# Chapter 13
# Vermicompost as a Biological Soil Amendment

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## 13.1 Introduction

Today, the viability of using earthworms as a treatment technique for numerous waste streams has been well established. Vermicompost is considered as an excellent product since it is homogeneous, has desirable esthetics, reduced level of contaminates, plant growth hormones, higher level of soil enzymes, and greater microbial population, and tends to hold more nutrients over a longer period without adversely impacting the environment. Earthworms while ingest organic waste and soil, consume heavy metals through their intestine as well as through their skin, wherefore concentrating heavy metals in their body (Hand et al. 1988; Logsdon 1994; Singh and Sharma 2002).

A growing awareness of some of the adverse economic and environmental impacts of agrochemicals in crop production has stimulated greater interest in the utilization of organic amendments such as compost or vermicompost for crop production (Follet et al. 1981). Utilization of earthworms may be an answer as an ecologically sound, economically viable, and socially acceptable technology (Sharma et al. 2005).

Vermicomposting as a principle originates from the fact that earthworms in the process of feeding fragment the substrate thereby increasing its surface area for further microbial colonization (Chan and Griffiths 1988). During this process, the important plant nutrients such as nitrogen, potassium, phosphorus, and calcium

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present in the feed material are converted through microbial action into forms that are much more soluble and available to the plants than those in the parent substrate (Ndegwa and Thompson 2001). Earthworms are voracious feeders on organic waste and while utilizing only a small portion for their body synthesis they excrete a large part of these consumed waste material in a half digested form. Since the intestine of earthworms harbor wide ranges of microorganisms, enzymes, hormones, etc., these half digested substrates decompose rapidly and are transformed into a form of vermicompost within a short time (Edwards and Lofty 1972). Earthworm prepares organic manures, through their characteristic functions of breaking up organic matter and combines it with soil particles. The final product is a stabilized, well-humidified, organic fertilizer, with adhesive effects for the soil and stimulator for plant growth and most suitable for agricultural application and favorable environmentally. Biochemical changes in the degradation of organic matter are carried out through enzymatic digestion, enrichment by nitrogen excrement, and transport of organic and inorganic materials. About 5–10% of ingested material is absorbed into the tissue for their growth and metabolic activity and rest is excreted as vermicast. The vermicast is mixed with mucus secretion of the gut wall, and of the microbes and transformed into vermicompost (Edwards and Lofty 1972). The decomposition process continues even after the release of the cast by the establishment of microorganisms. The studies on the effect of vermicomposting on some components of organic waste showed that vermicompost enhances degree of polymerization of humic substances along with a decrease of ammonium N and an increase of nitric N (Cegarra et al. 1992).

Vermicompost is a peat-like material with high porosity, aeration, drainage, water holding capacity, and microbial activity, (Edwards and Burrows 1988), and has large particular surface area that provides many microsites for microbial activity and for the strong retention of nutrients. The plant growth regulators and other plant growth influencing materials, that is, auxins, cytokinins, humic substances, etc., produced by microorganisms have been reported from vermicompost (Atiyeh et al. 2002; Muscolo et al. 1999). The humic materials extracted from vermicomposts have been reported to produce auxin-like cell growth and nitrate metabolism of carrots (*Daucus carota*) (Muscolo et al. 1999).

## 13.2 Characteristics of Vermicompost

The nutrient status of vermicompost produced with different organic wastes is: 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 22.7–70 mg per 100 g, copper 2–9.3 ppm, Zinc 5.7–11.5 ppm, and available sulfur 128–548 ppm (Kale 1995).

Several researchers have compared vermicasts with the surrounding soils and reported their results (Lavelle 1978). The vermicasts have been reported with a higher Base Exchange capacity and are rich in total organic matter, phosphorus, potassium, and calcium with reduced electrical conductivity, large increase in oxidation potential, and significant reductions in water-soluble chemicals which constitute possible, environmental contaminants. Vermicompost is rich in microbial diversity, population, and activity (Subler et al. 1998), and vermicast contains enzymes such as *proteases*, *amylases*, *lipase*, *cellulase*, and *chitinase* which continue to disintegrate organic matter even after they have been ejected. The chemical analysis of casts shows 2 times the available magnesium, 5 times the available nitrogen, 7 times the available phosphorus, and 11 times the available potassium compared to the surrounding soil (Bridgens 1981). The vermicompost is considered an excellent product since it is homogeneous, has reduced level of contaminants, and tends to hold more nutrients over a longer period without impacting the environment (Ndegwa and Thompson 2001).

## 13.3 Potential Application of Earthworms and Vermicompost in Plant Growth

Being rich in macro- and micronutrients, vermicompost has been found an ideal organic manure enhancing biomass production of a number of crops (Vasudevan and Sharma 1997; Hidalgo 1999; Pashanasi et al. 1996). The importance of vermicompost in agriculture, horticulture, waste management, and soil conservation has been reviewed by many workers (Edwards et al. 1995; Riggle and Holmes 1994; Kaviraj and Sharma 2003). Darwin (1881) stated that the earthworms prepare the ground in an excellent manner for the growth of fibrous-rooted plants and for seedlings of all kinds. The beneficial effect of earthworms on plant growth may be due to several reasons apart from the presence of macronutrients and micronutrients in vermicasts and in their secretions in considerable quantities. It is believed that earthworms produce certain metabolites, vitamins, and similar substances into the soil which may be the B or D group vitamins (Nielson 1965). The use of earthworm compost in commercial production was advocated by Martinez and Gomez Zambrano (1995).

