Chapter 9
Vermicompost, Its Applications and Derivatives

Abstract Vermicomposts are products derived from the accelerated biological degradation of organic wastes by interactions between earthworms and microorganisms as we have discussed in previous chapters. Earthworms consume and fragment the organic wastes into finer particles by passing them through a grinding gizzard, and they derive their nourishment from the microorganisms that grow on the organic matter. The process accelerates the rates of microbiological decomposition of the organic matter, increases microbial populations, and alters the physical and chemical properties of the material, leading to accelerated humification, during which the unstable organic matter is fully oxidized and stabilized (Albanell et al. Biol Fertil Soils 6:266–269, 1988). Vermicomposts are finely divided peat-like materials with high porosity, aeration, and drainage and good water-holding capacities (Edwards and Burrows. The potential of earthworm composts as plant growth media. In: Edwards CA, Neuhauser E (eds) Earthworms in waste and environmental management. SPB Academic Press, The Hague, pp 21–32, 1988; Edwards and Arancon. BioCycle 45:51–53, 2004). High-quality vermicompost has a good physical texture and color, no odors, and few contaminants or pollutants (Edwards. Breakdown of animal, vegetable and industrial organic wastes by earthworms. In: Edwards CA, Neuhauser EF (eds) Earthworms in waste and environmental management. SPB, The Hague, pp 21–31, 1988; Edwards and Arancon. BioCycle 45:51–53, 2004). Vermicomposts are suitable both as plant growth media and as soil amendments. Graphical representation of percentage recovery of vermicasts from earthworms is shown in Fig. 9.1.

Keywords Physico-chemical properties • Biological properties • Soil fertility • Plant growth promotion • Pathogen control • Pest control • Vermiwash • Vermicompost tea • Vermicomposting leachate

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9.1 General

Vermicomposts are products derived from the accelerated biological degradation of organic wastes by interactions between earthworms and microorganisms as we have discussed in previous chapters. Earthworms consume and fragment the organic wastes into finer particles by passing them through a grinding gizzard, and they derive their nourishment from the microorganisms that grow on the organic matter. The process accelerates the rates of microbiological decomposition of the organic matter, increases microbial populations, and alters the physical and chemical properties of the material, leading to accelerated humification, during which the unstable organic matter is fully oxidized and stabilized (Albanell et al. 1988). Vermicomposts are finely divided peat-like materials with high porosity, aeration, and drainage and good water-holding capacities (Edwards and Burrows 1988; Edwards and Arancon 2004). High-quality vermicompost has a good physical texture and color, no odors, and few contaminants or pollutants (Edwards 1988; Edwards and Arancon 2004). Vermicomposts are suitable both as plant growth media and as soil amendments. Graphical representation of percentage recovery of vermicasts from earthworms is shown in Fig. 9.1.

9.2 Physical Properties

Vermicomposts are dark and homogeneous, with a mull-like soil odor. They have greatly increased surface areas, providing more microsites for microbial decomposing organisms, and strong adsorption and retention of nutrients (Shi-wei and Fu-zhen 1991). Albanell et al. (1988) reported that vermicomposts tend to have pH

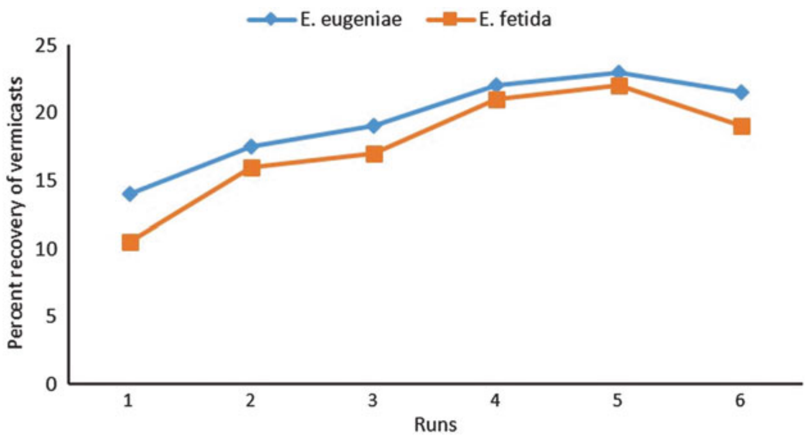

Fig. 9.1 Percent recovery of vermicasts from *E. eugeniae* and *E. fetida* with *Colocasia* as feed (Reproduced from Kurien and Ramasamy 2006)

values near neutrality, which may be due to the production of CO_2 and the organic acids produced during microbial metabolism. Elvira et al. (1995) reported that humification rates were increased significantly in paper-pulp mill sludge processed by the earthworm *Eisenia andrei* (Bouché). The transformations into humic compounds during passage through the earthworm gut showed that the rates of humification of ingested organic matter were intensified during gut transit (Kretzschmar 1984). In a finished vermicompost, the organic-matter content should be greater than 20–25 % (but probably less than 50 %). The ash content is simply the nonvolatile solids of the compost, excluding inert particulate materials such as glass, metal, plastic, gravel, and large clay aggregates. In high-quality vermicomposts, contamination with inert materials should be very low, less than 0.5–1.0 % by weight. Bulk density is an important physical property of vermicomposts that influences other factors critical to plant growth, such as porosity, aeration, and moisture-holding capacity, and so on. For organic materials suitable for potting media, pore space should occupy 70–80 % of the total volume. High bulk density usually has the disadvantage of increasing the transport cost of the container medium, and reducing porosity and air capacity, which should be avoided as far as possible in commercial culture media. However, very low bulk density can cause excessive aeration of the substrate and concomitantly a decline in available water. de Boodt and Verdonck (1972) proposed optimum physical properties for an ideal substrate for plant growth: as a minimum 85 % total porosity, container capacity between 55 % and 75 %, and air space between 20 % and 30 %. The percentage air space (10.04 %) of the vermicompost can be defined as the percentage by volume of air-filled macropores in a saturated substrate (Beeson 1996). The percentage total porosity is the sum of air-filled macropores and water-filled micropores in a saturated substrate. High-quality vermicomposts should typically have a relatively fine maximum particle size (less than 0.2 mm (0.007 in) diameter). Moisture contents of vermicomposts should be between 75 % and 90 % during processing, but moisture contents may vary widely in finished vermicomposts. Moisture content of a vermicompost can be modified by adding water or by drying. Vermicomposts outstanding physicochemical and biological properties make them excellent materials to use as amendments to greenhouse container growth media, as organic fertilizers, or as soil amendments for various horticultural crops.

