Dynamic Soil, Dynamic Plant ©2010 Global Science Books

Vermicompost as Modulator of Plant Growth and Disease Suppression

Birinchi K. Sarma* • Pratibha Singh • Susheel K. Pandey • Harikesh B. Singh

Department of Mycology and Plant Pathology, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi 221005, India

Corresponding author: * birinchi_ks@yahoo.com

ABSTRACT

Vermicompost (VC) is a rich source of macro- and micro-nutrients and is used to enliven soils. It is mostly considered as an efficient supplement of organic matter to soils and horticultural container media low in organic content. Recently VC has also been explored extensively for its various other useful activities especially its role in enhancing plant growth promoting effect as well as in suppression of plant diseases by various mechanisms. VC is considered superior to conventional compost especially for substitution of soils or greenhouse container media for its ability to modify soil properties in a better way. The role of VC in plant growth promotion is largely believed to be due to its nutrient rich composition as well as its ability to modify soil physical and chemical properties suitably in a way to favor plant growth and development. Among its role in suppression of plant pathogens and nematodes, it is believed that it modulates a plant's innate resistance response to resist microbial attack. Apart from this, VC-mediated soil physicochemical properties also favors growth and multiplication of saprophytic soil microbes including the biocontrol agents and thus helps in enhancing performance of most biocontrol agents against a wide range of phytopathogens. VC prepared from various sources and methods have also been identified to playing different roles in promoting plant growth and achieving biological management of phytopathogens. In the present review various roles and mechanisms of VC as plant growth regulator and disease suppressor unearthed recently are discussed.

Keywords: enhanced biocontrol, growth promotion, growth regulators, nutrient uptake, systemic resistance, vermicompost tea

Abbreviations: ACTC, aerated compost tea; **ACTME**, aerated vermicompost tea augmented with microbial enhancer; **ACTV**, aerated vermicompost tea; **AVC**, aqueous extracts of vermicompost; **CMM**, *Clavibacter michiganensis* subsp. *michiganensis*; **EFB-HA**, humic acids isolated from empty fruit bunch of oil palm compost; **FYM**, farm yard manure; **FOM**, *Fusarium oxysporum* f. sp. *melonis*; **GM-EPC**, grape marc wastes and extracted olive press cake; **HA**, humic acid; **MM360**, Metro-Mix 360; **NCTV**, non-aerated vermicompost tea; **PGR**, plant growth regulator; **PMR**, composted paper mill residuals; **RSVC**, rice straw vermicompost; **SAR**, systemic acquired resistance; **SF**, size-fraction; **VC**, vermicompost

CONTENTS

INTRODUCTION

Improving plant vigour and maintaining optimal growth conditions can reduce host susceptibility to pathogen attack and the best way to maintain plant health is to manage its growing medium. Organic amendment in soil manages soil-borne phytopathogens by changing the soil and rhizosphere environment. It affects the life cycle of pathogens adversely and enables plants to resist their attack by achieving better vigour and/or altering root physiology. Composts as well as vermicomposts (VCs) are sustainable source of macro- and micro-nutrients, plant growth regulators (PGRs), and suppressive microbial communities (Kale and Karmegam 2010). Enhancement in plant growth by substituting greenhouse container media with composts and/or VC may be attributed due to modifications of the soil structure physically, chemically and biologically. It is therefore possible that VC, in a similar way to compost, can affect plant

Received: 21 April, 2010. Accepted: 19 October, 2010.

Invited Review

growth and manage soil-borne plant pathogens by modifying the physicochemical and microbiological characteristics of the plant growth medium beneficially.

VERMICOMPOST AS A PLANT GROWTH MODULATOR

Compost in general as well as VC is able to promote plant growth through various mechanisms. According to Atiyeh *et al*. (2000) the growth of marigold and tomato seedlings, in a standard horticultural, green house container bedding plant medium Metro-Mix 360 (MM360), was enhanced significantly with pig solids VC or food wastes VC substitution, when all required nutrients were supplied. The shoot dry weights of raspberry plants, grown in a mineral soil mixed with pig wastes VC weighed more than those grown in unfertilized control soil, and the growth was comparable with soils receiving a complete fertilizer treatment. Similar results were obtained by Baskaran *et al*. (2009) when the sugar mill effluent polluted soil was mixed with VC, it improved the soil fertility and growth of green gram plants. Karmegam and Daniel (2008) also demonstrated a similar effect of VC on growth and yield of hyacinth bean. Warman and Anglopez (2010) also showed that amendment of 10% VC derived from different feedstocks increased leaf area and biomass of radish, marigold and upland cress although the VC extract was inhibitory to seed germination of the three species. Similarly, Sallaku *et al*. (2009) showed that VC influenced plant growth positively even under saline conditions. A significantly higher relative growth rate during the nursery stage was observed for young cucumber seedlings grown in VC compared to commercial peat compost that continued to the stand establishment period also. Although the morphological differences existed during that stage, the differences regarding physiological performance of transplanted seedlings differed even more significantly. However, dry matter per plant and relative leaf expansion rate were found to be higher for VC prior to transplanting and end of stand establishment period.

Similarly, Pant *et al*. (2009) obtained non-aerated VC tea (NCT), aerated VC tea (ACT) and aerated VC tea augmented with microbial enhancer (ACTME), and applied to the plants to see their effect on them. Mineral nutrients were significantly higher in ACTME compared to the other teas, but total microbial population and activity did not differ with extraction method. All VC teas similarly enhanced plant production, mineral nutrients and total carotenoids, and this effect was most prominent under organic fertilisation. Antioxidant activity and total phenolics were also higher under organic compared to synthetic fertilisation. VC teas generally decrease phenolic contents under organic fertilisation but they were increased under synthetic fertilisation compared to the control. In the same way, Bachman and Metzger (2008) used VC of pig manure (20% v/v) in the germination media at different points in the production cycle of tomato, marigold, pepper, and cornflower that enhanced plant growth in both tomato and French marigold seedlings but were ineffective for seed germination. When seedlings of tomato, French marigold, and cornflower were transplanted into 6-cell packs there was greater plant growth in media amended with VC compared to the control media, and the greatest growth was obtained when VC was amended into both the germination and transplant media. This effect was further enhanced when seedlings in the transplant media were irrigated with water containing fertilizer. Sodium induced inhibitory effects of VC in ginger had been shown by Ahmad *et al*. (2009). VC amendments improved net yield, fresh and dry biomass of shoot and rhizome yield of ginger plants along with their chlorophyll, carbohydrate and protein contents both in the saline and non-saline conditions. This showed the possibility to obtain permissible economic returns by this method from moderately saline soil, which are generally considered not suitable for crop production.