Edwards et al. (1995) reported that in a Rothamsted study with 25 types of vegetables, fruits, or ornamentals, earthworm casts performed better than compost or commercial potting mixture amendments. The beneficial effects of earthworm cast utilization in other horticulture settings have also been reported (Hidalgo 1999). Fresh casts often contain high ammonium levels, but rapid nitrification results in stable levels of both nitrogen forms due to organic matter protection in dry casts (Decaëns et al. 1999). Nutrients in casts are initially physically protected, but this is reduced as the aggregate structure weakens over time (McInerney and Bolger 2000). In addition to increased N availability, C, P, K, Ca, and Mg availability in the casts is also greater than in the starting feed material (Orozco et al. 1996). Earthworm cast amendment has been shown to increase plant dry weight (Edwards et al. 1995) and plant N uptake (Tomati et al. 1994). Cantanazoro et al. (1998) demonstrated the importance of the synchronization between nutrient release and plant uptake and showed that slower release fertilizers can increase plant yield and reduce nutrient leaching. Soil quality is affected by soil aggregates and these aggregates often determine the retention and movement of water, diffusion of gasses, growth and development of roots in the soil.

## 13.4 Metals and Agrochemicals Accumulation from Soil by Earthworms

Earthworms ingest large amount of soil and are therefore exposed to heavy metals through their intestine as well as through the skin, therefore concentrating heavy metals from the soil in their body (Morgan and Morgan 1999). Earthworms may serve as bioindicators of soil contaminated with pesticides, that is, polychlorinated biphenyls, polycyclic hydrocarbons (Saint-Denis et al. 1999), and heavy metals (Spurgeon and Hopkins 1999). Lead, cadmium, zinc, and copper are accumulated and under some environmental conditions, bioconcentrated in earthworms (Cortet et al. 1999). It is presumed that in many cases zinc is the critical toxic metal for these organisms (Spurgeon and Hopkins 2000). Mortality and fecundity of earthworms as bioindicating organisms may serve as reliable, but ultimate and time-consuming, indices of environmental pollution (Morgan and Morgan 1999).

Suppression of labile aluminum in acidic soils by the use of vermicompost extract was observed by chelation combined with pH-induced precipitation (Mitchell and Alter 1993). The same authors in 1992 also reported that in solutions above pH 6.0, a 98% reduction of total aluminum was obtained due to chelation (Alter and Mitchell 1992). Ireland (1977) reviewed the effect of various pesticides and heavy metals on earthworms. This will bring down the risk of entry of these pollutants into plant system and then into sequential food chain. When worms are used for this purpose, they should be prevented from entering into food chain as they are found to concentrate very high levels of these toxins in their tissue.

## 13.5 Plant Growth Trials Using Vermicomposts

The potential of vermicompost for plant growth was raised by Edwards and Burrows (1988). Various animal, agricultural, and industrial wastes were vermicomposted, including pig, poultry, and cattle manure, potato, brewery, paper, and mushroom wastes. Plant trials were carried out on ornamental shrubs, vegetables, and bedding plants, using a commercial plant growth medium as a control. Because most of the castings tended to be alkaline ($pH > 7$), it was necessary to dilute with peat for some trials.

Early plant growth was reported to be better with vermicompost than in the commercial growing medium, and seeds germinated faster for most plant species grown in vermicompost. After transplanting into pots, the ornamentals grew better in vermicompost/peat mixtures than in the commercial growth medium. Also, several of the flowering plants flowered much earlier.

Overall, Edwards and Burrows (1988) concluded that vermicompost mixed with peat or other materials makes superb plant growth media and that there could be significant commercial potential. Edwards and Burrows also noted that the paper waste vermicompost was one of the best feed stocks in terms of consistency of product.

Subler et al. (1998) confirmed that the trend in trials for plants grown in container media was that the optimum responses normally occurred when worm castings constituted 10–20% of the volume of the mix. They believed that the substantial growth effects that were observed were more than simply a function of the mineral nutrient content of the castings. They considered that the effects might also be related to enhanced micronutrient availability, the presence of plant growth regulators, or the activity of beneficial microorganisms in the castings. However, that does not deny the fact that vermicomposts do contain nutrients in forms that are most readily taken up by the plants such as nitrates, exchangeable phosphorus, and soluble potassium, calcium, and magnesium (Edwards and Burrows 1988).

It has also been noted (Edwards and Burrows 1988; Subler et al. 1998) that vermicomposts tend to differ from composts in that they normally have higher nitrogen levels with more of that nitrogen in the nitrate rather than the ammonium form.