9.3 Chemical Properties

The chemical composition of vermicomposts is determined partly by the degree of earthworm activity and the conditions they have been exposed to but mainly by the composition of the parent wastes used (Tables 9.1 and 9.2). Vermicomposts, especially those produced from animal waste manures, usually contained greater quantities of mineral elements than commercial plant growth media, and many of these elements were in forms that could be taken up more readily by the plants, such as nitrates, exchangeable P, and soluble K, Ca, and Mg (Edwards and Burrows 1988;

Table 9.1 Characteristics of vermicompost prepared from industrial and institutional wastes at different time period (Reproduced from Garg et al. 2006)

	Textile											
	Sludge				Fibre				Institutional			
Days	EC (ms/cm)	TKN (%)	P (%)	TK (%)	EC (ms/cm)	TKN (%)	P (%)	TK (%)	EC (ms/cm)	TKN (%)	P (%)	TK (%)
0	0.3 ± 0.05	0.12 ± 0.005	0.004 ± 0	0.03 ± 0.05	0.4 ± 0	0.10 ± 0.005	0.026 ± 0	0.082 ± 0.002	0.2 ± 0.05	0.14 ± 0.01	0.04 ± 0	0.035 ± 0.0005
20	0.3 ± 0.05	0.14 ± 0.011	0.006 ± 0.0005	0.031 ± 0.001	0.5 ± 0.05	0.11 ± 0.005	0.03 ± 0.002	0.088 ± 0.003	0.2 ± 0.05	0.16 ± 0.023	0.06 ± 0.001	0.043 ± 0.0005
40	0.5 ± 0.08	0.2 ± 0.020	0.008 ± 0.0008	0.04 ± 0.002	1.2 ± 0.17	0.14 ± 0.011	0.04 ± 0.0005	0.101 ± 0.012	0.3 ± 0.1	0.25 ± 0.04	0.06 ± 0.001	0.047 ± 0.001
60	0.6 ± 0.05	0.2 ± 0.026	0.015 ± 0.0005	0.05 ± 0.002	1.4 ± 0.05	0.22 ± 0.005	0.04 ± 0.0005	0.187 ± 0.015	0.5 ± 0.1	0.37 ± 0.034	0.071 ± 0.001	0.055 ± 0.001
80	1.1 ± 0.1	0.4 ± 0.020	0.0022 ± 0	0.05 ± 0.002	1.8 ± 0.05	0.34 ± 0.025	0.05 ± 0.0001	0.222 ± 0.006	0.6 ± 0.05	0.56 ± 0.011	0.08 ± 0	0.065 ± 0.0005
100	1.6 ± 0.14	0.7 ± 0.023	0.026 ± 0	0.069 ± 0.001	2.4 ± 0.1	0.52 ± 0.043	0.06 ± 0.0001	0.247 ± 0.009	0.7 ± 0.05	0.73 ± 0.04	0.087 ± 0.0005	0.072 ± 0.001

All values are the mean and SD of three replicates

Table 9.2 Characteristics of the vermicompost prepared from kitchen and agricultural wastes at different time period (Reproduced from Garg et al. 2006)

	Kitchen				Agricultural			
Days	EC (ms/cm)	TKN (%)	P (%)	TK (%)	EC (ms/cm)	TKN (%)	P (%)	TK (%)
0	0.4±0.05	0.25±0.005	0.13±0	0.087±0.001	0.3±0.05	0.18±0	0.070±0.003	0.062±0.001
20	0.5±0.05	0.31±0.011	0.13±0.005	0.133±0.003	0.5±0.11	0.20±0.017	0.076±0.0005	0.090±0.001
40	1.4±0.05	0.38±0.01	0.15±0.005	0.195±0.003	0.5±0.11	0.30±0.036	0.080±0.0005	0.141±0.004
60	1.7±0.05	0.56±0.01	0.16±0.011	0.332±0.003	0.6±0.08	0.45±0.034	0.090±0.0005	0.181±0.012
80	1.9±0	0.78±0.034	0.17±0	0.387±0.006	1.4±0.05	0.66±0.096	0.10±0.0005	0.223±0.003
100	2.3±0.05	1.10±0.023	0.18±0	0.436±0.006	1.5±0.05	0.88±0.051	0.10±0.001	0.263±0.006

All values are the mean and SD of three replicates

Arancon et al. 2004a, b). Acceptable pH values of potting media or soils for plant growth range from 5.5 to 8.0, but preferred values range from 6.0 to 7.0. Vermicomposts vary in pH values depending on the parent organic materials from which they are produced; that is, vermicomposts produced from sheep manure had a pH of 8.6, vermicomposts from cattle manure had a pH of 6.0–6.7, and vermicomposts from sewage sludge had pH 7.2. In alkaline vermicomposts specification of the $CaCO_3$ (lime) content may also be appropriate. An adequate cation-exchange capacity for vermicomposts should be in the range of 50–100 meq/L. The total concentration of salts (mineral anions and cations) can reach levels in vermicomposts that inhibit plant growth or are toxic to plants, particularly when vermicompost is produced from animal manure feedstocks. Soluble salt concentrations (measured as electrical conductivity) in saturated extracts of high-quality plant growth media should not exceed 1–2 dS/m (100–200 mS/m) for sensitive plants and seedlings and 2–3 dS/m (200–300 mS/m) for established plants. Usually, vermicomposts have low salt contents because earthworm activity is inhibited at concentrations above 0.5 % (Edwards and Arancon 2004). Pig manure vermicompost had an electrical conductivity of 322 mS/m (Atiyeh et al. 2001a, b). The total carbon content of a vermicompost is directly related to the organic-matter content. Changes in total carbon content can therefore be an important indicator of the degree of stabilization that has occurred during the vermicomposting process. The total content of nitrogen in vermicomposts can range quite widely (from 0.1 % to 2–4 % or more). Total N in vermicomposts derived from pig manure was 0.43 % (Atiyeh et al. 2002). It is an important criterion for determining the overall value of the vermicomposts as a nutrient source. The C:N ratio is one of the most widely used and potentially useful indicators of the stability of organic materials such as composts and vermicomposts. The C:N ratio of microorganisms is generally between 15 and 25, and the C:N ratio of humus is around 11–12. Material that has been sufficiently stabilized will typically have C:N ratios below 20–22. C:N ratios much higher than this may indicate the presence of bioavailable carbon and therefore material that is not completely stabilized. Changes in the C:N ratio from the raw material feedstock to finished product may be as important as the absolute final value, since nitrogen-rich products may not necessarily be completely stabilized, even though their C:N ratios may be low. Orozco et al. (1996) reported that vermicomposting of coffee pulp increased the availability of nutrients such as P, C, and Mg. Werner and Cuevas (1996) reported that most vermicomposts contained adequate amounts of macronutrients, micronutrients, and trace elements of various kinds, but amounts inevitably depended on the type of the parent earthworm feedstock. Edwards (1988) reported larger amounts of mineral nutrients in vermicomposts compared to a commercial plant growth medium. The quantity and quality of the nutrients in vermicomposts can be explained by the accelerated mineralization of organic matter, increased microbial activity, breakdown of polysaccharides, and higher rates of humification achieved during vermicomposting (Albanell et al. 1988; Elvira et al. 1995). During the bioconversion of solid paper-pulp mill sludge by earthworms, it was reported that the total carbohydrate content decreased while the total extractable C, non-humified fraction, and humification rates increased by the end of the experiment (Elvira et al. 1997).

9.4 Enzyme Activity

Research has shown that some enzyme activities are correlated with overall microbial activity, soil fertility, plant growth, and plant disease resistance. During vermicomposting, earthworms enhance selectively the activities of enzymes such as invertase, urease, and alkaline phosphatases, which are of microbial origin.