Growth promotion by enhanced nutrient uptake

Increase nutrient uptake by plants grown in VC amended soil had been observed to enhance plant growth. Chamani *et al*. (2008) correlated the beneficial effects of VC with elevated tissue macronutrient concentrations. They saw significant positive effects of VC on growth of *Petunia hybrida* compared to control and peat-amended media. The plants performed best in the 20% VC medium while further increase in the VC content decreased flower numbers, leaf growth rates and shoot fresh and dry weights. Subsequent analysis of plant tissues revealed higher total extractable nitrogen (N), phosphorous (P) and potassium (K) along with calcium (Ca), magnesium (Mg) and iron (Fe) in VC medium. However, zinc (Zn) concentrations were lesser than in peat medium and copper (Cu) and manganese (Mn) concentrations were lower than for those grown in the control medium. Similarly, Kumari and Ushakumari (2002) also showed that even under field conditions enriched VC had effect on the yield and uptake of nutrients by cowpea. Enriched VC showed increased yield and uptake of major nutrients like N, P, K, Ca and Mg. But the micronutrient uptake was not significantly influenced by non-enriched VC treatment. In another experiment, García-Gomez *et al*. (2008) found that VC leachate stimulated plant development when diluted, but fertilized with NPK for achieving maximum growth. VC cattle manure, in combinations with soil also affected growth, yield, and chemical characteristics of parsley (*Petroselinum crispum*) as its addition to soil not only increased plant growth and yields but also the amounts of K, P, and total soluble solids in the plants grown in 10% VC amended soil (Peyvast *et al*. 2008).

Growth promotion by VC blended with useful microbes

Several workers enhanced the plant growth promoting properties of VC by mixing with other useful microbes. Jeyabal and Kuppuswamy (2001) showed that integrated nutrition comprising VC, fertilizer N and biofertilizers could be applied to rice–legume cropping system to achieve higher yields and sustain soil health. They found that the integrated application of VC, fertilizer N and biofertilizers viz., *Azospirillum* and phosphobacteria increased rice yield by nearly 15% over application with fertilizer N alone. On average, integrated application also increased the N, P and K uptake. Organic carbon content in the residual soil after rice was also not depleted due to the integrated application. However, the amount of depletion of available N, P and K in the fertilizer alone treatment was greater than to the integrated nutrition. The microbial population of the residual soil was also increased by the integrated application. Similarly, Hameeda *et al*. (2007) reported that rice straw VC (RSVC) when applied at 2.5 t ha^{-1} showed significant improvement in shoot length, leaf area, plant biomass, root volume and mycorrhizal (*Glomus* species) colonization and further increase in RSVC, resulted in decrease in plant biomass even after mycorrhization compared to the application of RSVC alone. The study shows that the application of microbial inoculants along with higher concentrations of composts may not be synergistic for plant growth. In another experiment, Gutiérrez-Miceli *et al*. (2008) also reported the effect of sheep manure VC on mycorrhization on maize plant, and its growth. VC explained most of the variation found for leaf number, wet weight, stem height, and diameter through increased P content in the plants, but not the N content. Mycorrhizal colonization also increased when diazotrophic bacteria were added along with VC. A similar effect was also observed on maize plants cultivated in peat moss amended with VC and supplemented with *Glomus fasciculatum* and diazotrophic bacteria.

Growth promotion by humic acid fractions

HA fractions obtained from VC also influences plant growth. Seedlings of maize and Arabidopsis when treated with different concentrations of size-fractions (SFs) of HAs extracted from VC, it was found that all SF promoted root growth in Arabidopsis and maize seedlings but the effects differed according to molecular size and plant species. In Arabidopsis seedlings, the bulk HA and its SF revealed a classical large auxin-like exogenous response, through exhibition of shortened principal root axis and induced lateral roots, while the effects in maize corresponded to low auxin-like levels, through exhibition of enhanced principal axis length and induction of lateral roots. These molecules were found to be dynamically released from humic superstructures and exert their bioactivity when the humic conformational stability is weaker (Canellas *et al.* 2010). However, according to Dobbss *et al.* (2010) all humic derivatives from VC exhibited more bioactivity compared to the original humic substances and both $KMnO_4$-oxidised as well as methylated materials being the most effective in modifying root architecture and photon pump activation of tomato and maize. They did not found any relationship between bioactivity and humic molecular sizes but found that hydrophobicity index was significantly related with photon pump stimulation. They suggested that the hydrophobic domain preserves bioactive molecules like auxins in the humic matter and while being in contact with the root-exuded organic acids the hydrophobic weak forces could be disrupted, and releases the bioactive compounds from humic aggregates. Similarly, Arancon *et al.* (2003a) also extracted HAs by an alkali/acid fractionation procedure from cattle, food and paper-waste VCs and applied to a soil-less growth medium MM360, at different rates to young marigold, pepper, tomato and strawberry plants. The HAs increased root growth of marigolds and peppers, and root growth and numbers of fruits in strawberries. They found that although the plant growth parameters increased considerably in HA containing pots but they were not significantly different from those grown without HA supplementation.

Growth promotion by plant growth regulators

PGRs accumulate in VC through various ways have a positive impact on plants grown in VC amended medium. Suthar (2009) studied the effect of VC amendment along with NPK fertilizers and observed that 15t/ha VC with half the dose of NPK, enhanced maximum range of plant parameters including root length, shoot length, leaf length, fruit weight, number of cloves in garlic fruit and number of leaves per plant. This has contributed to an increased average fruit weight by approximately 26% in the treatment than the recommended NPK treated plot. The farm yard manure (FYM) VC also showed comparatively better plant growth than composted manure. The increase in plant growth indicated the presence of some growth-promoting substances in the worm-processed material. The FYM VC also contained a considerable amount of some essential plant micronutrients including Cu, Fe, Mn and Zn that might have contributed positively for better plant growth and productivity. Similarly, Arancon *et al.* (2004a) produced VC from food wastes and substituted at different concentrations into the soil-less commercial bedding plant container medium MM360. They attained 45% more fruit weights and 17% greater mean number of fruits, in peppers grown in potting mixtures containing food waste VCs than those grown in MM360 only. They attributed that improvement of the physical structure of the potting medium, increases in populations of beneficial microorganisms and the potential availability of plant growth-influencing-substances produced by microorganisms in VCs for the increase in pepper yields. In another observation, Arancon *et al.* (2004b) found that VCs processed commercially from food wastes and paper in field plots under high plastic hoop tunnels increased growth and yields of strawberries (*Fragaria ananasa*) significantly. However, the responses did not seemed to be dose-dependent, rather, the differences in growth and yield characteristics was due to production of PGRs produced by microorganisms during vermicomposting.

Atiyeh *et al.* (2001) also conducted an experiment to characterize the physical, chemical and microbial properties of the soil-less plant medium MM360 by substituting pig manure VC in an increasing way in relation to tomato growth responses. The growth of tomato seedlings was maximum in between 25 and 50% pig manure VC supplementation along with liquid fertilizer solutions. Enhancement of seedling growth in these mixtures were attributed to the combined effects of improved porosity, aeration and water retention in the medium and the high nitrate content of the substrate, which produced an increased uptake of nitrogen by the plant tissues. They also attributed higher growth responses in lower pig manure VC substitution to other biological inputs provided by VC, such as PGRs into the container medium. In a similar experiment, Arancon *et al.* (2002) compared plots treated with recommended rates of inorganic fertilizers only with VC-treated plots supplemented with inorganic fertilizers to equalize the initial N levels available to plants in all plots at transplanting. The marketable tomato yields in all VC-treated plots were consistently greater than yields from the inorganic fertilizer-treated plots. They concluded that the improvements in plant growth and increases in fruit yields could be partially due to large increases in soil microbial biomass after VC applications, leading to production of hormones or humates in the VCs acting as plant-growth regulators independent of nutrient supply. In a different experiment Arancon *et al.* (2008) also demonstrated that VCs produced from cattle manure, food waste and paper waste influences germination, growth and flowering of petunias in greenhouse mediated by plant growth-influencing-substances such as hormones and humates produced by microorganisms during vermicomposting.