Several of the plant growth trials undertaken by Edwards' group have been discussed by Atiyeh et al. (2000a, b). Noticing that the germination of tomato, pepper, and lettuce were very low in pit/perlite mixtures, Atiyeh et al. (2000b) substituted some of the peat/perlite mixtures with equal amounts of vermicomposts. This enhanced germination rates greatly, comparable to the germination obtained in a commercial medium that already contained a starter nutrient fertilizer in its formulation. The researchers also made a key observation that vermicomposts still boosted growth rates even when additional fertilizers were applied. That is, their effects must be due to more than just nutrient values. Tomati et al. (1994) used earthworm castings as a propagation and growing substrate for ornamental plant production and found a promotion of root development and a reduction in fertilizer use in plants grown in substrates containing castings.

While the researchers have demonstrated that the addition of vermicomposts to growing media normally produces beneficial effects on plant growth, the reasons why the effects happen are still not yet fully understood. The earthworms certainly fragment the organic waste substrates stimulate enhanced microbial activity and increase rates of mineralization, rapidly converting the wastes into humus-like substances (Atiyeh et al. 2002). A decrease in the carbon from fulvic acids and an increase in the percentage of the carbon from humic acids are seen in the vermicomposting process.

## 13.6 Disease and Pest Suppression

The beneficial effects of worm casts on plant growth can be put down largely to increased microbial populations that produce plant growth hormones. Those hormones are believed to be adsorbed on to the humates produced during the vermicomposting process. Edwards and Arancon (2004) noted that beneficial effects were not simply confined to plant growth. They were apparent on the incidence of plant diseases and pest attacks from plant parasitic nematodes, insects, and mites.

Edwards and Arancon (2004) and Chaoui et al. (2002) have shown on their research that relatively small applications of commercially produced vermicomposts significantly reduce attacks by *Pythium* sp on cucumbers, *Rhizoctonia* sp on radishes plants in the greenhouse, *Verticillium* on strawberries, and *Phomopsis* and *Sphaerotheca fulginae* on grapes. The pathogen suppression was almost eliminated if the vermicomposts were sterilized prior to use. Edwards and Arancon (2004) consider it most likely that the effects arise through microbial antagonism.

Low applications of vermicomposts have also been found to affect the populations of plant parasitic nematodes. Vermicomposts from paper waste, food waste, and cattle manure, applied at 2–8 tons per acre to soils planted with tomatoes, peppers, strawberries, or grapes, gave a consistent and significant suppression of plant parasitic nematodes.

The incorporation of small proportions of vermicompost was found to reduce arthropod pests (aphids, mealy bugs, spider mites) on tomatoes, peppers, and cabbage and the extent of crop damage caused by them.

Szczech and Smolinska (2001) investigated the effect of vermicomposts on the growth and infection of tomato seedlings by *Phytophthora nicotianae*. While vermicomposts produced from animal manure significantly reduced the infections in the seedlings, vermicomposts from sewage sludge offered no protection.

## 13.7 Accumulation of Heavy Metals

Heavy metals include several elements which have a biological function or are toxic to some organisms. According to Lee (1985), the most important environmental pollutants are lead (Pb), cadmium (Cd), mercury (Hg), zinc (Zn), copper (Cu), nickel (Ni), antimony (Sb), and bismuth (Bi). Although many other elements are involved, but most attention has been given to the first two. Since earthworms ingest large quantities of substrate they are particularly susceptible to accumulation of pollutants which may be passed to other animals directly (e.g., predation by birds or mammals), or indirectly via plant uptake of earthworm products from the soil. The main issues are toxicity and the rate and means of heavy metal accumulation in earthworms.

Beyer (1981) and Ireland (1983) have reported that earthworms can accumulate heavy metals from both contaminated and noncontaminated environments. Ireland (1983) states that Cd does not appear to concentrate on earthworm tissues indefinitely, and the ratio decreases with increasing Cd concentration, unlike Pb, which appears to accumulate continuously.

Graff (1982) examined the accumulation of heavy metals in *Eisenia fetida* and *Eudrilus eugeniae* before and after feeding on compost made from municipal garbage. The heavy metal contents before and after feeding were: for *E. fetida*, Cu

4–29, Zn 140–640, Pb 3–14, Cd 2–9, Hg 0.1–14; for *E. eugeniae*, Cu 17–55, Zn 165–360, Pb 10–72, Cd 4–6, Hg 1–15. These data indicate that the earthworms are extracting the heavy metals from the compost and are concentrating them in their tissues.

## 13.8 Potential for Transmission of Pathogens

Earthworms feeding on sludge may be potential vectors of a wide range of parasitic and pathogenic organisms (Lee 1985; Satchell 1983). It has been determined that passage of organic material through the gut of an earthworm can reduce numbers of some microorganisms and increase numbers of others (Satchell 1983). Spores and cysts of some parasites pass unharmed through the gut of earthworms while some pathogens are reduced.

Brown and Mitchell (1981) reported that *E. fetida* feeding on a growing medium inoculated with *Salmonella eneritidus*, reduced populations of this enteric pathogen by 42 times, compared to controls, after 28 days with the greatest rate of reduction of pathogen in the first 4 days. Satchell (1983) reported the findings of Day (1950) and Bruzewitz (1959) that two species of Enterobacteriaceae, *Serratia marcessens* and *Escherichia coli*, which inoculated in soil were killed when ingested by the earthworm *Lumbricus terrestris*.