9.5 Biological Properties

It is generally presumed that the larger the total populations of microorganisms in composts or vermicomposts, the better. Microbial activity and food webs are much higher in vermicomposts than in thermophilic composts, Vermicomposts are rich in bacteria, actinomycetes, fungi, and cellulose degrading bacteria (Edwards 1983; Werner and Cuevas 1996) (Table 9.3). In addition, Tomati et al. (1983) reported that

Table 9.3 Population of different microorganisms present in vermicompost (Reproduced from Pramanik et al. 2007)

Treatments	Total bacterial count ($\times 10^8$)		Cellulolytic fungal count ($\times 10^6$)		Nitrifier population ($\times 10^4$)	
	L_0	L_1	L_0	L_1	L_0	L_1
Cow dung						
M_0	29	32	50	52	4	3
M_1	20	169	72	55	10	13
M_2	16	110	59	45	3	28
M_3	49	49	76	59	49	5
Grass						
M_0	17	19	34	35	2	3
M_1	29	31	44	76	12	11
M_2	25	38	41	52	7	15
M_3	35	30	51	38	13	9
Aquatic weeds						
M_0	13	18	41	43	4	4
M_1	27	33	47	49	9	10
M_2	29	37	43	63	8	12
M_3	35	28	51	48	11	9
MSW						
M_0	9	10	19	17	0.7	1
M_1	17	19	23	20	1.5	2.1
M_2	15	23	21	22	1.7	2.9
M_3	20	17	25	21	2	2.3

L_1 is lime at 5 g/kg and L_0 is control; M_0, M_1, M_2, and M_3 are control and incubation of *Trichoderma viridae, Bacillus polymxa* and *Phenerocrete crysosporium*, respectively at 50 ml/kg earthworm castings, obtained after sludge digestion, had large population of microorganisms, especially bacteria. Vermicomposts contain much larger populations of bacteria (5.7×10^7), fungi (22.7×10^4), and actinomycetes (17.7×10^8) compared with those in conventional thermophilic composts (Nair et al. 1997). *Actinobacteria*, which have potential to suppress fungal pathogens in plants, were reported to be the dominant communities in extracts from paper-sludge vermicomposts (Yasir et al. 2009). Gopal et al. (2009) reported that vermicomposted coconut leaves and cow manure had a greater range of microbial communities than the original substrate. They reported that vermicompost was conducive to multiplication of aerobic heterotrophic bacteria, actinomycetes, *Trichoderma* sp., and *Azotobacter*. Vivas et al. (2009) reported that vermicomposting of olive-mill waste produced more dehydrogenase and other enzyme activities than the parent material or thermophilic compost from the same materials.

9.6 Humates

Various plant growth regulating compounds, particularly PGRs (Plant Growth Regulators), are produced during vermicomposting. Plant growth hormones such as auxins, kinetins and gibberellins could be absorbed by humates and fulvates in vermicomposts and released gradually on a time scale synchronized closely with plant growth. Atiyeh et al. (2002) showed clearly that humates could influence plant growth considerably. Vermicomposts originating from animal manure, sewage sludges or paper-mill sludges have been reported to contain large amounts of humic and fulvic substances (Elvira et al. 1998). Applications of humic substances to soils increased the dry matter yields of corn and oat seedlings; numbers and lengths of tobacco roots; dry weights of shoots, roots, and nodules of soybean, peanut, and clover plants; it also induced shoot and root formation in tropical crops grown in tissue culture. Humates can be extracted from organic materials such as vermicomposts by an acid/alkali fractionation technique (Valdrighi et al. 1996), yielding approximately 4 g humic acids per kilogram (0.064 oz.$1b^{-1}$) of vermicompost (Atiyeh et al. 2001a, b). The plant hormone–like activity of humic acids produced from vermicomposts has been shown to be the most probable mechanism, through plant growth hormones adsorbed onto the complex structure of humic acids (Canellas et al. 2000). The adsorption of plant growth hormones onto humates would allow these relatively transient compounds to persist in soil over the life of crops, be released slowly, and thereby have much greater effects on plant growth over a considerably longer period. Canellas et al. (2000) identified exchangeable auxin groups attached to humic acids that had been extracted from cattle manure vermicompost, following a detailed structural analysis. These complexes enhanced root elongation, lateral root emergence, and plasma membrane H+ATPase activity of maize roots.

9.7 Various Applications of Vermicomposts

9.7.1 Role of Vermicompost in Soil Fertility

Vermicomposts can significantly influence the growth and productivity of plants (Sinha et al. 2009) due to their micro and macro elements, vitamins, enzymes and hormones (Makulec 2002). Vermicomposts contain nutrients such as nitrates, exchangeable phosphorus, soluble potassium, calcium, and magnesium in plant available forms (Edwards 1998) and have large particular surface area that provides many microsites for microbial activity and for the strong retention of nutrients (Shi-wei and Fu-zhen 1991). Uptake of nitrogen (N), phosphorus (P), potassium (K) and magnesium (Mg) by rice (*Oryza sativa*) plant was highest when fertilizer was applied in combination with vermicompost (Jadhav et al. 1997). Nitrogen uptake by ridge gourd (*Luffa acutangula*) was higher when the fertilizer mix contained 50 % vermicompost (Sreenivas et al. 2000). Apart from providing mineralogical nutrients, vermicomposts also contribute to the biological fertility by adding beneficial microbes to soil. Mucus, excreted through the earthworm's digestive canal, stimulates antagonism and competition between diverse microbial populations resulting in the production of some antibiotics and hormone-like biochemicals, boosting plant growth (Edwards and Bohlen 1996). In addition, mucus accelerates and enhances decomposition of organic matter composing stabilized humic substances which embody water-soluble phytohormonal elements and plant-available nutrients at high levels (Edwards and Arancon 2004; Atiyeh et al. 2000a, b).

Adding vermicasts to soil improves soil structure, fertility, plant growth and suppresses diseases caused by soil-borne plant pathogens, increasing crop yield (Singh et al. 2008). Kale (1995) reported the nutrient status of vermicomposts with organic carbon 9.15–17.98 %, total nitrogen 0.5–1.5 %, available phosphorus 0.1–0.3 %, available potassium 0.15 %, calcium and magnesium 22.70–70 mg/100 g, copper 2–9.3 (ppm), zinc 5.7–11.5 (ppm) and available sulphur 128–548 (ppm). Effects of a variety of vermicomposts on a wide array of field crops, vegetable plants, ornamental and flowering plants under greenhouse and field conditions have been documented (Arancon et al. 2004b; Edwards and Burrows 1988; Atiyeh et al. 2000a, b). Vermicomposts are used as alternative potting media due to their low-cost, excellent nutrient status and physiochemical characters. Considerable improvements in plant growth recorded after amending soils with vermicomposts have been attributed to the physico-chemical and biological properties of vermicomposts.

Vermicompost addition favorably affects soil pH, microbial population and soil enzyme activities and also reduces the proportion of water-soluble chemical, which cause possible environmental contamination (Maheswarappa et al. 1999; Mitchell and Edwards 1997). Vermicompost addition increases the macropore space ranging from 50 to 500 (μm), resulting in improved air-water relationship in the soil, favourably affecting plant growth (Marinari et al. 2000). Evaluation of various organic and inorganic amendments on growth of raspberry proves that vermicompost has beneficial buffering capability and ameliorate the damage caused by excess of nutrients which may otherwise cause phytotoxicity (Subler et al. 1998). Thus, vermicompost acts a soil conditioner and a slow-release fertilizer (Atiyeh et al. 2000b). During vermicomposting the heavy metals forms complex, aggregates with humic acids and other polymerized organic fractions resulting in lower availability of heavy metals to the plant, which are otherwise phytotoxic (Dominguez and Edwards 2004). Soil amended with vermicompost produced better quality fruits and vegetables with less content of heavy metals or nitrate, than soil fertilized with mineral fertilizers (Kolodziej and Kostecka 1994).

