Abelmoschus esculentus* (Vijaya and Seethalakshmi 2011), harvest index of crossandra (*C. undulaefolia*) (Gajalakshmi and Abbasi 2002), higher marketable yield of tomato (*Lycopersicum esculentum*) (Atiyeh et al. 2000a), yield of lettuce (*Lactuca sativa*) (Papathanasiou et al. 2012) and net yield of *Amaranthus* species (Uma and Malathi 2009) by vermicompost applications. Oil yields of geranium (*Pelargonium species*) (Chand et al. 2011) and *Matricaria chamomilla* (Hadi et al. 2011) increased by vermicompost treatments.

7.9 Effect on ions uptake

The vermicompost introduce the microorganisms in rhizosphere of plants, which leads to more availability of N and K by biological fixation of nitrogen and biological solubilization of P (Mackey et al. 1982; Mycin et al. 2010). Non-aerated vermicompost tea application increased B, Zn, Fe, Mn, Cu content in the tissues of pak choi (*Brassica rapa*) as compared to control, aerated vermicompost tea and vermicompost tea with microbial enhancer (Pant et al. 2009). Increase have been reported in N, P, K, Zn, Fe, Mn, Cu content in plant of geranium (*Pelargonium species*) (Chand et al. 2011), average N, P, K, Mg content of plant tissue of *Amaranthus* species (Uma and Malathi 2009), N, P, K, Ca content of groundnut (*Arachis hypogaea*) (Mycin et al. 2010) on applying vermicomposts. Vermicompost treatments increased uptake of P, K in african marigold (*Tagetes*) (Paul and Bhattacharya 2012), K, Ca, Mg uptake of *Setaria* grass (Sabrina et al. 2013), K, Zn, Ca, Fe content in the stem and root tissues of *Lilium* plant (Moghadam et al. 2012), K, Ca content of marigold (*Tagetes*) plant (Shadanpour et al. 2011), increase in total N (%) of spinach (Peyvast et al. 2008), P content in the leaves of maize (*Zea mays*) (Gutiérrez-Miceli et al. 2008). Vermicompost improves soil environment leading to better uptake of K (Mycin et al. 2010). Humic acids increase the availability of micronutrients (Stevenson 1991; Nardi et al. 2002) and help in Fe acquisition (Chen and Aviad 1990; Pinton et al. 1999; Nardi et al. 2002) and nutrient uptake (Nardi et al. 1996, 2002) by plants.

7.10 Effect on quality

Potassium plays an important role in metabolism of plants and is the key constituent of chlorophyll, biosynthesis, protein, nucleic acid and other constituents (Mycin et al. 2010). There was an increase in protein content of *Andrographis paniculata*, TSS of spinach, average caretenoid content, total sugar content, reducing sugars content and non-reducing sugars content of *Amaranthus* species, protein (%) and fat (%) of okra (*Abelmoschus esculentus*), total soluble protein(%) and carbohydrates of *A. esculentus* as reported by Vijaya et al. (2008), Peyvast et al. (2008), Uma and Malathi (2009), Ansari and Kumar Sukhraj (2010) and Vijaya and Seethalakshmi (2011) respectively. Better plant growth in different vermicompost amendments may be the reason for a better quality of fruits (Singh et al. 2008; Azarmi et al. 2009).

8 Effect of humic acids derived from vermicompost on plant growth

Humic acid is formed by the biodegradation of dead organic matter and is a major component of soil humus (Stevenson 1994). Soil humic substances are of three types: Humic acids, Fulvic acids and Humin. Fluvic acids are humic acids of low molecular weight and high oxygen content (Baigorri et al. 2009). A humic acid molecule has many molecules and has surface charge. Surface charge is due to functional groups and reactivity phenolic and carboxylic groups (Stevenson 1994) (Fig. 1). They have pK values around 4 and around 6 for protonation of carboxylic and phenolate groups respectively. They act like mixtures of dibasic acids (Ghabbour and Davies 2001). Molecules are held together by non-covalent forces like Van der Waal forces, Π–Π and CH–Π bonds (Piccolo 2002). List of parameters of various plants enhanced by applying humic acids extracted from vermicompost are given in Table 4.