## 13.9 Effect of Worm Castings on Crop Yields

There is little scientific literature on the subject of the usefulness of vermicompost on plant growth (Edwards and Burrows 1988).

During the passage through the gut of the earthworm, ingested material is mixed and has its physical, chemical, and biotic components altered, but very little material is actually digested by the worm, and the structure and composition of the casts is dependent on the composition of the food source (Edwards and Burrows 1988; Buchanan et al. 1988). Organic materials differ greatly in their nutrient content; processing by the earthworm can change the form of these compounds but has very little effect on the total amounts contained. The physical structure of the casts also depends on the source material; however, the final product usually comprises finely mixed and relatively stable aggregates with good structure, porosity, and moisture-holding capacity (Edwards 1981; Lee 1985). The composition of casts from earthworms feeding on sewage sludge can be expected to have a different composition to those produced by earthworms feeding on unamended soils.

Casts produced from soil have increased nitrate and exchangeable calcium, magnesium, potassium, and phosphorus than the original soil (Lunt and Jacobson 1944). Other chemical and physical changes in earthworm casts compared to parent soil are given by Zhang and Schrader (1993) and changes in microbial populations are covered by Satchell (1983).

Edwards and Burrows (1988) also compared the nutrient contents of several organic wastes before and after being worked by earthworm: all had increased nitrate, soluble P and exchangeable potassium, calcium, and magnesium when worm-worked. They found that emergence and growth of range of seedlings in pots was frequently enhanced in these worm-worked compared to unworked media. Fresh earthworm casts may contain high salt soluble concentrations, especially of $Na^+$, sufficient to damage plants. Stark et al. (1978) found that leaching cast with water reduced these salts to tolerable levels while still retaining most of the plant beneficial nutrients.

Handrek (1986) compared the porosities, salinities, nutrient contents, pH values, and trace elements of several vermicomposts and potting mixes. Vermicomposts varied widely in total nutrient content: most had negligible amounts of soluble N-nitrates but had ample amounts of P and some had high concentrations of Zn and Cu.

Few reports deal with field trials involving the application of vermicompost. Kale et al. (1992) studied vermicompost in a rice paddy in India. Significant increases in the colonization of soil by microbes (including N-fixers, Actinomycetes, spore formers, and Mycorrhizae) occurred in the experimental plots compared to the control plots without added vermicompost. Higher levels of total N in the experimental plot where vermicompost was added was attributed to higher counts of N-fixing microbes. Lee (1985) mentions findings by Khan (1966) that the growth of maize on a loamy soil in Pakistan was enhanced by the addition of casts of *Metaphire posthuma* and that their effect was greater than was obtained with the addition of farmyard manure. In India, Reddy (1988) compared the growth of an ornamental shrub, *Vinca rosea* and rice, *Oryza sativa*, in soils with or without the casts of *Pheretima alexandri*. Those *V. rosea* plants in casts grew better and produced flowers and fruits earlier than plants in soil alone. Rice growing for 4 months in pots with highest concentrations of added casts grew best, the whole plant lengths (means) being 81.5 cm in soil mixed with casts compared to 62.8 cm in soil alone.

## 13.10 Detrimental Effects of Earthworms

Despite the many documented and putative beneficial effects of earthworms on soil structure, nutrient dynamics, and plant growth, some aspects of earthworm activities are considered undesirable (Edwards and Bohlen 1996; Lavelle et al. 1998; Parmelee et al. 1998). Detrimental activities include removing and burying of surface residues, which would otherwise protect soil surfaces from erosion; producing fresh casts that increase erosion and surface sealing; increasing compaction of surface soils; depositing castings on the surface of lawns and golf greens, where they are a nuisance; dispersing weed seeds in gardens and agricultural fields;

transmitting plant or animal pathogens; riddling irrigation ditches, making them less able to carry water; increasing losses of soil nitrogen through leaching and denitrification; and increasing loss of soil carbon through enhanced microbial respiration.

It is the net result of positive and negative effects of earthworms that determines whether they have detrimental impacts on ecosystems (Lavelle et al. 1998). Obviously, an effect such as mixing of organic and mineral soil horizons may be considered beneficial in one setting (e.g., urban gardens) and detrimental in another (e.g., native forests). The undesirable impacts of exotic species are central to assessing the risks associated with their introduction and spread.

## 13.11 Interpretation of Findings

Some microbial and enzyme activities are occurring within the gut of the earthworm that (1) enhances the breakdown of cellulose material, and (2) conveys some property, or properties, to the breakdown product (casting) that are generally beneficial to plant growth. The research team at Ohio State University has demonstrated that it is not just because of the relatively high levels of nutrients and micronutrients within castings. The explanation may be more deeply linked to the richer microbial calories conveyed through the castings, or could be due to the relatively high humification, and specifically the levels of humic acid associated with the castings (Tucker 2005).