Cultivar specific growth promotion response

Crop cultivars also tend to response differentially to the growing medium. In an interesting experiment Albaho *et al.* (2009) showed that different cultivars of a same plant species respond differently to different growing medium. They saw the effect of three substrates on growth and yield of two cultivars of sweet peppers (*Capsicum annuum* cv. 'Yara' (green) and 'Piment Doux' (red)). The substrates used in the study were peatmoss and perlite mix, peatmoss, perlite and VC and peatmoss, perlite, VC and cocopeat mix. The results showed that the cultivars responded differently to the substrates and they had significant effects on cultivars heights, number of leaves, chlorophyll index and plants' total yields. Similarly, VC prepared from food and cotton waste when amended to a commercial peat potting substrate significantly influenced emergence and elongation of seedlings of different tomato variety specifically. Biomass allocation (root: shoot ratio) was also affected significantly by VC amendments for two varieties in seedling stage and one field-grown tomato variety along with morphological (circumference, dry matter content, peel firmness) and chemical fruit parameters (contents of C, N, P, K, Ca, Mg, L-ascorbic acid, glucose, fructose) in seedling substrates. The results of Zaller (2007) concluded that VC could be an environmentally friendly substitute for peat in potting media with similar or beneficial effects on seedling performance and fruit quality and the response is variety-specific. Similarly, Lazcano *et al.* (2010) investigated the effect of VC and VC extract on germination and early development of six different progenies of the maritime pine (*Pinus pinaster*) and compared the effects. VC incorporation in the growing media increased germination of maritime pine particularly by the VC water extract. Plants germinated with VC showed higher N content, and that might have helped the treated seedlings for faster maturation. Since the best effects on pine germination were observed after application of VC water extract, the mechanisms like the presence of water soluble nutrients and HAs and plant growth regulating substances in the VC, rather than the physical amelioration of the substrate might have involved in promoting seed germination. The response of the different pine progenies to VC application was also varied thereby confirming again the necessity of taking genetic variability into account in order to study the potential of VC and other biologically-active organic potting materials.

COMPOST AS PLANT DISEASE SUPPRESSOR

It is generally accepted that composts suppress plant diseases, improve soil nutrient availability and stimulate plant growth mediated through both biotic and abiotic factors. Ndegwa and Thompson (2001) adopted an integrated approach to study the pertinent attributes of traditional composting and vermicomposting of activated sewage sludge mixed with paper-mulch, and combined them to enhance the overall process and improve the products qualities. The two approaches adopted in this study were pre-composting followed by vermicomposting, and pre-vermicomposting followed by composting. The results indicated that, a system that combines the two processes not only shortens stabilization time, but also improves the products quality. Combining the two systems resulted in a product that was more stable and consistent (homogenous), with less potential impact on the environment and met the pathogen reduction requirements. In another experiment Boulter *et al.* (2002) evaluated two composts for suppression of Fusarium Patch (*Microdochium nivale*) and Typhula Blight (*Typhula ishikariensis*) snow molds in field experiments. Fall applications of compost reduced snow mold severity to levels comparable to fungicide controls. In addition, a significant increase in green-up of turf recovered from disease and/or winter dormancy was observed compared to fertilizer and fungicide controls. The two composts showed no significant differences in their capacities to suppress disease and the plots that received a higher application rate of compost had significantly less disease than in the lower application rate plots. There were also no significant differences between the composts at either experimental location on any rating date.

Pharand *et al.* (2002) investigated the potential of a pulp and paper mill residues compost for the control of crown and root rot of tomato caused by *Fusarium oxysporum* f. sp. *radicis-lycopersici*. Peat moss amended with compost substantially reduced disease-associated symptoms. Histological and cytological observations of root samples from *Fusarium*-inoculated plants revealed increased plant resistance to fungal colonization. The wall-bound chitin of the pathogen was also altered in severely damaged hyphae. Similarly, Asciutto *et al.* (2006) evaluated the effect of different proportions of VC on the growth and health of patience-plant (*Impatiens wallerana*). Treatments used were infested substrate, substrate, sterilized substrate, VC, and VC mixed with infested substrate at different rates. They found that treatments with 100-75% of VC showed important increases in above ground plant parts and VC at 75% provided slight control of damping-off caused by *R. solani.* Rose *et al.* (2003) also showed that addition of chitin (4%, v/v) to a peat-based medium significantly enhanced seedling growth, increased soil pH, and reduced *Fusarium oxysporum* f. sp. *radicis-cucumerinum* populations, but the severity of disease was increased. However, the addition of composted media, greenhouse compost, windrow composted dairy solids, and dairy solids VC, to the seeding cavity in a rock wool block medium, followed by inoculation with *F. oxysporum* f. sp. *radicis-cucumerinum*, reduced seedling mortality significantly. Van Heerden *et al.* (1995) used compost prepared from citrus waste of fruit-processing plants. Composted citrus waste inhibited cress seed germination to a greater extent than two commercial composts but it suppressed *Phytophthora nicotianae* and *Phytophthora cinnamomi*. Suppression of *Clavibacter michiganensis* subsp. *michiganensis* (CMM) by composts was studied by Yogev *et al.* (2009) in comparison to conductive peat. Composts based on tomato or pepper residues combined with cattle or chicken manure reduced disease caused by CMM up to 100% under both natural infection and artificial inoculation. Populations of CMM in composts declined to undetectable levels within 15–20 days, while those in peat remained high for 35–40 days. Similarly, the colonization of compost-grown tomato-plant tissues by the pathogen was reduced compared to plants growing in peat or perlite. They conclude that the plant-residue composts can be used for suppression of CMM and serve as a component in integrated-management programs. Chaoui *et al.* (2002) attained suppression of *Pythium* by substituting 10% VCs into a soilless plant growth medium MM360. A similar range of substitutions of sterilized or non-sterilized MM360 and VC also suppressed *Rhizoctonia* infection in radish. Suppression of *Rhizoctonia* by VCs was correlated progressively with increasing rates of substitution of VC. The incidence of *Verticillium* wilt of strawberries in field was also suppressed significantly by the application of 5 and 10 t/ha of commercial paper and food waste VCs.

Disease suppression by compost extract

Compost extract contains water soluble fraction of the compost and it can be used for diverse activities. Singh *et al.* (2003) showed that aqueous extracts of VC (AVC) inhibited spore germination of several fungi. They also affected the development of powdery mildews on balsam (*Impatiens balsamina*) and pea (*Pisum sativum*) caused by *Erysiphe cichoracearum* and *Erysiphe pisi*, respectively, in the field at very low concentrations (0.1–0.5%). Soil amendment with VC (1–5%) also induced synthesis of phenolic acids in pea and maximum phenolic acids were detected in pea plants treated with 4% VC. The induction of phenolic acids in plants was correlated with the degree of resistance in treated as compared to non-treated pea plants. The growth of plants grown in VC-amended soil was also much better than the growth of plants raised in non-amended soil. Similarly, McQuilken *et al.* (1994) used manure-straw mixture compost and water extracts, for biological control of the grey mold pathogen *Botrytis cinerea*. Extracts of all ages inhibited conidial germination and reduced mycelial growth *in vitro*. Mixing extracts of all ages with droplets of suspensions of *B. cinerea* conidia on detached *Phaseolus* bean leaves suppressed lesion development, but only 3- to 8-day-old extracts had an effect when sprayed onto leaves prior to inoculation. On examination, it was found that the extracts contained a large and varied microbial population of actinomycetes, bacteria, filamentous fungi and yeasts and old aged extracts lost activity completely on filter sterilization or autoclaving. Weekly sprays of 8-day-old extracts onto lettuce had no effect on the incidence of grey mould, but significantly reduced its severity and increased marketable yield.