9.7.2 Role of Vermicompost Bacteria in Biomedical Waste Management

The importance of sewage sludge, biosolids and biomedical waste management by safe, cheap and easy methods need no further emphasis. All these wastes are infectious and have to be disinfected before being disposed into the environment. Biosolids also contain an array of pathogenic microorganisms (Hassen et al. 2001). Biocomposting of wastes bring about biological transformation and stabilization of organic matter and effectively reduces potential risks of pathogens (Masciandaro et al. 2000). Vermicomposting does not involves a thermophilic phase which might increase the risk of using this technology for management of infectious wastes, but surprisingly vermicomposting resulted into a noticeable reduction in the pathogen indicators such as fecal coliform, *Salmonella* sp., enteric virus and helminth ova in biosolids (Sidhu et al. 2001). Vermicomposting of biosolids resulted in the reduction of faecal coliforms and *Salmonella* sp. from 39,000 MPN/g to 0 MPN/g and <3 MPN to <1 MPN/g respectively (Dominguez and Edwards 2004). Vermicomposting of municipal sewage sludge with *L. mauritii* eliminated *Salmonella* and *Escherichia* sp., and the earthworm gut analysis also proved that *Salmonella* sp. ranging $15–17 \times 10^3$ CFU/g and *Escherichia* sp. ranging $10–14 \times 10^2$ CFU/g were completely eliminated in the gut after 70 days of vermicomposting period (Ganesh Kumar and Sekaran 2005). Activities by earthworms on sludge reduced levels of pathogens and odors of putrefaction and accelerated sludge stabilization (Hartenstein 1983). The reduction or removal of these enteric bacterial populations at the end of vermicomposting period, correlates with the findings that earthworm's diet include microorganisms and earthworms ability to selectively digest them (Edwards and Bohlen 1996). Apart from solid waste management, earthworms are also used in sewage water treatment.

Earthworms promote the growth of 'beneficial decomposer bacteria' in wastewater and acts as aerators, grinders, crushers, chemical degraders, and biological stimulators (Sinha et al. 2002). Earthworms also granulate the clay particles and increase the hydraulic conductivity and natural aeration and further grind the silt and sand particles and increase the total specific surface area and thereby enhance adsorption of the organic and inorganic matter from the wastewater. In addition, earthworm's body acts as a 'biofilter' and remove the biological oxygen demand (BOD), chemical oxygen demand (COD), total dissolved solids (TDS) and total suspended solids (TSS) from wastewater by 90 %, 80–90 %, 90–92 % and 90–95 % respectively by 'ingestion' and biodegradation of organic wastes, heavy metals, and solids from wastewater and by their 'absorption' through body walls (Sinha et al. 2008). Reports reveal that vermicomposting converts the infected biomedical waste containing various pathogens viz., *Staphylococcus aureus, Proteus vulgaris, Pseudomonas pyocyaneae* and *Escherichia coli* to an innocuous waste containing commensals like *Citrobactor* freundii and aerobic spore bearing microorganism usually found in the soil and alimentary canal of earthworms (Umesh et al. 2006). Vermicomposting plays a vital role for safe management of biomedical wastes and solid wastes generated from wastewater treatment plants and its bioconversion into valuable composts free from enteric bacterial populations. Depending on the earthworm species, vermicomposting was known to reduce the level of different pathogens such as *Salmonella enteriditis, Escherichia coli*, total and faecal coliforms, helminth ova and human viruses in different types of waste. Direct means of reduction in these microbial numbers during gut passage might be due to the digestive enzymes and mechanical grinding, while indirect means of pathogen removal might be due to promotion of aerobic conditions which could bring down the load of coliforms (Aira et al. 2011).

9.7.3 Role of Vermicompost in Plant Growth Promotion

Use of vermicomposts as biofertilizers has been increasing recently due to its extraordinary nutrient status, and enhanced microbial and antagonistic activity. Vermicompost produced from different parent material such as food waste, cattle manure, pig manure, etc., when used as a media supplement, enhanced seedling growth and development, and increased productivity of a wide variety of crops (Subler et al. 1998; Atiyeh et al. 2000a). Vermicompost addition to soil-less bedding plant media enhanced germination, growth, flowering and fruiting of a wide range of greenhouse vegetables and ornamentals marigolds pepper strawberries and petunias (Arancon et al. 2004a; Chamani et al. 2008). Vermicompost application resulted in a significant and consistent increase in plant growth in both field and greenhouse conditions (Edwards et al. 2004), thus providing a substantial evidence that biological growth promoting factors play a key role in seed germination and plant growth (Edwards 1998). Investigations revealed that plant hormones and plant-growth regulating substances (PGRs) such as auxins, gibberellins, cytokinins, ethylene and abscisic acid are produced by microorganisms (Arshad and Frankenberger 1993). Several researchers have documented the presence of plant growth regulators such as auxins, gibberellins, cytokinins of microbial origin and humic acids in vermicompost in appreciable quantities. Cytokinins produced by *Bacillus* and *Arthrobacter* spp. in soils increase the vigour of seedlings (Jagnow 1987; Muscolo et al. 1999; Atiyeh et al. 2002). Microbially produced gibberellins influence plant growth and development and auxins produced by *Azospirillum brasilense* affects the growth of plants belonging to paoceae (Barbieri et al. 1988; Arshad and Frankenberger 1993). Extensive investigations on the biological activities of humic substances showed that they also possess plant growth stimulating property (Chen and Aviad 1990). Humic substances increased the dry matter yields of corn and oat seedlings; number and length of tobacco roots; dry weights of roots, shoots and number of nodules of groundnut, soyabean and clover plants and vegetative growth of chicory plants and induced root and shoot formation in plant tissue culture (Albuzio et al. 1994; Goenadi and Sudharama 1995; Valdrighi et al. 1996). High levels of humus have been reported from vermicomposts originating from food wastes, animal manure, sewage, and paper mill sludges (Arancon et al. 2003a, b). The humic and fulvic acid in the humus dissolves insoluble minerals in the organic matter and makes them readily available to plants and in addition they also help plants to overcome stress and stimulates plant growth (Sinha et al. 2010). Studies on biological activities of vermicompost derived humic substances, revealed that they had similar growth promoting hormonal effect (Muscolo et al. 1993). The humic materials extracted from vermicomposts have been reported to produce auxin-like cell growth and nitrate metabolism in carrots (*Daucus carota*) (Muscolo et al. 1996). Humates obtained from pig manure vermicompost increased growth of tomato (Atiyeh et al. 2002) and those obtained from cattle, food and paper waste vermicompost increased the growth of strawberries and peppers (Arancon et al. 2003a, b).

Earthworms produce plant growth regulators (Gavrilov 1963). Since earthworms increase the microbial activity by several folds they are considered as important agents which enhance the production of plant growth regulators. Plant growth stimulating substances of microbial origin were isolated from tissues of *Aporrectodea longa, L. terrestris* and *Dendrobaena rubidus* and indole like substances were detected from the tissue extracts of *A. caliginosa, L. rubellus* and *E. foetida* which increased the growth of peas and dry matter production of rye grass (Nielson 1965; Graff and Makeschin 1980). *A. trapezoids* aided in the dispersal of Rhizobium through soil resulting in increased root colonization and nodulation of leguminous plants (Bernard et al. 1994). Use of earthworm casts in plant propagation promoted root initiation, increased root numbers and biomass. The hormone-like effect produced by earthworm casts on plant metabolism, growth and development causing dwarfing, stimulation of rooting, internode elongation and precociousness of flowering was attributed to the fact of presence of microbial metabolites (Edwards 1998). Earthworm casts stimulated growth of ornamental plants and carpophore formation in *Agaricus bisporus* when used as casing layer in mushroom cultivation (Tomati et al. 1987). Aqueous extracts of vermicompost produced growth comparable to the use of hormones such as auxins, gibberellins and cytokinins on Petunia, Begonia and Coleus, providing solid evidence that vermicompost is a rich source of plant growth regulating substances (Tomati et al. 1988). Addition of vermicompost at very low levels to the growth media dramatically increased the growth of hardy ornamentals *Chamaecyparis lawsonian, Elaeagnus pungens, Pyracantha* spp., *Viburnum bodnantense, Cotoneaster conspicus* and *Cupressocyparis leylandi*. Cucumber, dwarf maize and coleus bioassays evidenced that vermicompost contained appreciable amounts of cytokinins, gibberellins and auxins respectively