When humic acids derived from pig manure vermicompost were mixed in different ratios in MM360 medium to grow tomato (*Lycopersicum esculentum*) seedlings, and humates extracted from pig manure and food waste vermicomposts were mixed with vermiculite to grow cucumber (*Cucumis sativus*) seedlings, there was a significant increase in the growth and yield of tomato (*Lycopersicum esculentum*) and cucumber (*Cucumis sativus*) seedlings. It was observed that effect of humic acids on plant growth depended upon their applied concentrations, plant species, nature of container medium and source of vermicompost. Authors attributed the increase in growth to hormone like activity of vermicompost (Atiyeh et al. 2002). In another study by Arancon et al. (2003b), humic acids extracted from cattle, food and paper-waste vermicomposts substituted in soilless growth medium, Metro-Mix 360 (MM360) increased growth and yields of marigold (*Tagetes*), peppers

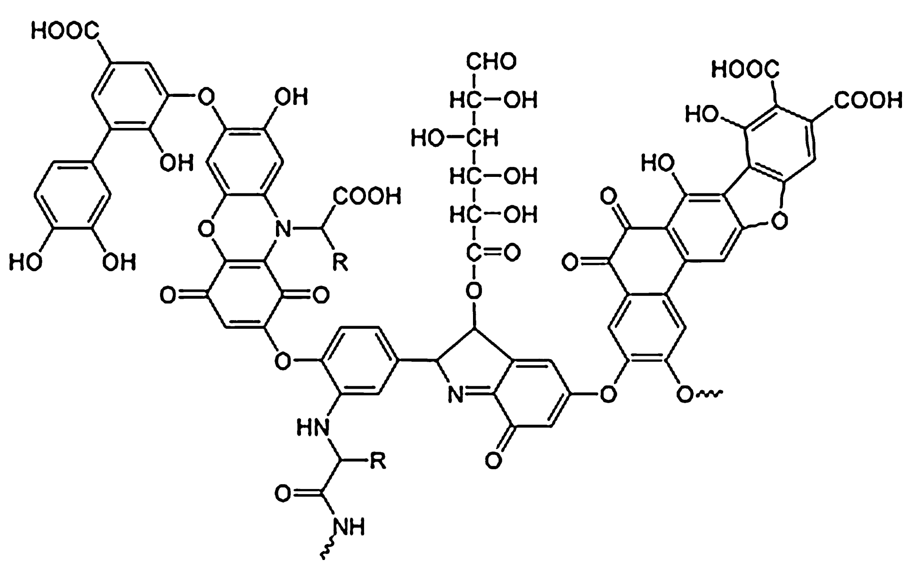

Fig. 1 Structure of humic acid (*Source*: Stevenson 1994)

Table 4 List of various parameters of plants enhanced by applying humic acids extracted from vermicompost

S. no	Crop/plants	Parameters enhanced	References
1	Basil (*Ocimum basilicum* L.)	Wet and dry yield, essence yield, chlorophyll content	Befrozfar et al. (2013)
2	Marigold (*Tagetes*), pepper (*Capsicum*), and strawberry (*Fragaria* × *ananassa*)	Plant heights, leaf areas, shoot dry weights, root dry weights, numbers of fruits	Arancon et al. (2003a, b)
3	Tomato (*Lycopersicum esculentum*) and Cucumber (*Cucumis sativus*)	Plant height, leaf area, root dry weight, shoot dry weight	Atiyeh et al. (2002)

(*Capsicum*) and strawberry (*Fragaria* × *ananassa*) plants. Parametrs like plant heights, leaf areas, shoot dry weights, root dry weights increased in all the three crops. A field study was conducted by Befrozfar et al. (2013) to evaluate the effect of vermicompost, plant growth promoting bacteria and humic acid on growth and essence of basil (*Ocimum basilicum*). Humic acids were applied as foliar spray and seed treatment. Highest yield, plant height and essence percentage was recorded in combined treatments of humic acids with plant growth promoting bacteria. Authors suggested that treatments of humic acids, plant growth promoting bacteria and vermicomposts can be used for a sustainable agriculture discouraging the use of chemical fertilizers.