The importance of foliar sprays of VCs for fertilization and biological disease prevention was shown by Zaller (2006). He applied aqueous VC extracts produced from fruit, vegetable and cotton waste as foliar spray and its affect was seen on growth, yields, morphological and chemical fruit quality and natural infection with late blight disease (*Phytophthora infestans*) on tomato. Foliar application of VC extracts did not affect plant growth, biomass or nutrient allocation, or yields significantly but increased fruit circumference consistently as well as contents of nitrogen. He also observed that only half as many VC sprayed plants showed clear signs of *P. infestans* infection compared to water sprayed plants. In the study conducted by Manandhar *et al.* (2008) different types of compost tea (aerated VC tea (ACTV), non aerated VC tea (NCTV), aerated compost tea (ACTC) and non aerated compost tea (NCTV) were tried for suppression of the Foot rot disease of Rice caused by *Fusarium moniliforme* and the result was compared with carbendazim treatment. Among the compost teas, ACTV showed maximum increment of healthy seedlings. In concurrence with field trial experiment, treatment of the rice seeds with compost tea revealed highest efficiency of ACTV in reducing the number of affected seeds. Application of compost tea also increased the germination percentage of seeds, with maximum effect obtained by ACTV. Similarly, extracts prepared from composted cow manure, composted pine bark, an organic farm compost, or composted yard waste, applied as foliar sprays on tomato transplants, resulted in a moderate but statistically significant reduction in the severity of bacterial spot caused by *Xanthomonas vesicatoria*. The population of *X. vesicatoria* in infected leaves was reduced significantly by extracts prepared from composted cow manure. The degree of control provided by foliar sprays with the most effective compost extracts was comparable with the plant activator acibenzolar-*S*-methyl (Al-Dahmani *et al.* 2003). Ozer and Koycu (2006) treated onion seeds with leachates of composts prepared from alfalfa and sunflower stalks, and found that both the composts were able to reduce incidence of black mold pathogen *Aspergillus niger* in sets, but not disease severity in onion seedlings. They found association of fluorescent pseudomonads and *Pantoae agglomerans* in both leachates and the population of *P. agglomerans* was higher in the sunflower compost leachate compared to the alfalfa leachate. Both the tested strains of bacteria were inhibitory to mycelial growth of *A. niger*. Utkhede and Koch (2004) also used concentrated VC tea against CMM *in vitro* and on young tomato seedlings inoculated with the pathogen under greenhouse conditions. They found that VC tea had the ability to prevent the incidence of bacterial canker of tomato plants caused by CMM under greenhouse conditions.

Disease suppression by microbial community of compost

Microbial community in different composts varies and they have a great influence on the overall activity of the compost including disease suppression. Saadi *et al.* (2010) demonstrated that compost suppressiveness against fusarium wilt of melon is retained for at least a year under different storage conditions, without change in the suppressive capacity. They studied relationship of *Fusarium oxysporum* f. sp. *melonis* (FOM) with the dynamics of compost microbial activity and biodegradability. For this purpose, mature suppressive compost, prepared from tomato plants and separated cow manure, was divided into four portions and stored for one year under different temperature and moisture levels. They found that all the composts retained and even enhanced their suppressive capacity during storage. The microbial activity of composts stored under wet conditions was higher than that of those stored under dry condition along with decrease organic matter content. They concluded that high compost microbial populations under wet storage conditions compete and interfere with the saprophytic stage of FOM conidia, between germination and host invasion and reduces infection of FOM. Yasir *et al.* (2010) isolated a novel bacterial species *Chitinophaga vermicomposti* having antifungal properties from VC. McKellar and Nelson (2003) also showed that communities of leaf compost-inhabiting microorganisms that colonize cottonseeds within the first few hours after sowing in a *Pythium*-suppressive compost play a major role in the suppression of *P. ultimum*. Suppressiveness was expressed within the first few hours of seed germination as revealed by reduced *P. ultimum* sporangium germination, reduced seed colonization, and reduced damping-off in transplanted seedlings in contrast to the conducive leaf compost. Microbial consortia recovered from the surface of cottonseeds during the first few hours of germination in suppressive compost were highly effective against the damping-off pathogen, whereas no suppression was observed by the microbes recovered from cottonseeds germinated in conducive compost. The populations of fatty-acid metabolizing bacteria and actinobacteria were higher in suppressive consortia than in conducive consortia and the suppressive consortia could metabolize lenoleic acid rapidly. This shows the importance of fatty acid metabolizing bacteria in suppressive compost for suppression of damping-off caused by *P. ultimum.*

Schonfeld *et al.* (2003) analyzed the effects of compost amendment and simulated solarisation of soil on the survival of *Ralstonia solanacearum* biovar 2 strains 1609, as well as on the indigenous soil bacterial communities. In untreated soil in microcosms and the field, strain 1609 showed slow progressive declines, and in the suppressiveness tests, most of the plants showed symptoms of wilting and pathogen association. Solarisation alone also did not drastically affect *R. solanacearum* survival or plant invasiveness. However, the addition of household compost showed declined *R. solanacearum* population in a drastic rate, as well as lesser diseased plants in suppressiveness tests. On the other hand, combined solarisation and compost addition differed between microcosms and the field as some healthy-looking plants from compost treated soils revealed the latent presence of the pathogen strain 1609 in the lower stem parts. The eubacterial and L-subgroup proteobacterial communities in the two treatments were stable in the microsome but detectable changes were observed in the compost amendment towards the end of the experiment. Similarly, composts prepared from a variety of feedstocks were tested for their ability to suppress seedling and root diseases of creeping bentgrass caused by *Pythium graminicola*. Different batches of a brewery sludge compost and a biosolids compost which were highly suppressive, were initially not suppressive to *Pythium* damping-off but became more suppressive with increasing compost age. Microbial populations also varied among all of the composts tested and the highest populations of heterotrophic fungi and antibiotic-producing actinomycetes were found in all batches of the brewery sludge compost. Heat treatment of suppressive composts also reduced microbial populations as well as disease suppressiveness and the suppressive effect was restored by amending heated composts with small amounts of non-heated compost. A significant level of suppressiveness was also evident in field conditions. The study also indicated suppressiveness of the relationship between *Pythium* diseases by brewery sludge and biosolids composts to the microbial activities in the composts (Craft and Nelson 1996).