In general, researches have shown that blending vermicomposts with traditional growth media has shown positive effects on plant growth, particularly on root growth but also on shoot and leaf growth and fruit and flower production as well. Some experiments have shown that the application of vermicompost produces poorer growth than that produced in the controls. The scientific evidence is less strong with regards to vermicompost having any positive effects on seed germination. Some researchers have found it may inhibit germination slightly, though once germinated the plants can then pick up and forge ahead in the vermicompost.

Effects on plants have been seen with as little as 5–10% of vermicompost added to the growing media. An addition of around 20–40% vermicompost is considered to provide the optimum blend. Then there appears to be a turnaround for concentrations above 40% with the higher rates impacting negatively on plant growth (Tucker 2005).

## 13.12 Conclusion

Some species of epegic earthworms can live in decaying organic waste materials and convert it to odor free fine particulate materials high in available nutrient (Marsh et al. 2005; Suthar 2006, 2007).

The utility of epigeic earthworm for successful degradation of organic wastes is well documented for different industries such as paper and pulp (Elvira et al. 1997, 1998; Reddy and Shantaram 2005). Compared to thermal composting, vermicomposting with earthworm often produces a product with a lower mass, lower processing time, and humus content; phytotoxicity is less likely; more N is released; fertilizer value is usually greater; and additional product (earthworms) which can have other uses is produced (Lorimor et al. 2001). Therefore, vermicomposting seems to be more appropriate and an efficient technology to convert industrial waste to a valuable community resources at low input basis. However, the composting efficiency and biology of only a few epigeic earthworm species has been studied, for example, *Eisenia foetida* (Maboeta and van Resenburg 2003; Kaushik and Garg 2004; Gupta et al. 2005), *Eisenia andrei* (Elvira et al. 1997, 1998; Nogales et al. 2005; Benitez et al. 1999), and *E. eugeniae* (Kale 1998).

Compost is an excellent product; being homogenous and retaining most of the original nutrients and reduced levels of organic contaminants with respect to the starting material (Ndegwa et al. 2000), it can be applied to soil to increase soil organic matter content and content of nutrients, which can be released upon decomposition, improve soil structure, and increase cation exchange capacity. Composting has been updated to process organic wastes of different origin, such as sewage sludge, animal manure, and agro-industrial wastes (Paredes et al. 1996; Bernal et al. 1998). However, composting is a time-consuming process taking at least 6 months and requiring frequent mixing with possible losses of nutrients, that is, $NH_3$. Additionally, earthworms reduce numbers of pathogens and the same effect is obtained in traditional composting by the increase in temperature. Vermicomposting has been successfully used for composting different types of wastes, such as municipal and industrial sludges (Edwards and Bohlen 1996; Elvira et al. 1998), though optimal moisture and the best proportions of organic waste are required for an efficient vermicomposting.

Vermicomposting technology involves harnessing earthworms as versatile natural bioreactors, which play a vital role in decomposition of organic matter, maintaining soil fertility, and bringing out efficient nutrient recycling and enhanced plants' growth. A variety of organic solid wastes, domestic, animal, agro-industrial, human wastes, etc. can be vermicomposted. The value of vermicompost is further enhanced as it has simultaneously other benefits: excess worms can be used in medicines and as protein rich animal feed provided they are not growing on polluted wastes and can be used as an antisoil pollutant.

Earthworm can be used as bioindicators for the monitoring of ecosystem state and changes. Various workers identified the earthworms for evaluating the effect of soil contamination with heavy metals and pesticides, agricultural practices, and acid rain, etc. (Paoletti et al. 1991). There are numerous studies about the heavy metal influence on the growth, reproduction, and mortality of earthworms. Marcel et al. (1997) reported that earthworms increase the water infiltrations rate of the soil and observed a mean rate of 150 mm $h^{-1}$ per 100 g $m^{-2}$ of earthworms, however the anecic species shows maximum infiltration (282 mm $h^{-1}$ per g $m^{-2}$).

Heavy metals are perhaps of greatest concern, and it may be possible to exploit some aspect of earthworm behavior for their removal. Processing by the earthworms may alter the solubility or stability of some heavy metals or perhaps, enhance other physical, chemical, or microbial means of removal (e.g., Tyagi and Couillard 1991). Accumulation of pesticide may be less of a problem as these chemicals and their metabolites often have known rates and products of decay. Earthworms may be used in combination with conventional composting techniques to reduce pathogens, although the temperatures involved are incompatible for earthworm survival (Blakemore 1995).

Vermicomposting of municipal wastes may be particularly suitable option for production of useable products. Composition and consistency of these products would largely depend on the composition of the initial waste materials and of any materials with which they are combined. As for sludge treatment, there would be a requirement to constantly monitor nutrients, contaminants and to prevent pathogen regrowth, in both the raw materials and the final products.