9 Biocontrol through vermicompost/vermiwash

When other living organisms are used to control pests, such method of controlling the pests is known as biocontrol. In India, each year there is a loss of about 18–30 % of the crop yield due to pests attack. Value of this loss is about Rs. 900–1500 billion (14.94–24.89 billion US dollars). Biological control provides an eco-friendly management of crop pests by their antagonistics. In late 1800s, efforts were made on international level to introduce biological control agents from one continent to other and during this period biocontrol got importance. Efforts were made to conserve local biological control agents. About 60 % protection from crop pests is provided by natural antagonistics in several crop ecosystems. A variety of pests in different crop ecosystems can be successfully managed by the use of biological control agents (Table 5). Fungal and bacterial antagonistics of plant diseases and phyto-nematodes, predators (lacewings, predatory bugs, ants, spiders, reptiles, birds, mammals, ladybird, beetles and others); parasitoids (parasite wasps and flies); entopathogenic microorganisms (viruses, protozoa, bacteria, fungi) are used as biological control agents (ICAR 2009). There are evidences that microbiota of vermicompost helps in biocontrol when microbiota of vermicomposts was killed by autoclaving, such vermicomposts were no longer effective to suppress the pathogen (Szczech and Smolinska 2001; Simsek-Ersahin et al. 2009).

Mycorhhizal fungi can be propagated in the soil by earthworms (Turk et al. 2006). Pathogens fail to penetrate in plants because of changes induced by mycorhhizal fungi in those root exudates which stimulate them (Turk et al. 2006). There was inhibition of mycelial growth *of Botrytis cinerea*, *Sclerotinia sclerotum*, *Corticium rolfsii*, *Rhizoctonia solani* and *Fusarium oxysporum* by the application of aqueous extracts of vermicompost (Nakasone et al. 1999). Aqueous extracts of aerated vermicompost teas could significantly suppress *Fusarium moniliforme* and control foot rot disease of rice (Manandhar and Yami 2008). Vermicompost produced from animal manures suppressed *Phytophthora nicotianae* pathogen (Szczech and Smolinska 2001).

There was suppression of *Fusarium oxysporum* when vermicompost obtained from separated dairy solids was applied (Kannangara et al. 2000). Suppression of *Fusarium oxysporum f.* sp was observed through cattle manure vermicompost (Szczech 1999). Szczech and Smolinska (2001) reported that vermicompost prepared using sewage sludge as raw material suppressed lycopersici pathogen. Simsek-Ersahin et al. (2009) observed the suppression of *F. oxysporum* and *R. solani* through vermicompost prepared by a mixture of vegetable wastes, bark (Salix spp.), and cattle manure. Similarly, suppressions of *Phytophthora infestans* (Szczech and Smolinska 2001), *Phytophthora brassicae*, *P. nicotianae*, *Fusarium wilt* (Nakamura 1996), *R. solani* (Asciutto et al. 2006,

Table 5 List of different pests/pathogens controlled through vermicompost/vermiwash applications in different crops