(Edwards et al. 2004). Maize seedlings dipped in vermicompost water showed marked difference in plumule length compared to normal water indicating that plant growth promoting hormones are present in vermicompost (Nagavallemma et al. 2004). Comparative studies on the impact of vermiwash and urea solution on seed germination, root and shoot length in *Cyamopsis tertagonoloba* proved that vermiwash contained hormone like substances (Suthar 2010). High performance liquid chromatography (HPLC) and gas chromatography mass spectroscopy (GC-MS) analyses of aqueous extracts of cattle waste derived vermicompost showed presence of significant amounts Indole-acetic-acid (IAA), gibberellins and cytokinins (Edwards et al. 2004). Earthworm gut associated microbes enrich vermicomposts with highly water-soluble and light-sensitive plant growth hormones, which gets absorbed onto humic acid substances in vermicompost making them extremely stable and helps them persist longer in soils thereby influencing plant growth (Atiyeh et al. 2002; Arancon et al. 2003a). This is confirmed by presence of exchangeable auxin group in the macrostructure of humic acid extract from vermicompost (Canellas et al. 2002). Apart from the rich nutritional status and ready nutrient availability, presence of humic acids and plant growth regulating substances makes vermicompost a biofertilizer which increases germination, growth, flowering and fruiting in a wide range of crops. Vermicompost substitution in a relatively small proportion (10–20 %) to the potting mixture increased dry matter production and tomato growth significantly (Subler et al. 1998). Soil amended with 20 % vermicompost was more suitable for tomato seedling production (Valenzuela et al. 1997). Similarly vermicompost addition up to 50 % in the medium resulted in enhanced growth of *Chamaecyparis lawsoniana* (Lawson's Cypress), *Juniperus communis* (Juniper) and *Elaeagnus pungens* (Silverberry) rooted liners (Bachman and Edgar Davice 2000).

Vermicompost application increased plant spread (10.7 %), leaf area (23.1 %), dry matter (20.7 %) and increased total strawberry fruit yield (32.7 %) (Singh et al. 2008). Substitution of vermicompost drastically reduced the incidence of physiological disorders like albinism (16.1–4.5 %), fruit malformation (11.5–4.0 %) and occurrence of grey mould (10.4–2.1 %) in strawberry indicating its significance in reducing nutrient-related disorders and Botrytis rot, thereby increasing the marketable fruit yield up to 58.6 % with better quality parameters. Fruit harvested from plant receiving vermicompost were firmer, had higher total soluble solids (TSS), ascorbic acid content and attractive colour. All these parameters appeared to be dose dependent and best results were achieved at 7.5 t ha^{-1} (Singh et al. 2008). Vermicompost application showed significant increase in germination percent (93 %), growth and yield of mung bean (*Vigna radiata*) compared to the control (Karmegam et al. 1999). Similarly, the fresh and dry matter yields of cowpea (*Vigna unguiculata*) were higher in soil amended with vermicompost than with bio-digested slurry, (Karmegam and Daniel 2000). Combined application of vermicompost with N fertilizer gave higher dry matter (16.2 g plant^{-1}) and grain yield (3.6 t ha^{-1}) of wheat (*Triticum aestivum*) and higher dry matter yield (0.66 g plant^{-1}) of the following coriander (*Coriandrum sativum*) crop in wheat-coriander cropping system (Desai et al. 1999). Vermicompost application produced herbage yields of coriander cultivars comparable to those obtained with chemical fertilizers (Vadiraj et al. 1998). Yield of pea (*Pisum sativum*) increased with the application of vermicompost (10 t ha^{-1}) along with recommended NPK (Meena et al. 2007). Vermicompost application to sorghum (*Sorghum bicolor*), sunflower (*Helianthus annuus*), tomato (*Lycopersicon esculentum*), eggplant (*Solanum melangona*), okra (*Abelmoschus esculentus*), hyacinth bean (*Lablab purpureas*), grapes and cherry showed a positive result (Guerrero and Guerrero 2006; Karmegam and Daniel 2008; Gupta et al. 2008). Vermicompost amendment at the rate of 10 t ha^{-1} along with 50 % of recommended dose of NPK fertilizer increased the number and fresh weight of flowers per plant, flower diameter and yield, while at the rate of 15 t ha^{-1} along with 50 % of recommended dose of NPK increased vase life of *Chrysanthemum chinensis* (Nethra et al. 1999). Red Clover and cucumber grown in soil amended with vermicompost showed an increase in mineral contents viz., Ca, Mg, Cu, Mn and Zn in their shoot tissues (Sainz et al. 1998). Vermicomposted cow manure stimulated the growth of lettuce and tomato plants while the unprocessed parent material did not (Atiyeh et al. 2000). Similarly, vermicomposted duck wastes resulted in better growth of tomatoes, lettuce, and peppers than the unprocessed wastes (Wilson and Carlile 1989). The enhancement in plant growth might be attributed to the fact that processed waste had improved physicochemical characteristics and nutrients, in forms readily available to the plant as well as the presence of plant growth promoting and antagonistic disease suppressing beneficial bacteria.

9.7.4 Role of Vermicompost in Plant Disease Management and Pathogen Control

Soils with low organic matter and microbial activity are conducive to plant root diseases and addition of organic amendments can effectively suppress plant disease (Stone et al. 2004). Several researchers reported the disease suppressive properties of thermophilic compost on a wide range of phytopathogens viz., *Rhizoctonia*, *Phytopthora*, *Plasmidiophora brassicae* and *Gaeumannomyces graminis* and *Fusarium* (Kannangowa et al. 2000; Cotxarrera et al. 2002). Microbial antagonism might be one of the possible reasons for disease suppression as organic amendments enhances the microbial population and diversity. Traditional thermophilic composts promote only selected microbes while non-thermophilic vermicomposts are rich sources of microbial diversity and activity and harbour a wide variety of antagonistic bacteria thus acts as effective bio-control agents aiding in suppression of diseases caused by soil-borne phytopathogenic fungi (Scheuerell et al. 2005).