Chen and Nelson (2008) in an interesting study determined that seed-colonizing microbial consortia from municipal biosolids compost significantly suppressed *Pythium* damping-off on cucumber, wheat, and pea. The suppression of damping-off on cucumber and wheat was evident as early as 8 h of sowing and could be eliminated by autoclaving the compost prior to sowing. Therefore, they concluded that compost-induced suppression of *P. ultimum* damping-off of cucumber and wheat is due to microbial consortia colonizing on the seeds within 8 h of sowing. Rivera *et al.* (2004) also evaluated the suppressive effects of different concentrations of VC against the tomato seedling basal rot pathogen *Rhizoctonia solani*, and the ability of VC to promote tomato seedlings growth. The microbial composition of the substratum was also explored and out of thirty six microorganisms isolated, 13 were antagonistic to *R. solani in vitro*. The addition of VC promoted seedlings growth as well as prevented damping-off. Similarly, compost prepared from organic household and garden waste was used to substitute part of the peat in potting mixtures and its effect on colonization by *R. solani* (AG 1) on cucumber was observed. Long matured 20% compost from two commercial composting facilities suppressed growth of *R. solani* in the potting mixtures. In contrast, short-matured compost from the same batches stimulated pathogen growth. *In vitro* mycelial growth of *R. solani* on mixtures with mature compost was inhibited by high population densities of cellulolytic and oligotrophic actinomycetes. The ratio of the population density of actinomycetes to that of other bacteria was around 200-fold higher in mature suppressive compost than in conducive compost (Tuitert *et al.* 1998).

Enhanced disease suppression by compost through microbe fortification

The inherent property of compost for disease suppression could be enhanced through external fortification of the compost with antagonistic microbes. Nakasaki *et al.* (1998) enhanced disease suppressiveness of compost for disease prevention by incorporation of a suppressive bacterium to the VC material. They used grass clippings discharged from golf courses as the raw material for production of a suppressive compost to control *Rhizoctonia* large-patch disease in mascarene grass followed by incorporation of *Bacillus subtilis* N4, a mesophilic bacterium with suppressive effects on *Rhizoctonia solani* AG2-2 in the composting material. Similarly, the effects of three composts (C1, C2 and C3) produced from Solid Olive Mill wastes, *Posidonia oceanica* and Chicken Manure, at different proportions, were seen on *Pythium aphanidermatum* by Jenana *et al.* (2009). Pure extracts inhibited growth of the pathogen *in vitro*. *In vivo* tests also showed resistance towards *P. aphanidermatum* where tomato seedlings were drench inoculated with the composts. However, root dip inoculated seedlings had a more sustained growth in substrates mixed with composts further confirming the disease suppressive ability of composts. Zhang *et al.* (1998) also used another biocontrol agent-fortified compost mix for induction of systemic acquired resistance (SAR) in cucumber against anthracnose caused by *Colletotrichum orbiculare* and in Arabidopsis against bacterial speck caused by *Pseudomonas syringae* pv. *maculicola* KD4326. They found that a peat mix conducive to soil-borne diseases did not induce SAR. The compost mix reduced infection of *P. syringae* pv. *maculicola* KD4326 significantly in Arabidopsis plants grown in the compost mix compared to those grown in the peat mix. Interestingly, autoclaving destroyed the SAR-inducing effect of the compost mix, and the effect was restored by inoculation of the autoclaved mix with non-autoclaved compost mix, suggesting the SAR-inducing activity of the compost mix was of biological origin. Topical sprays with water extract prepared from the compost mix reduced symptoms of bacterial speck and the population size of the pathogen in Arabidopsis grown in the peat mix but not in the compost mix. In contrast, the peat mix water extract applied as a spray did not control bacterial speck on plants grown in either mix. The activity of the compost water extract was heat stable and filterable through a 0.2-μm membrane. β-1,3-Glucanase activity was induced to significantly higher levels in plants grown in the compost mix than in plants grown in the peat mix after the pathogen challenge, suggesting that compost-induced disease suppression was more likely involved in the potentiation of resistance responses rather than their activation and that compost-induced SAR is different from SAR induced by pathogens, salicylic acid, or compost water extract. Similarly, Sahni *et al.* (2008) adopted an integrated approach for the management of collar rot of chickpea caused by *Sclerotium rolfsii*, which is otherwise very difficult to control, by using VC and an antagonistic strain of *Pseudomonas syringae* (PUR46) possessing plant growth-promoting characteristics. Treatments with VC and PUR46 alone and in combination reduced seedling mortality in chickpea under glasshouse conditions. The combined effect of 25% VC substitution along with seed bacterization with PUR46 was the most effective treatment, which not only increased the availability and uptake of minerals like P, Mn, and Fe in chickpea seedlings, resulting in an increase in plant growth, but also reduced plant mortality. These effects are correlated with improvement in soil physical conditions and enhanced nutritional factors due to VC substitution as well as plant growth promotion and the antagonistic activity of PUR46 against the pathogen. Performance of PUR46 was enhanced in the presence of 25% VC compared with its application alone and they concluded that this combination will be useful to manage *S. rolfsii* under field conditions.

Disease suppressiveness of VC produced from agricultural wastes consisting of cattle manure, tree bark (*Salix* spp.), potato culls, and apples alone and in blend with *Trichoderma harzianum* was assayed on damping-off of cucumber seedlings infected by *Rhizoctonia solani* (AG-4). Disease suppression effect increased in proportion to the pot amendment rate of VC and lone application of VCs effectively controlled damping-off of cucumber. Plant growth promotion in blended and non-blended VC was comparable. Water extracts of VC also inhibited growth of *R. solani in vitro* which upon heat sterilization eliminated the suppressive and antagonistic effect showing antagonistic activity associated with compost microorganisms (Ersahin *et al.* 2009). In another experiment, Sathianarayanan and Khan (2008) used composts and VCs of coffee husk, coir pith and cow manure with *Trichoderma viride* as inoculant. Extracts of compost and VC suppressed the growth of the pathogen *R. solani* and the percentage of growth inhibition was higher in the media amended with the extracts of coir pith VC followed by extract of coffee husk VC. Pathogen suppression by cow manure VC was not retained longer. Growth suppression of *R. solani* by coir pith vermicasts was attributed partly to higher potassium content, which helps in the absorption of plant nutrients along with high nitrogen and phosphates availability leading to enhanced plant growth promotion and thereby disease resistance. In a similar way, plant growth media when amended with composted bark suppressed Fusarium wilts whereas media amended with composted municipal sludge aggravated this disease. However, a compost prepared from vegetable and animal market wastes, sewage sludge and yard wastes showed a high ability to suppress Fusarium wilt of tomato caused by *Fusarium oxysporum* f. sp. *lycopersici* race 1. The suppressive ability of the compost was compared with that of a peat mix (peat: vermiculite, 1: 1, v/v) conducive to the pathogen and a naturally suppressive soil from Chateaurenard, France. Amendment with this compost significantly increased the suppressiveness of the peat mix. The bacterial populations and microbial activity were highest in the compost and the compost–peat mix. The suppressiveness of the substrates was restored by inoculation of *Trichoderma asperellum* isolate isolated from natural compost–peat mix, and the nonpathogenic biocontrol agent *F. oxysporum* Fo47 isolated from Chateaurenard soil into sterilized compost–peat mix and Chateaurenard soil, respectively (Cotxarrera *et al.* 2002).