S. no.	Crops	Pest/pathogen	References
1	Corn (*Zea mays*) plant	Earworm (*Helicoverpa zea*)	Cardoza and Buhler (2012)
2	Cabbage (*Brassica oleracea*)	Earworm (*Helicoverpa zea*)	Little and Cardoza (2011)
3	Brinjal (*Solanum melongena*)	*Meloidogyne incognita*	Nath et al. (2011)
4	Chickpea (*Cicer arietinum*)	Fusarium wilt	Gopalakrishnan et al. (2011)
5	Mustard (*Brassica Juncea*) plant	Aphid (*Lipaphis erysimi*)	Nath and Singh (2011)
6	*Arabidopsis* plant	Earworm (*Helicoverpa zea*)	Little and Cardoza (2011)
7	Cucumber (*Cucumis sativus*) and Tomato (*Lycopersicum esculentum*)	Beetles and hornworms	Edwards et al. (2010a)
8	Tomato (*Lycopersicum esculentum*) and cucumber (*Cucumis sativus*) plants	Green peach aphid, citrus mealybug and two spotted mites	Edwards et al. (2010b)
9	Cucumbers (*Cucumis sativus*), tomatoes (*Cucumis sativus*), bush bean (*Phaseolus vulgaris*) and eggplant (*Solanum melongena*)	Mealy bugs, two-spotted spider mites and aphids	Arancon et al. (2007)
10	Tomato (*Lycopersicum esculentum*) and cucumber (*Cucumis sativus*)	Hornworm and beetles	Yardim et al. (2006)
11	Tomato (*Lycopersicum esculentum*)	Late blight disease	Zaller (2006)
12.	Peppers, tomatoes (*Lycopersicum esculentum*) and Cabbage (*Brassica oleracea*)	Aphids, mealy bugs, white caterpillars	Arancon et al. (2005b)

Simsek-Ersahin et al. 2009) and *P. nicotianae* (Szczech and Smolinska 2001) have been reported by vermicompost treatments. Plant resistance to pests increases due to some essential nutrient elements present in vermicompost which are not present in inorganic fertilizer (Arancon et al. 2005b).

Soluble nutrients, free enzymes, soluble phenolic compounds, and a wide range of microorganisms pass into tissues of plants from aqueous extracts of vermicompost which may be the reason for suppression of pests (Edwards et al. 2010a, b). Vermicomposts contain chitinase enzyme (Hahn 2001) which helps in controlling arthropod pests (Edwards et al. 2010a, b). Edwards et al. (2010b) studied the effect of aqueous extracts of vermicompost prepared from food waste (5, 10 and 20 %) on attack of pests green peach aphid, citrus mealybug and two spotted mites) on tomato (*Lycopersicum esculentum*) and cucumber (*Cucumis sativus*) plants. In green peach aphid experiments for tomato (*Lycopersicum esculentum*) plants, all the three treatments of aqueous solutions of vermicompost suppressed the green peach population. Maximum suppression was recorded in 20 % aqueous solution of vermicompost while minimum was recorded in 5 % solution. Twenty-five aphids were introduced on each plant by settling over the plants. In deionized control, there was a significant increase in the number of aphids. This number reached up to 40 in 14 days. Increase was recorded in plants receiving 5 % extracts even. In case of plants receiving 10 % extracts, there was an increase only for 1st 7 days but after this, a significant decrease was noticed. In case of 20 % extracts, a continuous decrease was observed in the number of aphids from day 1 to day 14. Similarly, damage rate was found to be 5.0, 4.0, 3.0 and 2.0 for control, 5 % extracts, 10 % extracts and 20 % extracts respectively. In case of cucumber (*Cucumis sativus*), the number of aphids increased up to 43 in 14 days in control treatment. Like in case of tomato (*Lycopersicum esculentum*) plants, this number increased in 5 % treatment and decreased in 10 and 20 % treatments. Damage ratings were found to be 5.0, 3.3, 2.1 and 1.4 in control, 5 % extract, 10 % extract and 20 % extract respectively. There were significant increases in shoot dry weights and leaf areas in 10 % extract and 20 % extract treatments. In citrus mealybug experiments, trends were similar as in case of aphids in tomato (*Lycopersicum esculentum*) plants. Damage ratings were found to be 2.5, 2.0, 1.5 and 1.35 in case of control, 5 % extracts, 10 % extracts and 20 % extracts respectively. Significant increases in dry shoot weights and leaf areas were observed in all vermicompost extract treatments. For cucumber (*Cucumis sativus*) plants, Damage rating was 2.5 in control, 1.9