Earthworm feeding reduces the survival of plant pathogens such as *Fusarium* sp. and *Verticillium dahlia* and increases the densities of antagonistic fluorescent pseudomonads and filamentous actinomycetes while population densities of *Bacilli* and *Trichoderma* spp. remains unaltered (Moody et al. 1996; Elmer 2009). Earthworm activities reduce root diseases of cereals caused by *Rhizoctonia* (Doube et al. 1994). It has been proved that earthworms decreased the incidence of field diseases of clover, grains, and grapes incited by *Rhizoctonia* spp. and *Gaeumannomyces* spp. (Clapperton et al. 2001). Earthworms *Aporrectodea trapezoides* and *Aporrectodea rosea* act as vectors of Pseudomonas corrugate 214OR, a biocontrol agent for wheat take-all caused by *G. graminis* var. tritd (Doube et al. 1994). Greenhouse studies on augmentation of pathogen infested soils with *L. terrestris* showed a significant reduction of disease caused by *Fusarium oxysporum f.* sp. *asparagi* and *F. proliferatum* on susceptible cultivars of asparagus (*Asparagus officinalis*), *Verticillium dahliae* on eggplant (*Solanum melongena*) and *F. oxysporum f.* sp. *Lycopersici* race 1 on tomato. Plant weights increased by 60–80 % and disease severity reduced by 50–70 % when soils were augmented with earthworms. Incorporation of soil with vermicompost effectively suppressed *R. solani* in wheat, *Phytophthora nicotianae*, and *Fusarium* in tomatoes, *Plasmodiophora bras*sicae in tomatoes and cabbage, *Pythium* and *Rhizoctonia* (root rot) in cucumber and radish, *Botrytis cineria* and *Verticillium* in strawberry and *Sphaerotheca fulginae* in grapes (Nakamura 1996; Szczech 1999; Edwards et al. 2004; Simsek Ersahin et al. 2009). Vermicompost application drastically reduced the incidence of 'Powdery Mildew', 'Color Rot' and 'Yellow Vein Mosaic' in Lady's finger (*Abelmoschus esculentus*) (Agarwal et al. 2010). Substitution of vermicompost in the growth media reduced the fungal diseases caused by *R. solani, P. drechsleri* and *F. oxysporum* in gerbera (Rodriguez et al. 2000). Amendment of vermicompost at low rates (10–30 %) in horticulture bedding media resulted in significant suppression of *Pythium* and *Rhizoctonia* under greenhouse conditions (Edwards et al. 2004). Research findings proved that vermicompost when added to container media significantly reduced the infection of tomato plants by *P. nicotianae* var. *nicotianae* and *F. oxysporum* sp. *lycopersici* (Szczech 1999). Club-rot of cabbage caused by *P. brassicae* was inhibited by dipping cabbage roots into a mixture of clay and vermicompost. Potato plants treated with vermicompost were less susceptible to *P. infestans* than plants treated with inorganic fertilizers (Kostecka et al. 1996). Aqueous extracts of vermicompost inhibited mycelial growth of *B. cineria, Sclerotinia sclerotiorum, Corticium rolfsii, R. solani* and *F. oxysporum* (Nakasone et al. 1999), effectively controlled powdery mildew of barley (Weltzien 1989) and affected the development of powdery mildews on balsam (*Impatiens balsamina*) and pea (*Pisum sativum*) caused by *Erysiphe cichoracearum* and *E. pisi*, respectively in field conditions (Singh et al. 2003).

9.7.4.1 Mechanisms That Mediate Pathogen Suppression

Two possible mechanisms of pathogen suppression have been described, one depends on systemic plant resistance and the other is mediated by microbial competition, antibiosis and hyperparasitism (Hoitink and Grebus 1997). The microbially mediated suppression is again classified into two mechanisms viz., 'general suppression' where a wide range of microbes suppress the pathogens such as *Pythium* and *Phytopthora* (Chen et al. 1987) and 'specific suppression' where a narrow range of organisms facilitates suppression, for instance disease caused by *Rhizoctonia* (Hoitink and Grebus 1997). The disease suppressive effect of vermicompost against *fusarium* wilt of tomato clearly depicted that fungus inhibition was purely biotic and no chemical factors played any role, since the experiments with heat-sterilized vermicompost failed to control the disease (Szczech 1999). Experiments on suppression of damping-off caused by *R. solani*, in vermicompost amended nurseries of white pumpkin proved that vermicompost suppressed the disease in a dosage and temperature dependent manner (Rivera et al. 2004). Earthworm castings are rich in nutrients and calcium humate, a binding agent that reduces desiccation of individual castings and favors the incubation and proliferation of beneficial microbes, such as *Trichoderma* spp., *Pseudomonas* spp., and mycorrhizal spores (Gange 1993; Doube et al. 1995; Tiunov and Scheu 2000). Earthworm activity increased the communities of Gram-negative bacteria (Clapperton et al. 2001; Elmer 2009). Vermicompost associated chitinolytic bacterial communities viz., *Nocardioides oleivorans*, several species of *Streptomyces* and *Staphylococcus epidermidis* showed inhibitory effects against plant phytopathogens such as, *R. solani, Colletotrichum coccodes, Pythium ultimum, P. capsici* and *Fusarium moniliforme* (Yasir et al. 2009).

9.7.5 Role of Vermicompost in Arthropod Pest Control

Addition of organic amendments helped in suppression of various insect pests such as European corn borer, other corn insect pests, aphids and scale insects and brinjal shoot and fruit borer (Phelan et al. 1996; Biradar et al. 1998; Sudhakar et al. 1998). Several reports also evidenced that vermicompost addition decreased the incidence of Spodoptera litura, Helicoverpa armigera, leaf miner (*Apoaerema modicella*), jassids (*Empoasca kerri*), aphids (*Aphis craccivora*) and spider mites on groundnuts (Rao et al. 2001; Rao 2002, 2003) and psyllids (Heteropsylla cubana) on a tropical leguminous tree (*Leucaena leucocephala*) (Biradar et al. 1998). Vermicompost amendment decreased the incidence of sucking pests under field conditions and suppressed the damage caused by of two-spotted spider mite (*Tetranychus* spp.), aphid (*Myzus persicae*) and mealy bug (*Pseudococcus* spp.) under greenhouse conditions (Ramesh 2000; Edwards et al. 2007; Arancon et al. 2007). Vermicompost substitution to soil less plant growth medium MetroMix 360 (MM360) at a rate less than 50 % reduced the damage caused by infestation of pepper seedlings by *M. persicae* and *Pseudococcus* spp. and tomato seedlings by *Pseudococcus* spp., cabbage seedlings by *M. persicae* and cabbage white caterpillars (*Pieris brassicae* L.) (Arancon et al. 2005a, b). Greenhouse cage experiments conducted on tomatoes and cucumber seedlings infested with *M. persicae*, citrus mealybug (*Planococcus citri*), two spotted spider mite (*Tetranychus urticae*); striped cucumber beetles (*Acalymna vittatum*) attacking cucumbers and tobacco hornworms (*Manduca sexta*) attacking tomatoes proved that treatment of infested plants with aqueous extracts of vermicompost suppressed pest establishment, and their rates of reproduction. Vermicompost teas at higher dose also brought about pest mortality (Edwards et al. 2010). Suppression of aphid population gains importance since they are key vectors in transmission of plant viruses. Addition of solid vermicompost reduced damage by *A. vittatum* and spotted cucumber beetles (*Diabotrica undecimpunctata*) on cucumbers and larval hornworms (*Manduca quinquemaculata*) on tomatoes in both greenhouse and field experiments (Yardim et al. 2006). Combined application of vermicompost and vermiwash spray to chilli (*Capiscum annum*) significantly reduced the incidence of 'Thrips' (*Scirtothrips dorsalis*) and 'Mites' (*Polyphagotarsonemus latus*) (Saumaya et al. 2007).

9.7.6 Role of Vermicompost in Nematode Control

It has been well documented that addition of organic amendments decreases the populations of plant parasitic nematodes (Akhtar and Malik 2000). Vermicompost amendments appreciably suppress plant parasitic nematodes under field conditions. Vermicomposts also suppressed the attack of *Meloidogyne incognita* on tobacco, pepper, strawberry and tomato and decreased the numbers of galls and egg masses of *Meloidogyne javanica* (Ribeiro et al. 1998; Arancon et al. 2002; Edwards et al. 2007). There are several feasible mechanisms that attribute to the suppression of plant parasitic nematodes by vermicompost application and it involves both biotic and abiotic factors. Organic matter addition to the soil stimulates the population of bacterial and fungal antagonists of nematodes (e.g., *Pasteuria penetrans, Pseudomonas* spp. and chitinolytic bacteria, *Trichoderma* spp.), and other typical nematode predators including nematophagous mites viz., *Hypoaspis calcuttaensis*, *Collembola* and other arthropods which selectively feeds on plant parasitic nematodes (Bilgrami 1996; Thoden et al. 2011). Vermicompost amendment promoted fungi capable of trapping nematode and destroying nematode cysts and increased the population of plant growth-promoting *rhizobacteria* which produce enzymes toxic to plant parasitic nematodes (Kerry 1988; Siddiqui and Mahmood 1999). Vermicompost addition to soils planted with tomatoes, peppers, strawberry and grapes showed a significant reduction of plant parasitic nematodes and increased the population of fungivorous and bacterivorous nematodes compared to inorganic fertilizer treated plots (Arancon et al. 2002). In addition, few abiotic factors viz., nematicidal compounds such as hydrogen sulphide, ammonia, nitrates, and organic acids released during vermicomposting, as well as low C/N ratios of the compost cause direct adverse effects while changes in soil physiochemical characteristics viz., bulk density, porosity, water holding capacity, pH, EC, CEC and nutrition possess indirect adverse effects on plant parasitic nematodes (Rodriguez-Kabana 1986).