Disease suppression by compost through microbe-mediated induction of resistance

Composts have also been shown to induce resistance in the plants systemically against a variety of pathogens. The induced resistance potential of some compost samples originated from four different countries (Greece, France, Netherlands and Israel) and manufactured from various raw materials was evaluated in an *Arabidopsis thaliana–Verticillium dahliae* pathosystem under greenhouse conditions (Paplomatas *et al.* 2005). Five out of 11 composts showed significant disease suppressiveness compared to the control treatment. Two of them were further evaluated under field conditions against Verticillium wilt of eggplant but neither of them significantly reduced disease severity. However, as a consequence of a growth-promoting effect, one of the compost samples tested in the field resulted in a significant yield increase compared with the other. Vallad *et al.* (2003) also reported that plants grown in soils with composted paper mill residuals (PMR)-amendments were resistant to the bacterial speck pathogen *Pseudomonas syringae* pv. *tomato* (Pst) due to induction of plant resistance, similar to SAR. The identity of the PMR elicitor(s) is unknown, but it is heat labile. *Arabidopsis thaliana* grown in soil amended with PMR compost exhibited reduced bacterial speck symptoms compared to plants grown in soil amended with a non-composted PMR or non-amended soils. Similar results were obtained with tomato also. However, no relationship between foliar disease suppression and plant nutrition or stature was observed. An *Arabidopsis npr1* defense mutant and a *NahG* transgenic line, both disrupted in SAR, were also unable to suppress bacterial speck symptoms in composted PMR treatments. Arabidopsis grown in soil amended with composted PMR also displayed an increased expression of pathogenesis-related (PR) defense genes prior to pathogen inoculation showing the responsiveness of SAR pathway to PMR compost. Similarly, a transgenic GUS-expressing strain of *Fusarium oxysporum* f.sp. *radicis-lycopersici* was used by Kavroulakis *et al.* (2005) to see its penetration in roots of tomato plants grown on a compost mix made from grape marc wastes and extracted olive press cake (GM-EPC). The plants exhibited an enhanced resistance against the pathogen compared to the plants grown on peat. Moreover, the sterilized compost extract was also able to protect the plants. Systemic resistance was also induced by GM-EPC compost against the foliar pathogen *Septoria lycopersici* and expressed PR genes in leaves of tomato plants. They concluded that induction of plant defense response was the main mechanism of biological control mediated by the GM-EPC compost.

Compost modulates microbial community and disease suppression

The microbial community in the compost is also determined by the nature of the compost which can have an impact on disease suppression. Cellulose is the most abundant polymer in nature and constitutes a large pool of carbon for decomposing soil microbes. Cellulolysis takes place due to the result of the combined action of fungi and bacteria. Earthworms influence decomposition indirectly by affecting microbial population structure and dynamics and also directly because the guts of some species possess cellulolytic activity. To evaluate the role of *Eisenia fetida* in cellulose decomposition, Aira *et al.* (2006) carried out an experiment in which pig slurry, a microbial-rich substrate, was treated in small-scale vermireactors with and without earthworms. The presence of earthworms in vermireactors significantly increased the rate of cellulose decomposition through increased microbial biomass and cellulase and β-glucosidase activities. The activity of *E. fetida* also triggered fungal growth during vermicomposting. Similarly, four commercial composts were added to soil and their effect on plant growth, total rhizosphere microflora, and incidence of plant growth-promoting rhizobacteria in the rhizosphere of tomato plants was seen. The results showed that the addition of composts to soil increased the incidence of siderophore producing bacteria in the tomato rhizosphere exhibiting antagonism towards *Fusarium oxysporum* f. sp. *radicis-lycopersici*, *Pyrenochaeta lycopersici*, *Pythium ultimum*, and *Rhizoctonia solani*. The results suggest that compost may stimulate the proliferation of antagonists in the rhizosphere and protect plants from soil-borne root pathogens (de Brito Alvarez *et al.* 1995). In the same way, Suárez-Estrella *et al.* (2007) conducted a study to see the effect of pathogen infected horticultural waste composting on the viability of pathogenic fungi and bacteria by mixing infected material throughout compost. They observed disappearance of these microorganisms during the initial phase of composting and the bacterial pathogens showed a greater capacity to persist during composting than the fungi.

Disease suppression by compost humic fractions

The HA fractions from various composts also have a disease suppressive effect. The effect of addition of a municipal solid waste compost and its water-soluble and humic fraction were studied to see the suppressive effect on *Pythium ultimum* on pea plants and compared with that of metalaxyl (Pascual *et al.* 2002). The addition of whole composts and their humic fractions into soil reduced the number of root lesions and *Pythium* populations significantly and promoted plant growth. Although, the greatest pathogen suppression was achieved with metalaxyl, it had a significant negative impact on the nontarget bacteria and fungi as well as on beneficial soil microorganisms including *Trichoderma* and *Pseudomonas*. However, addition of compost and humic fractions increased population size of nontarget and specific biocontrol microorganisms. Similarly, HAs isolated from empty fruit bunch of oil palm compost (EFB-HA) and commercial grade HA were found to be inhibitory on the conidial germination and mycelial growth of *Choanephora cucurbitarum*. Higher fungicidal activity was seen with increase in HA concentrations. The maximum inhibition of conidial germination was exerted by EFB-HA at the highest concentration (1000 mg L^{-1}) and it was concluded that the efficiency of HA was apparently related to HA origin and nature apart from its concentration (Siddiqui *et al.* 2009).

Suppression of plant parasitic nematode

Apart from the suppression of soil borne fungal and bacterial phytopathogens, VC can also modify the population of nematodes (Villenave *et al.* 2010). Commercial VCs, produced from cattle manure, food and recycled paper wastes, were applied at different rates along with inorganic fertilizers to field plots planted with tomatoes, bell peppers, strawberries or grapes and compared the populations of plant parasitic nematodes in inorganic fertilizers applied plots only. Populations of plant-parasitic nematodes were depressed significantly by the three VCs in all four field experiments compared with those in plots treated with inorganic fertilizer. Conversely, populations of fungivorous and bacterivorous nematodes were increased in the VC amended plots (Arancon *et al.* 2002). Similarly, the effects of VCs on plant parasitic, fungivorous and bacterivorous nematode populations were investigated in grape and strawberry field crops by Arancon *et al.* (2003b). Commercially-produced VCs derived from recycled paper, and supermarket food waste were applied to plots at different rates for the two crops along with inorganic fertilizer to balance the initial availability of macronutrients especially N, to the crop in all plots. Soils from all of the VC-treated plots contained smaller populations of plant parasitic nematodes than soil from inorganic fertilizer-treated plots. Interestingly, populations of fungivorous nematodes and to lesser extent bacterivorous nematodes increased in the VC-treated plots compared to the inorganic fertilizers treated plots.

CONCLUSION

Amendment of organic matter is soil or horticultural container medium with either compost or VC is essential to improve the soil physical, chemical and biological properties which subsequently enhance plant growth substantially. The enhancement in growth is mainly attributed to enhanced nutrient uptake by plants, action of the HA fractions, and PGRs. It also helps in suppression of soil borne diseases through suppressive microbial communities present in the composted organic matter as well as induces systemic resistance against the foliar pathogens.