in 5 % extract treatment, 1.75 in 10 % extract treatment and 1.5 in 20 % extract treatment. So, 20 % extract proved to be best in this case also. Similar trends were observed in two spotted spider mite experiments for both tomato (*Lycopersicum esculentum*) and cucumber (*Cucumis sativus*) plants. Hence, Mean damage rating per plant decreased with increase in the concentration of vermicompost extracts. Plant parameters (mean dry shoot weight and mean leaf area) increased in all the three treatments of vermicompost extracts as compared to control. Maximum increase in plant parameters was recorded in treatments receiving highest concentrations of vermicompost extracts. So, treatment of 20 % vermicompost extract proved to be most effective to control pests in this study.

In another study by Yardim et al. (2006), effects of food waste vermicomposts were checked on pests of tomato hornworm and cucumber beetles. Vermicompost was applied both in field and greenhouse. In the field, vermicompost was applied at the rates of 1.25 and 2.5 t/ha while it was applied 20 and 40 % in MM360 in green house. In field, number of striped cucumber beetle per plant on cucumber were highest in treatment with inorganic fertilizer and lowest in treatment with vermicompost applied in field at the rate of 2.5 t/ha. However, no significant difference was observed in number of beetles in both treatments of vermicompost. Cucumber beetle (*Diabrotica undecimpunctata*) was found to be highest on Cucumber plants with inorganic fertilizer treatment but its number did not vary significantly between all the three treatments. Damage by hornworm caterpillar on tomato (*Lycopersicum esculentum*) plants was reported to be highest in inorganic fertilizer. Damage did not vary significantly between two treatments of vermicompost. For greenhouse experiment, highest damage was observed in plants treated with 100 % MM360. Hence, decreases in number of beetles and damage by vermicompost substitutions in both greenhouse and field experiment were observed.

Arancon et al. (2007) investigated the application of different percentages of vermicompost in MM360 for different pests on four different crops (cucumbers, tomatoes, bush bean and eggplant). Application of 20 and 40 % food waste vermicompost in MM360 decreased the number of mealy bugs/plant for cucumber (*Cucumis sativus*) seedlings. Three treatments of vermicompost (10, 40 and 80 % in MM360) increased plant height, shoot dry weight and leaf area of tomato (*Lycopersicum esculentum*) plants infested with equal number of two-spotted spider mites for each treatment. Simliarly, damage ratings and losses in leaf areas decreased in bush bean (*Phaseolus vulgaris*) seedlings on vermicompost application at the rate of 20 and 40 % in MM360 when plants in all treatments were infested with equal number of two-spotted spider mites. Similiar were the trends for eggplants (*Solanum melongena*) (infested with two-spotted mites) treated with and cabbage (*Brassica oleracea*) plants (infested with aphids). In a similar study, mixtures of vermicompost with MM360 suppressed aphids and mealy bugs in peppers (*Capsicum*), mealy bugs in tomato (*Lycopersicum esculentum*) and white caterpillars in cabbage (*Brassica oleracea*) (Arancon et al. 2005b).