9.8 Vermicompost in Market

Vermicomposts are marketed for a broad range of purposes, including gardening, landscaping, agriculture, forestry, and horticulture and pollution management. For the high-value end markets, the vermicompost products must be very uniform and consistent in quality and nutrient content. Markets for vermicomposts and vermicompost teas are growing, rapidly. Large producers of vermicompost in the United States have reported receiving from $75.00 to as much as $300.00 per ton (or its volume equivalent) when selling to bulk buyers during 1990s (Edwards 1988). When processed and packaged attractively for retail sale, reported values of vermicomposts can be up to 5–10 times higher. Market-development advances for vermicomposts continue to increase considerably as their benefits become known better. Research projects around the world are showing that the benefits of vermicomposts go far beyond the usual provision of organic matter and plant nutrients, to providing plant growth stimulants and other plant- and soil-improving properties.

9.9 Derivatives of Vermicompost

9.9.1 Vermiwash

Vermiwash is a liquid that is collected after the passage of water through a column of worm action and is very useful as a foliar spray. It is a collection of excretory products and mucus secretion of earthworms along with micronutrients from the soil organic molecules. These are transported to the leaf, shoots and other parts of the plants in the natural ecosystem (Ansari and Ismail 2012). Vermiwash, if collected properly, is a clear and transparent, pale yellow coloured fluid (Ismail 1997). Vermiwash seems to possess an inherent property of acting not only as a fertilizer but also as a mild biocide (Pramoth 1995). Vermiwash is also 'productive' and 'protective' for farm crops. This liquid partially comes from the body of earthworms and is rich in amino acids, vitamins, nutrients like nitrogen, potassium, magnesium, zinc, iron, copper, and some some growth hormones like 'auxins', 'cytokinins'. It also contains plenty of nitrogen-fixing and phosphate solubilising bacteria (*nitrosomonas, nitrobacter* and actinomycetes). Vermiwash has great 'growth promoting' as well as 'pest killing' properties. Buckerfield et al. (1998) reported that weekly application of vermiwash increased radish yield by 7.3 %. Thangavel et al. (2003) also observed that both growth and yield of paddy increased with the application of vermiwash and vermicast extracts. George (2007) studied the use of vermiwash for the management of 'Thrips' (*Scirtothrips dorsalis*) and 'Mites' (*Polyphagotarsonemus latus*) on chilli amended with vermicompost to evaluate its efficacy against thrips and mites. Vermiwash was used in three different dilutions e.g. 1:1, 1:2 and 1:4 by mixing with water both as 'seedling dip' treatment and 'foliar spray'. Six rounds of vermiwash sprays were taken up at 15 days interval commencing at 2 weeks after transplanting. Among the various treatments, application of vermicompost at the rate of 0.5 t/ha with 6 sprays of vermiwash at 1:1 dilution showed significantly lower incidence of thrips and mites attack. The treatment resulted in very low mean population of thrips and mites, namely 0.35 and 0.64 per leaf, respectively. In addition, the application of vermicompost gave a highest yield (2.98 quintal/ha). Giraddi

(2003) also reported significantly lower pest population in chilli applied with vermiwash (soil drench 30 days after transplanting, and foliar spray at 60 and 75 days after transplanting) as compared to untreated crops. Suthar (2010) has reported hormone like substances in vermiwash. He studied its impact on seed germination, roots and shoots length in *Cyamopsis tertagonoloba* and compared with urea solution (0.05 %). Maximum germination was 90 % on 50 % vermiwash as compared to 61.7 % in urea solution. Maximum root and shoot length was 8.65 and 12.42 cm on 100 % vermiwash as compared to 5.87 and 7.73 on urea. The seedlings with 100 % vermiwash foliar spray showed the maximum level of total protein and soluble sugars in their tissues.

9.9.2 Vermicompost Tea

Vermicompost tea is the water extracts of solid vermicomposts from which microorganisms, soluble nutrients, and plant-beneficial substances are converted into a liquid form. It can be used in a wide range of horticultural and agricultural systems to elicit plant growth and pest and disease management responses through a variety of mechanisms. It can be applied directly to plant foliage. It is also used as a soil drench and has been shown to be effective in relatively small quantities (Edwards et al. 2011). Vermicompost teas are more precisely characterized by the organic substrates, vermicomposts, from which the beneficial substances are extracted. As vermicomposts have proved to be a consistently prolific source of plant-beneficial compounds, increasing numbers of grower testimonials and some recent scientific studies suggest that vermicompost teas are similarly effective. Diagrammatic design of reactor producing compost tea is shown in Fig. 9.2.

The chemical and biological characteristics of vermicompost tea may differ with changes in inputs and other process variables. The ratio of vermicompost to water used in producing vermicompost tea is a variable that can be held constant. Ratios between 5 % (1:20) and 20 % (1:5) solid vermicompost to water have proved to be effective in laboratory and greenhouse trials. Regardless of the ratio of vermicompost to water used in the production process, the final extract can be diluted further as needed for specific applications. Vermicompost tea involves agitation/stirring and aeration during extraction to proliferate aerobic microbes in the aqueous solution or tea and also to decrease the development of anaerobes that may produce metabolic by-products. The aerated tea solution can be supplied with additives or supplements that can enhance the microbial activity. Molasses, humic acids, kelp, rock powders, fish emulsions, and a variety of other ingredients have been used as additives or supplements (Duffy et al. 2004). There is considerable debate within the realm of compost/vermicompost tea enthusiasts, scientists, regulators, and other interested parties regarding the use of additives, due to the potential of carbohydrate-rich materials to promote the growth of undesirable microorganisms, especially human pathogens that could be transferred to food crops, thereby posing potential consumer health risks. The amount of time it takes to produce vermicompost tea

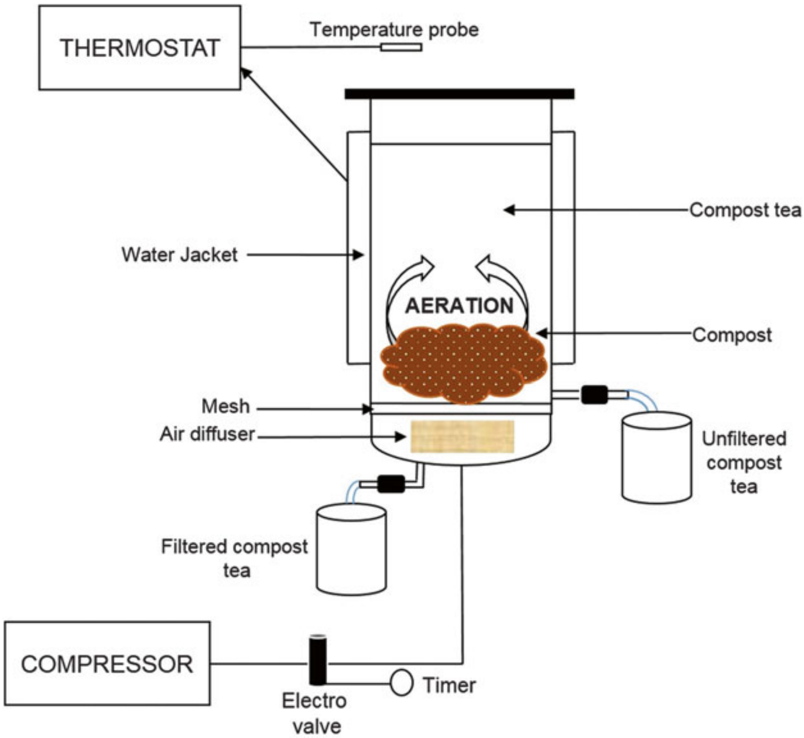

Fig. 9.2 Diagrammatic design of reactor producing compost tea (Reproduced from Carballo et al. 2008)

varies from hours to days. The physical extraction of soluble components and microorganisms from vermicomposts occurs fairly rapid and is less time-dependent than the actual brewing process. A commonly-used and convenient brewing time is 24 h, with continuous aeration and agitation, although this varies widely according to the type and size of equipment and other factors. Temperature affects the types of organisms that will grow, as well as their rates of growth.