REFERENCES

Ahmad R, Azeem M, Ahmad N (2009) Productivity of ginger (*Zingiber officinale*) by amendment of vermicompost and biogas slurry in saline soils. *Pakistan Journal of Botany* **41**, 3107-3116

Aira M, Monroy F, Domínguez J (2006) *Eisenia fetida* (Oligochaeta, Lumbricidae) activates fungal growth, triggering cellulose decomposition during vermicomposting. *Microbial Ecology* **52**, 738-747

Albaho M, Bhat N, Abo-Rezq H, Thomas B (2009) Effect of three different substrates on growth and yield of two cultivars of *Capsicum annuum. European Journal of Scientific Research* **28**, 227-233

Al-Dahmani JM, Abbasi PA, Miller SA, Hoitink HAJ (2003) Suppression of bacterial spot of tomato with foliar sprays of compost extracts under greenhouse and field conditions. *Plant Disease* **87**, 913-919

Arancon N, Edwards CA, Yardim F, Lee S (2002) Management of plant parasitic nematodes by use of vermicomposts. *Proceedings of the Brighton Crop Protection Conference – Pests and Diseases*, Vol. II, 8B-2, pp 705-710

Arancon NQ, Edwards CA, Atiyeh R, Metzger JD (2004a) Effects of vermicomposts produced from food waste on the growth and yields of greenhouse peppers. *Bioresource Technology* **93**, 139-144

Arancon NQ, Edwards CA, Babenko A, Cannon J, Galvis P, Metzger JD (2008) Influences of vermicomposts, produced by earthworms and microorganisms from cattle manure, food waste and paper waste, on the germination, growth and flowering of petunias in the greenhouse. *Applied Soil Ecology* **39**, 91-99

Arancon NQ, Edwards CA, Bierman P, Welch C, Metzger JD (2004b) Influences of vermicomposts on field strawberries: 1. Effects on growth and yields. *Bioresource Technology* **93**, 145-153

Arancon NQ, Edwards CA, Bierman P, Metzger JD, Lee S, Welch C (2003a) Effects of vermicomposts on growth and marketable fruits of field-grown tomatoes, peppers and strawberries. *Pedobiologia* **47**, 731-735

Arancon NQ, Galvis P, Edwards C, Yardim E (2003b) The trophic diversity of nematode communities in soils treated with vermicompost. *Pedobiologia* **47**, 736-740

Asciutto K, Rivera MC, Wright ER, Morisigue D, López MV (2006) Effect of vermicompost on the growth and health of *Impatiens wallerana*. *International Journal of Experimental Botany* **75**, 115-123

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. *Bioresource Technology* **78**, 11-20

Atiyeh RM, Edwards CA, Subler S, Metzger JD (2000) Earthworm processed organic wastes as components of horticultural potting media for growing marigold and vegetable seedlings. *Compost Science and Utilization* **8**, 215-223

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

Baskaran L, Sankar Ganesh K, Chidambaram ALA, Sundaramoorthy P (2009) Amelioration of sugar mill effluent polluted soil and its effect of greengram (*Vigna radiata* L.). *Botany Research International* **2**, 131-135

Boulter JI, Boland GJ, Trevors JT (2002) Assessment of compost for suppression of Fusarium patch (*Microdochium nivale*) and Typhula blight (*Typhula ishikariensis*) snow molds of turfgrass. *Biological Control* **25**, 162-172

Canellas LP, Piccolo A, Dobbss LB, Spaccini R, Olivares FL, Zandonadi DB, Arnoldo R, Façanha AR (2010) Chemical composition and bioactivity properties of size-fractions separated from a vermicompost humic acid. *Chemosphere* **78**, 457-466

Chamani E, Joyce DCA, Reihanytabar A (2008) Vermicompost effects on the growth and flowering of *Petunia hybrida* 'Dream Neon Rose'. *American-Eurasian Journal of Agriculture and Environmental Sciences* **3**, 506-512

Chaoui H, Edwards CA, Brickner A, Lee SS, Arancon NQ (2002) Suppression of the plant diseases, *Pythium* (damping-off), *Rhizoctonia* (root rot) and *Verticillium* (wilt) by Vermicomposts. *Proceedings of Brighton Crop Protection Conference – Pests and Diseases* Vol II, 8B-3, pp 711-716

Chen MH, Nelson EB (2008) Seed-colonizing microbes from municipal biosolids compost suppress *Pythium ultimum* damping-off on different plant species. *Phytopathology* **98**, 1012-1018

Cotxarrera L, Trillas-Gay MI, Steinberg C, Alabouvette C (2002) Use of sewage sludge compost and *Trichoderma asperellum* isolates to suppress Fusarium wilt of tomato. *Soil Biology and Biochemistry* **34**, 467-476

Craft CM, Nelson EB (1996) Microbial properties of composts that suppress damping-off and root rot of creeping bentgrass caused by *Pythium graminicola*. *Applied and Environmental Microbiology* **62**, 1550-1557

de Brito Alvarez MA, Gagné S, Antoun H (1995) Effect of compost on rhizosphere microflora of the tomato and on the incidence of plant growth-promoting rhizobacteria. *Applied and Environmental Microbiology* **61**, 194-199

Dobbss LB, Canellas LP, Olivares FL, Aguiar NO, Peres LE, Azevedo M, Spaccini R, Piccolo A, Façanha AR (2010) Bioactivity of chemically transformed humic matter from vermicompost on plant root growth. *Journal of Agriculture and Food Chemistry* **58**, 3681-3688

Ersahin YS, Haktanir K, Yanar Y (2009) Vermicompost suppresses *Rhizoctonia solani* Kühn in cucumber seedlings. *Journal of Plant Diseases and Protection* **116**, 182-188

García-Gómez RC, Luc D, Gutierrez-Miceli FA (2008) Vermicomposting leachate (worm tea) as liquid fertilizer for maize (*Zea mays* L.) forage production. *Asian Journal of Plant Sciences* **7**, 360-367

Gutiérrez-Miceli FA, Moguel-Zamudio B, Abud-Archila M, Gutiérrez-Oliva VF (2008) Sheep manure vermicompost supplemented with a native diazotrophic bacteria and mycorrhizas for maize cultivation. *Bioresource Technology* **99**, 7020-7026

Hameeda B, Harini G, Rupela OP, Reddy G (2007) Effect of composts or vermicomposts on sorghum growth and mycorrhizal colonization. *African Journal of Biotechnology* **6**, 9-12

Jenana RKB, Haouala R, Triki MA, Godon JJ, Hibar K, Khedher MB, Henchi B (2009) Composts, compost extract and bacterial suppressive action on *Pythium aphanidermatum* in tomato. *Pakistan Journal of Botany* **41**, 315-327

Jeyabal A, Kuppuswamy G (2001) Recycling of organic wastes for the production of vermicompost and its response in rice–legume cropping system and soil fertility. *European Journal of Agronomy* **15**, 153-170

Kale RD, Karmegam N (2010) The role of earthworms in tropics with emphasis on Indian ecosystems. *Applied and Environmental Soil Science* **2010**, 414356, 16 pp

Karmegam N, Daniel T (2008) Effect of vermicompost and chemical fertilizer on growth and yield of hyacinth bean, *Lablab purpureus* (L.) Sweet. *Dynamic Soil, Dynamic Plant* **2 (1&2)**, 77-81

Kavroulakisa N, Ehaliotisa C, Ntougiasa S, Zervakisa GI, Papadopouloua KK (2005) Local and systemic resistance against fungal pathogens of tomato plants elicited by a compost derived from agricultural residues. *Physiological and Molecular Plant Pathology* **66**, 163-174