## References

Alter D, Mitchell A (1992) Use of vermicompost extract as an aluminum inhibitor in aqueous solution. Commun Soil Sci Plant Anal 23:231–240

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

Atiyeh RM, Edwards CA, Subler S, Metzger J (2000b) Earthworm-processed organic wastes as components of horticultural potting media for growing marigold and vegetable seedlings. Compost Sci Util 8:215–223

Atiyeh RM, Lee Edwards CA, Arancon NQ, Metzger JD (2002) The influence of humic acids derived from earthworm-processed organic wastes on plant growth. Biores Technol 84:7–14

Benitez E, Nogales R, Elvira C, Masciandaro G, Ceccanti B (1999) Enzyme activities as indicators of the stabilization of sewage sludges composting *Eisenia foetida*. Bioresour Technol 67:297–303

Bernal MP, Paredes C, Sanchez-Monedero MA, Cegarra J (1998) Maturity and stability parameters of composts prepared with a wide range of organic waste. Bioresour Technol 63:91–99

Beyer WN (1981) Metals and terrestrial earthworms (Annelida: oligochaeta). In: Applehof M (ed) Workshop on the role of earthworms in the stabilization of organic residues. vol 1, Proceedings. Beach Leaf, Kalamazoo, MI, p 315

Blakemore RJ (1995) The use of earthworms for bioconversion of sewage sludge and municipal waste – a synopsis of relevant literature. Report commissioned by Gerry Gillespie of the ACT Dept. of Urban Services, Canberra, Australia. November, 1995. pp. 15

Bridgens S (1981) The importance of the earthworms. SPAN 22:20

Brown BA, Mitchell MJ (1981) Role of the earthworm, *Eisenia foetida*, in affecting the survival of *Salmonella enteritidis* ser. Typhimurium. Pedobiologia 22:434–438

Bruzewitz G (1959) Studies on the influence of earthworms on numbers of species and role of micro-organisms in soils. Arch Mikrobiol 33:52–82

Buchanan MA, Russell G, Block SD (1988) Chemical characterization and nitrogen mineralization, potential of vermicompost derived from differing organic wastes. In: Edwards CA, Neuhauzer EF (eds) Earthworms in waste and environmental management. SPB Academic Publishing, The Hague, pp 231–239

Cantanazoro CJ, Williams KA, Sauve RJ (1998) Slow release versus water soluble fertilization affects nutrient leaching and growth of potted chrysanthemum. J Plant Nutr 21:1025–1036

Cegarra J, Famandez FM, Tercero A, Roig A (1992) Effects of vermicomposting of some components of organic wastes. Preliminary results. Mitteilungen-aus-dem-hamburgischen zoologischen-museum-und-Institute 89:159–167

Chan PLS, Griffiths DA (1988) The vermicomposting of pre-treated pig manure. Biol Wastes 24:57–69

Chaoui H, Edwards CA, Brickner A, Lee SS, Arancon NQ (2002). Suppression of the plant diseases, Pythium (damping-off) Rehizoctonia (root rot), and Verticillium (wilt) by vermicomposts. Proceedings of Brighton Crop Protection Conference-Pest and Diseases. vol II, 8B-3:711–716

Cortet J, Gomot-De Vauflery A, Poinsot-Balaguer N, Texier GL, Ch CD (1999) The use of soil fauna in monitoring pollutants effects. Eur J Soil Bid 35:115–134

Darwin C (1881) The formation of vegetable mould through the action of worms with observations. Murrray, London, p 326

Day GM (1950) Influence of earthworms on soil micro-organisms. Soil Sci 69:175–184

Decaëns T, Rangel AF, Asakawa N, Thomas RJ (1999) Carbon and nitrogen dynamics in ageing earthworm cast in grassland of the eastern plains of Colombia. Biol Fertil Soils 30:20–50

Edwards CA (1981) Earthworms, soil fertility and plant growth. In: Applehof M. Workshop on the role of earthworms in the stabilization of organic residues. vol 1, Proceedings. Beech Leaf, Kalamazoo, MI pp 61–85

Edwards CA, Arancon NQ (2004) Interactions among organic matter, earthworms and microorganisms in promoting plant growth. Functions and management of organic matter. In: Magdoff F, Weil R (eds) Agro-ecosystems, vol 11. CRC, Boca Raton, pp 327–376

Edwards CA, Bohlen PJ (1996) Biology and ecology of earthworms, 3rd edn. Chapman and Hall, London

Edwards CA, Burrows I (1988) The potential of earthworm compost as plant growth media. In: Edwards CA, Neuhauser E (eds) Earthworms in waste and environmental management. SPB Academic, The Hague, pp 21–32

Edwards CA, Lofty JR (1972) Biology of earthworms. Chapman and Hall, London

Edwards CA, Bohlen PJ, Linden DR, Subler S (1995) Earthworms in agro ecosystems. In: Hendrix PF (ed) Earthworm ecology and biogeography in North America. Lewis, Boca Raton, pp 185–213

Elvira C, Sampedro L, Domingoez J, Mato S (1997) Vermicomposting of waste water sludge from paper-pulp industry with nitrogen rich materials. Soil Biol Biochem 29:759–762

Elvira C, Sampedro L, Benitez E, Nogales R (1998) Vermicomposting of sludges from paper mill and dairy industries with *Eisenia andrei*. A pilot scale study. Bioresour Technol 63:205–211

Follet R, Donahue R, Murphy L (1981) Soil and soil amendments. Prentice-hall Inc., NJ