Vermicompost teas are now being produced and used in large-scale agriculture, viticulture, orchards, horticulture, nurseries, turf greens, commercial landscaping, and home gardens. Rates, frequency, and modes of application vary according to the cropping system, pest and disease pressures, and existing conditions. Vermicompost tea is primarily known for its ability to boost soil microbiological activity by adding millions of bacteria, fungi, actinomycetes, and protozoa along with the by-products of their metabolism. The active components in vermicompost tea include microorganisms, water-soluble fulvic acids (building blocks for humic acids) and particulate humates, plant-growth hormones produced by microorganisms, and materials that improve the availability of micronutrients (chelating effect). Soluble nutrients present in vermicompost tea nourish plants directly as well as feed existing soil microorganisms. Like vermicompost, it increases soil biological activity and pro-

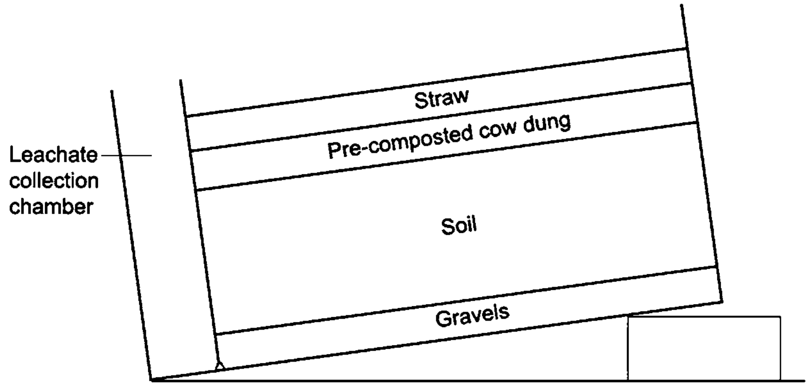

Fig. 9.3 Example of vermicomposting leachate design (Reproduced from Quaik 2014)

vides beneficial organic compounds. Unlike vermicompost, it can be applied directly to plant foliage as well as to the soil. Direct foliar application of vermicompost tea provides nutrients that may be utilized directly by the plant while also introducing a diverse array of microorganisms that colonize leaf surfaces.

9.9.3 Vermicomposting Leachate

During vermicomposting process, water is constantly added or sprayed in order to maintain the moisture level of the reactor. Besides, vermicomposting also produces leachate as microorganisms release water during the decomposition of the organic material (Gutiérrez-Miceli et al. 2008). The excess water that leaches out is commonly known as vermicomposting leachate or worm bed leachate. Vermicomposting leachate when collected, can be used as liquid fertilizer as it contains high concentration of plant nutrients and presence of humic and fulvic acids (Gutiérrez-Miceli et al. 2008). Draining the leachate can prevent saturation of the vermicomposting unit as well as to avoid leaching problem that may cause pollution especially when the site is located near to groundwater source. Vermicomposting leachate can be collected with the example of design shown in the figure, Fig. 9.3.

Studies have found that vermicomposting leachate contains high amount of plant nutrients that may act as liquid fertilizer for improving plant growth. Most of the animal wastes cannot be used directly without any treatment. Direct disposal may cause environmental contamination problems especially in large amount. Therefore it has become an environmental issue. The chemical composition of the vermicomposting derived leachate will largely depend on the chemical composition of the substrates used in the vermicomposting process and Cambardella et al. (2003) has stated animal wastes can be useful as reliable organic fertilizers. Application of vermicomposting in recycling organic waste has gained acceptance over the past

Table 9.4 Example of studies carried out using vermicomposting leachate (Reproduced from Quaik 2014)

Waste	Earthworm species	Plant tested	References
Cow manure	*Eisenia fetida*	Maize (Zea mays L.)	García-Gómez et al. (2008)
Cow manure	*Eisenia fetida*	Sorghum (Sorghum bicolor (L.) Moench)	Gutiérrez-Miceli et al. (2008)
Cow dung and green forages	*Eisenia fetida*	Tomato (Lycopersicum esculentum cv. Momotaro)	Tejada et al. (2008)
Cow manure	*Eisenia fetida*	Tomato (Lycopersicon esculentum Mill)	Oliva-Llaven et al. (2010)
Cow dung, vegetable waste and mixture of cow dung and vegetable waste (1:2)	*Eisenia fetida*	Strawberry (Fragaria x ananassa Duch.)	Singh et al. (2010)
Cow manure	*Eisenia fetida*	Lemongrass (Cymbopogon citrates (DC) Stapf.)	León-Anzueto et al. (2011)
Cow dung	*Eudrilus eugeniae*	*Coleus aromaticus*	Quaik et al. (2014)

two decades (Reynolds 2004). Hence, utilising animal waste such as cow dung in vermicomposting process will not only provides solution on animal waste disposal problem, but also produces value added products such as vermicompost and vermicomposting leachate. Studies on utilizing vermicomposting leachate/worm bed leachate and vermiwash (García-Gómez et al. 2008; Singh et al. 2010; Gopal et al. 2010; Gutiérrez-Miceli et al. 2011; Tharmaraj et al. 2011) as fertilizer have been carried out by researchers. Despite the high level of nutrient content, vermicomposting leachate might contribute to plant development as it contains humic acids (Arancon et al. 2005) which regulate many plant development processes including adsorption of macro and micro nutrients. Different types of wastes have been used in studies of vermicomposting leachate (Table 9.4). Plant height, fresh and dry shoot weight of maize were significantly affected by the use of vermicomposting leachate. Dilution on vermicomposting leachate was suggested by Garcia-Gomez et al. (2008) before being utilized as plant fertilizer. On the other hand, Gutiérrez-Miceli et al. (2008) reported there was no need of dilution when utilized as liquid fertilizer for the cultivation of sorghum but suggested additional NPK fertilization for maximum plant growth. High chlorophyll content, increased in plant height, leaf macronutrients contents, yield and average number of fruits per tomato plants were observed when treated with vermicomposting leachate (green forage) and vermicomposting leachate (cow dung) as foliar fertilizer compared to plants treated with solution of Hewitt (Tejada et al. 2008). Oliva-Llaven et al. (2010) application of worm bed leachate every 3 days resulted lower pH of tomato fruit compared to daily application. Vermicomposting leachate of cow dung waste, vegetable waste and mixture of vegetable and cow dung waste when applied as foliar fertilizer on strawberry plant, showed lesser incidence of albinism, malformation of fruit and gray mould respectively compared to control treatment (Singh et al. 2010). Study showed higher essential oil content in lemongrass when the plant was amended with 20 ml per plant of worm bed leachate compared to control (León-Anzueto et al. 2011).

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