Kumari MSS, Ushakumari K (2002) Effect of vermicompost enriched with rock phosphate on the yield and uptake of nutrient in cowpea (*Vigna unguiculata* L. Walp.). *Journal of Tropical Agriculture* **40**, 27-30

Lazcano C, Sampedro L, Zas R, Domínguez J (2010) Vermicompost enhances germination of the maritime pine (*Pinus pinaster* Ait.). *New Forests* **39**, 387-400

Manandhar T, Yami KD (2008) Biological control of foot rot disease of rice using fermented products of compost and vermicompost. *Scientific World* **6**, 52-57

McKellar ME, Nelson EB (2003) Compost-induced suppression of *Pythium* damping-off is mediated by fatty-acid-metabolizing seed-colonizing microbial communities. *Applied and Environmental Microbiology* **69**, 452-460

McQuilken MP, Whipps JM, Lynch JM (1994) Effects of water extracts of a composted manure-straw mixture on the plant pathogen *Botrytis cinerea. World Journal of Microbiology and Biotechnology* **10**, 20-26

Nakasaki K, Hiraoka S, Nagata H (1998) A new operation for producing disease-suppressive compost from grass clippings. *Applied and Environmental Microbiology* **64**, 4015-4020

Ndegwa PM, Thompson SA (2001) Integrating composting and vermicomposting in the treatment and bioconversion of biosolids. *Bioresource Technology* **76**, 107-112

Ozer N, Koycu ND (2006) The ability of plant compost leachates to control black mold (*Aspergillus niger*) and to induce the accumulation of antifungal compounds in onion following seed treatment. *BioControl* **51**, 229-243

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. *Journal of the Science of Food and Agriculture* **89**, 2383-2392

Paplomatas EJ, Tjamos SE, Malandrakis AA, Kafka AL, Zouvelou SV (2005) Evaluation of compost amendments for suppressiveness against Verticillium wilt of eggplant and study of mode of action using a novel *Arabidopsis* pathosystem. *European Journal of Plant Pathology* **112**, 183-189

Pascual JA, García C, Hernández T, Lerma S, Lynch JM (2002) Effectiveness of municipal waste compost and its humic fraction in suppressing *Pythium ultimum. Microbial Ecology* **44**, 59-68

Peyvast G, Olfati JA, Madeni S, Forghani A, Samizadeh H (2008) Vermicompost as a soil supplement to improve growth and yield of parsley. *International Journal of Vegetable Science* **14**, 82-92

Pharand B, Carisse O, Benhamou N (2002) Cytological aspects of compost-mediated induced resistance against fusarium crown and root rot in tomato. *Phytopathology* **92**, 424-438

Rivera MC, Wright ER, López MV, Garda D, Barragué MY (2004) Promotion of growth and control of damping-off (*Rhizoctonia solani*) of greenhouse tomatoes amended with vermicompost. *International Journal of Experimental Botany* **53**, 229-235

Rose S, Parker M, Punja ZK (2003) Efficacy of biological and chemical treatments for control of Fusarium root and stem rot on greenhouse cucumber. *Plant Disease* **87**, 1462-1470

Saadi I, Laor Y, Medina S, Krassnovsky A, Raviv M (2010) Compost suppressiveness against *Fusarium oxysporum* was not reduced after one-year storage under various moisture and temperature conditions. *Soil Biology and Biochemistry* **42**, 626-634

Sahni S, Sarma BK, Singh DP, Singh HB, Singh KP (2008) Vermicompost enhances performance of plant growth-promoting rhizobacteria in *Cicer arietinum* rhizosphere against *Sclerotium rolfsii*. *Crop Protection* **27**, 369-376

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. *Journal of Food, Agriculture and Environment* **7**, 869-872

Sathianarayanan A, Khan AB (2008) An eco-biological approach for resource recycling and pathogen (*Rhizoctonia solani* Kuhn.) suppression. *Journal of Environmental Protection Science* **2**, 36-39

Schonfeld J, Gelsomino A, Overbeek LSV, Gorissen A, Smalla K, Elsas JDV (2003) Effects of compost addition and simulated solarisation on the fate of *Ralstonia solanacearum* biovar 2 and indigenous bacteria in soil. *FEMS Microbiology Ecology* **43**, 63-74

Siddiqui Y, Meon S, Ismail R, Rahmani M, Ali A (2009) *In vitro* fungicidal activity of humic acid fraction from oil palm compost. *International Journal of Agriculture and Biology* **11**, 448-452

Singh UP, Maurya S, Singh DP (2003) Antifungal activity and induced resistance in pea by aqueous extract of vermicompost and for control of powdery mildew of pea and balsam. *Journal of Plant Diseases and Protection* **110**, 544-553

Suárez-Estrella F, Vargas-Garcı MC, López MJ, Moreno J (2007) Effect of horticultural waste composting on infected plant residues with pathogenic bacteria and fungi: Integrated and localized sanitation. *Waste Management* **27**, 886-892

Suthar S (2009) Impact of vermicompost and composted farmyard manure on growth and yield of garlic (*Allium sativum* L.) field crop. *International Journal of Plant Production* **3**, 27-38

Tuitert G, Szczech M, Bollen GJ (1998) Suppression of *Rhizoctonia solani* in potting mixtures amended with compost made from organic household waste. *Phytopathology* **88**, 764-773

Utkhede R, Koch C (2004) Biological treatments to control bacterial canker of greenhouse tomatoes *BioControl* **49**, 305-313

Vallad GE, Cooperband L, Goodmana RM (2003) Plant foliar disease suppression mediated by composted forms of paper mill residuals exhibits molecular features of induced resistance. *Physiological and Molecular Plant Pathology* **63**, 65-77

van Heerden I, Wehner FC, Kotzé JM (1995) Citrus waste compost for control of root-infecting *Phytophthora* species. *South African Avocado Growers' Association Yearbook* **18**, 38-40

Villenave C, Rabary B, Kichenin E, Djigal D, Blanchart E (2010) Earthworms and plant residues modify nematodes in tropical cropping soils (Madagascar): A mesocosm experiment. *Applied and Environmental Soil Science Volume* **2010**, 323640, 7 pages

Warman PR, Anglopex MJ (2010) Vermicompost derived from different feedstocks as a plant growth medium. *Bioresource Technology* **101**, 4479-4483

Yasir M, Aslam Z, Song GC, Bibi F, Jeon CO, Chung YR (2010) *Chitinophaga vermicomposti* sp. nov., with antifungal activity, isolated from vermicompost. *International Journal of Systematic and Evolutionary Microbiology* **60**, 580-584

Yogev A, Raviv MB, Kritzman G, Hadar Y, Cohen R, Kirshner B, Katan J (2009) Suppression of bacterial canker of tomato by composts. *Crop Protection* **28**, 97-103

Zaller JG (2006) Foliar spraying of vermicompost extracts: Effects on fruit quality and indications of late-blight suppression of field-grown tomatoes. *Biological Agriculture and Horticulture* **24**, 165-180

Zaller JG (2007) Vermicompost as a substitute for peat in potting media: Effects on germination, biomass allocation, yields and fruit quality of three tomato varieties. *Scientia Horticulturae* **112**, 191-199

Zhang W, Han DY, Dick WA, Davis KR, Hoitink HAJ (1998) Compost and compost water extract-induced systemic acquired resistance in cucumber and *Arabidopsis*. *Phytopathology* **88**, 450-455