Graff O (1982) Vergleich der Regenswurmaten *Eisenia foetida* und *Eudrilus eugeniae* hinsichlich ihrer Eignung zur proteinwinnung aus abfallstoffen. Pedobiologia 23:277–282

Gupta SK, Tewari A, Srivastava R, Murthy RC, Chandra S (2005) Potential of *Eisenia foetida* for sustainable and efficient vermicomposting of fly ash. Water Air Soil Pollut 163:293–302

Hand P, Hayes WA, Frankland JC, Satchell JE (1988) The vermicomposting of cow slurry. Pedobiologia 31:199–209

Handrek KA (1986) Vermicomposts as components of potting media. Biocycle 10(86):58–62

Hidalgo P (1999) Earthworm castings increase germination rate and seedling development of cucumber. Mississippi Agricultural and Forestry Experiment Station, Research Report 22:6

Ireland MP (1977) Hairy worms. New Sci 79:486–487

Ireland MP (1983) Heavy Metal uptake and tissue distribution in earthworms. In: Satchell JE (ed) Earthworm ecology: from Darwin to vermiculture. Chapman and Hall, London, pp 247–265

Kale RD (1995) Vermicomposting has a bright scope. Indian Silk 34:6–9

Kale RD (1998) Earthworm: nature's gift for utilization of organic wastes. In: Edwards CA (ed) Earthworm ecology. St. Lucile, New York, pp 355–376

Kale RD, Malesh BC, Bana K, Bagyaraj DJ (1992) Influence of vermicompost application on the available macro-nutrients and selected microbial populations in the paddy field. Soil Biol Biochem 24:1317–1320

Kaushik P, Garg VK (2004) Dynamics of biological and chemical parameters during vermicomposting of solid textile mill sludge mixed with cow dung and agricultural residues. Biores Technol 94:203–209

Kaviraj, Sharma S (2003) Municipal solid waste management through vermicomposting employing exotic and local species of earthworm. Biores Technol 90:169–173

Khan AW (1966) Earthworms of West Pakistan and their utility in soil improvement. Agic Pak 17:192–197

Lavelle P (1978) Les vers de terre de la savane de Lamto (cote d'Ivoire). Peuplements, populations et functions de locosysteme. Publ Lab Zool ENS 12:1–301

Lavelle P, Pashanasi B, Charpentier F, Gilot C, Rossi J-P, Derouard L, Andre J, Ponge J-F, Bernier F (1998) Large scale effects of earthworms on soil organic matter and nutrient dynamics. In: Edwards CA (ed) Earthworm ecology. St. Lucie, Boca Raton, pp 103–122

Lee KE (1985) Earthworms. Their ecology and relationships with soils and land use. Academic, Sydney, p 411

Logsdon G (1994) Word wide progress in vermicomposting. Biocycle 35:63–65

Lorimor J, Fulhage C, Zhang R, Funk T, Sheffield R, Sheppard C, Newton GL (2001) Manure management strategies/technologies. White paper on animal agriculture and the environment for national center for manure and animal waste management. MWPS, Ames, p 52

Lunt HA, Jacobson HGM (1944) The chemical composition of earthworm casts. Soil Sci 58:367–375

Maboeta MS, Van Resenburg L (2003) Vermicomposting of industrially produced woodchips and sewage sludge utilizing *Eisenia fetida*. Ecotoxicol Environ Saf 56:265–270

Marcel B, Boucle Fathel Al-Addan, Marcel B, Boucle Fathel Al-Addan (1997) Earthworms water infiltration and soil stability: some new assessments. Soil Biol Biochem 29:441–452

Marsh L, Subler S, Mishra S, Marini M (2005) Suitability of aquaculture effluent solid mixed with cardboard as a feedstock for vermicomposting. Bioresour Technol 96:413–418

Martinez SD, Gomez Zambrano J (1995) The use of earthworm composts in commercial production of chrysanthemums. Acta Agronomica Universidad Nacional de Colombia 45:79–84

McInerney M, Bolger T (2000) Temperature wetting cycles and soil texture effects on carbon and nitrogen dynamics in stabilized earthworm casts. Soil Biol Biochem 32:335–349

Mitchell A, Alter D (1993) Suppression of labile aluminum in acidic soils by the use of vermicompost extract. Commun Soil Sci Plant Anal 24:1171–1181

Morgan JE, Morgan AJ (1999) The accumulation of metals (Cd, Cu, Pb, Zn and Ca) by two ecologically contrasting earthworm species (*Lumbricus rubellus* and *Aporrectodea caliginosa*): implications for eco-toxicological testing. Appl Soil Ecol 13:9–12

Muscolo A, Bavolo F, Gionfriddo F, Nardi S (1999) Earthworm humic matter produces auxins-like effect on *Daucus Carota* cell growth and nitrate metabolism. Soil Biol Biochem 31:1303–1311

Ndegwa PM, Thompson SA (2001) Integrating composting and vermicomposting in the treatment of bio-conversion of bio-solids. Bioresour Technol 76:107–111

Ndegwa PM, Thompson SA, Das KC (2000) Effects of stocking density and feeding rate on vermicomposting of biosolids. Bioresour Technol 71:5–12