In another study, actinomycete isolates from vermicomposts were found to be effective in biocontrol of fusarium wilt in chick pea (*Cicer arietinum*). Out of 137 tested isolates, 33 isolates were reported to show an antagonistic potential against fusarium wilt and hence, could help to control it in chick pea (*Cicer arietinum*) plant (Gopalakrishnan et al. 2011). Vermicompost obtained from two sources (Raleigh and Oregon) was found to be effective in suppressing corn earworm (*Helicoverpa zea*) on corn plant (*Zea mays*) in its adult and immature stages. Percent leaf consumed of corn decreased as compared to control on application of vermicomposts of both sources. Mean number of eggs of *Helicoverpa zea* also decreased as compared to control on applying vermicomposts of both sources (Cardoza and Buhler 2012). Vermicomposts of these two sources (Raleigh and Oregon) could suppress *Helicoverpa zea* in its immature stage in case of *Arabidopsis* plants (Cardoza 2011). Resistan of *H. zea* and *Pieris rapae* lepidopterous pests in cabbage (*Brassica oleracea*) by the application of vermicompost has also been reported (Little and Cardoza 2011). Vermicompost is effective against fungi (*Rhizoctonia solani*, *Colletotrichum coccodes*, *Pythium ultimum*, *Phytophthora capsici and F. moniliforme*) because of antifungal activity present in its microflora and chitinase gene diversity (Yasir et al. 2009a). Combinations of vermicomposts and biopesticides were found to be effective against nematode (*Meloidogyne incognita*) in brinjal (*Solanum melongona*) crop. Vermicompost prepared from combination of buffalo dung and gram bran along with biopesticides (aqueous extracts of garlic) could most successfully suppress the nematode (*Meloidogyne incognita*) in comparison to other combinations of vermicomposts and biopesticides. Productivity of brinjal crop also increased as compared to control by the applications of vermicompost and biopesticides combinations (Nath et al. 2011).

In a similar study, combinations of vermicompost and biopesticides suppressed the aphid (*Lipaphis erysimi*) in mustard plant (*Brassica compestris*) (Nath and Singh 2012). When extracts of vermicompost were used as foliar sprays for three varieties of field grown tomato (*Lycopersicum esculentum*), there was indication that foliar vermicompost sprays could suppress the late blight disease (Zaller 2006). Foliar applications of vermiwash obtained from animal, agro and kitchen wastes in combination with biopesticides could suppress pest infestation of soybean (*Glycine max*). Combination of vermiwash and neem oil could most efficiently suppress pests and increased the growth and productivity of soybean (*Glycine max*) plants (Nath and Singh 2011).

There was suppression of Jassid (*Empoasca verri*) and the aphid (*Aphis craccivora*) in case of groundnut (*Arachis hypogaea*) when vermicompost was applied (Rao et al. 2001). Phenoiloxidase obtained from Lumbricus rubellus can form toxic phenols such as *p*-nitrophenol by bioactivating the compounds (Park et al. 1996; Edwards et al. 2010a, b). Soils with earthworms contain polychlorinated phenols and their metabolites (Knuutinen et al. 1990; Edwards et al. 2010a, b). Attacks by caterpillars could be controlled by spraying phenols and phenolic acids extracted from ginko plants. It has also been shown that sprays of phenols and phenolic acids extracted from gingko plants. (QiTian 2004; Edwards et al. 2010a). Less attack of pests on plants grown in vermicompost is due to the presence of soluble phenolic compounds in those plants (Edwards et al. 2010a, b). Growth of many fungi is suppressed by vermicompost application (Hoitink and Fahy 1986; Singh et al. 2008).

10 Conclusion

It is evident that vermicompost can improve physical, chemical and biological properties of soil and is an excellent organic fertilizer. Presence of microbiota and phenolic compounds in vermicompost help to effectively control a number of plant pathogens and pests. A number of growth, yield and quality parameters of various crops are positively affected by vermicompost. In most of the studies, vermicompost when applied in combination with chemical or other fertilizers has been proved as a substitute of using chemical fertilizers alone. However, it has been proved more effective than chemical fertilizers in few studies. At the same time, it is an effective tool for solid waste management also. As organic fertilizers are slow releasing and have to be applied in bulks because of their lower N, P, K values as compared to chemical fertilizers, application of vermicompost alone may be costlier than applying chemical fertilizers alone or applying vermicompost in combination with chemical fertilizers. Farmers must be educated and made aware for the use of organic amendments like vermicompost in combination with chemical or other fertilizers. Cost effectiveness of vermicompost should also be reflected in future studies. Net economics of applied vermicompost and inorganic fertilizers must be compared to know whether such organic amendments are cost-effective for farmers or not and how these amendments can be made more cost effective in future so that the farmers of both developed and developing world can take its advantage without hesitation.

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