Nielson RL (1965) Presence of plant growth substances in earthworms demonstrated by paper chromatography and the went pea test. Nature 208:1113–1114

Nogales R, Celia C, Benitez E (2005) Vermicomposting of winery wastes: a laboratory study. J Environ Sci Health Part B 40:659–673

Orozco FH, Cegarra J, Trujillo LM, Roig A (1996) Vermicomposting of coffee pulp using the earthworm *Eisenia fetida*: effects on C and N contents of the availability of nutrients. Biol Fertil Soils 22:162–166

Paoletti MG, Faveretto MR, Stinner BR, Purrington FF, Batter JE (1991) Invertebrates as bioindicators of soil use. Agric Ecosyst Environ 34:341–362

Paredes C, Bernal MP, Cegarra J, Roig A, Navarro AF (1996) Nitrogen transformation during the composting of different organic waste. In: Van Cleemput O, Hofman G, Vermoesen A (eds) Progress in nitrogen cycling studies. Kluwer, Dordrecht, pp 121–125

Parmelee RW, Bohlen PJ, Blair JM (1998) Earthworms and nutrient cycling processes: integrating across the ecological hierarchy. In: Edwards CA (ed) Earthworm ecology. St. Lucie, Boca Raton, pp 123–143

Pashanasi B, Lavelle P, Alegre J, Charpentier F (1996) Effect of the endogeic earthworm, *Pontoscolex corethrurus* on soil chemical characteristics and plant growth in a low input tropical agro-ecosystem. Soil Biol Biochem 28:801–802

Reddy MV (1988) The effect of casts of *Pheretima alexandri* (Beddard) on the growth of *Vinca rosea*, and *Oryza sativa* L. In: Edwards CA, Neuhauzer EF (eds) Earthworms in waste and environmental management. SPB Academic Publishing, The Hague, pp 241–248

Reddy KS, Shantaram MV (2005) Potential of earthworm in composting of sugarcane byproducts. Asn J Microbiol Biotechnol Environmen Sci 7:483–487

Riggle D, Holmes H (1994) New horizons for commercial vermiculture. Biocycle 35:58–62

Saint-Denis M, Narbonne JF, Arnaud C, Thybaud E, Ribera D (1999) Biochemical responses of the earthworm *Eisenia fetida*, *andrei* exposed to contaminated artificial soil: effects of benzo (a) pyrene. Soil Biol Biochem 315:1827–1846

Satchell JE (1983) Earthworm microbiology. In: Satchell JE (ed) Earthworm ecology: from Darwin to vermiculture. Chapman and Hall, London, pp 351–365

Sharma S, Pradhan K, Satya S, Vasudevan P (2005) Potentiality of earthworms for waste management. J Am Sci 1:4–16

Singh A, Sharma S (2002) Composting of a crop residue through treatment with microorganisms and subsequent vermicomposting. Bioresour Technol 85:107–111

Spurgeon DJ, Hopkin SP (1999) Comparisons of metal accumulation and excretion kinetics in earthworms (*Eisenia fetida*) exposed to contaminated field and laboratory soils. Appl Soil Ecol 11:227–243

Spurgeon DJ, Hopkin SP (2000) The development of genetically inherited resistance to zinc in laboratory-selected generation of the earthworm *Eisenia fetida*. Environ Pollut 109:193–201

Stark N, Pawlowski P, Bodmer S (1978) Quality of earthworm castings and the use of compost on arid soils. In: Hartenstein R (ed) Utilization of soils organisms in sludge management. Natl. Tech. Inf. Services, PB 286932. Springfield, Virginia, pp 87–102

Subler S, Edwards CA, Metzger J (1998) Comparing vermicomposts and composts. Biocycle 39:63–66

Suthar S (2006) Potential utilization of guargum industrial waste in vermicompost production. Bioresour Technol 97:2474–2477

Suthar S (2007) Vermicomposting potential of *Perionyx sansibaricus* (perrier) in different waste materials. Bioresour Technol 98:1231–1237

Szczech M, Smolinska U (2001) Comparison of suppressiveness of vermicomposts produced from animal manures and sewage sludge against *phytophthora* nicotianae Breda de Haan var. Nicotinae. J Phytopathol 149:77–82

Tomati U, Galli E, Grapelli A, Hard JS (1994) Plant metabolism as influenced by earthworm casts. Mitteilungen aus dem Hamburgischem Zoologischen Museum and Institute 89:179–185

Tucker P (2005) Co-composting paper mill sludges with fruit and vegetable wastes. University of Paisley, Paisley

Tyagi RD, Couillard D (1991) An innovative biological process for heavy metals removal from municipal sludge. In: Martin AM (ed) Biological degradation of wastes. Elsevier Science Publishers, London, pp 307–321

Vasudevan P and Sharma S (1997) Adoption of bio-fertilizers by farmers: some experiences processing at Int. Conference on Application of Biotechnology in Bio-fertilizers and Bio-pesticides, DBEB IIT Delhi

Zhang H, Schrader S (1993) Earthworm effects on selected physical and chemical properties of soil aggregates. Biol Fertil Soils 15:229–234