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Role of Earthworms in Breakdown of Different Organic Wastes into Manure: A Review

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ABSTRACT

Vermicomposting and composting are efficient methods of converting solid wastes into products richer in nutrients. Certain species of earthworms can consume organic residuals very rapidly and fragment them into much finer particles by passing them through a grinding gizzard, an organ that all earthworms' possess. Vermicast contain microorganisms, hormones, enzymes, inorganic minerals and organic matter in a form available to plants. Based on the physical, chemical and biological characteristics, vermicomposts have considerable commercial potential in the horticultural industry as container media for growing vegetable and bedding plants. The aim of this review is to compare the nutritive value of compost and vermicompost produced from different organic wastes including composting-vermicomposting of different tree leaf litters mixed with municipal solid waste (MSW) using *Eisenia foetida* under glasshouse conditions.

Keywords: available nutrients, growth stimulatory hormones, humic substances, mucus, nitrogenous excretory substances, vermiculture, vermiwash

Abbreviations: FYM, farm yard manure; **GI**, germination index; **MSW**, municipal solid waste; **WSC**, water-soluble carbon

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INTRODUCTION

During recent years, the problem of efficient disposal and management of organic solid wastes has become more significant due to rapidly increasing population, intensive agriculture and industrialization. Production of large quantities of organic waste all over the world poses major environmental (offensive odors, contamination of ground water and soil) and disposal problems (Edwards and Bater 1992). Therefore, the disposal of different types of wastes has become very important issue for maintaining environmental health (Senapati and Julka 1993). Although various physical, chemical and microbiological methods of disposal of organic solid wastes are currently in use, these methods are not only time-consuming but also involve high costs. Therefore, there is a pressing need to find out cost-effective alternative methods of shorter duration particularly suited to Indian conditions. In this context, vermicomposting has been reported to be a viable, cost-effective and rapid technique for the efficient management of the organic solid wastes (Hand *et al*. 1988; Raymond *et al.* 1988; Harris *et al*. 1990; Logsdon 1994). Considerable work has been carried out on the use of earthworms for composting various organic materials and it has been established that epigeic forms of earthworms can hasten the composting process to a significant extent with the production of a better quality of compost as compared with those prepared through traditional composting methods (Ghosh *et al.* 1999).

The recycling of wastes through vermicomposting reduces problems of disposal of agricultural wastes. Vermicomposting is used not only as an alternative source of organic fertilizers but also to provide economical animal feed protein for the fish and poultry industries worldwide (Edwards 1985; Kale 2000). Most vermicompost has more available nutrients than the organic wastes from which they are produced (Buchanan *et al.* 1988). Jambhekar (1990) reported that the application of vermicomposts increased available nitrogen (N), phosphorous (P) and potassium (K) contents in soil. Moreover, nutrients present in vermicomposts are readily available for plant growth. Transplantation of earthworms and mulching facilitate transfer of nutrients to plants (Ismail 2000).

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Invited Review

EARTHWORMS IN WASTE MANAGEMENT

Earthworms are very important components for the maintenance of soil fertility and nutrient cycling. Their utilization and importance have been stressed by renowned scientists like Muller (1878), Darwin (1881) and Swaminathan (1974). The practice of vermiculture is at least a century old. The first serious experiments on vermiculture were conducted in Holland in 1970 and subsequently in England and Canada (Sinha *et al.* 2002). The action of earthworms in the process of vermicomposting of waste is physical as well as biochemical. The physical process includes substrate aeration, mixing as well as actual grinding while the biochemical process is influenced by microbial decomposition of substrate in the intestine this results in vermicomposting of organic matter (Neuhauser *et al*. 1988; Frederickson *et al.* 1997) and gives chelating and phytohormonal elements (Tomati *et al*. 1995) which have a high content of microbial matter and stabilized humic substances. The chemical analyses of casts show two times available magnesium (Mg), 5 times available nitrogen (N) and 7 times available phosphorous (P) and 11 times potassium (K) compared to the surrounding soil (Bridgens 1981).

Researchers have explored an enormous variety of agricultural and municipal wastes as potential feedstock for vermicomposting. Manure is perhaps the most palatable of feedstock to composting worms due to its high rate of nitrogen and consequent rapid decomposition by edible microorganisms. Various organic wastes tested in past as feed material for different species of earthworms include sewage sludges (Mitchell *et al*. 1977; Hartenstein 1978; Lofs-Holmin 1986; Neuhauser *et al*. 1988; Diaz-Burgos *et al.* 1992; Delgado *et al.* 1995; Benitez *et al.* 1996), combined sewage sludge and municipal refuse (Grappelli *et al.* 1983), paper mill industry sludge (Butt 1993; Elvira *et al.* 1997, 1998), pig waste (Chan and Griffiths 1988; Wong and Griffiths 1991 and Reeh 1992), water hyacinth (Gajalakshmi *et al.* 2002), paper waste (Gajalakshmi *et al.* 2001), brewery yeast (Butt 1993), crop residues (Bansal and Kapoor 2000), cow slurry (Hand *et al.* 1988), cattle manure (Mitchell 1997), farmyard manure (Nardi *et al.* 1983; Sagar *et al.* 2002), cotton industrial waste (Albanell *et al.* 1988), industrial and vegetable waste (Bano *et al.* 1987; Kavian *et al.* 1996; Elvira *et al.* 1999), animal and vegetable waste (Edwards 1988), animal waste (Garg *et al.* 2005), sugar waste (Kale 2004), slurries (Dominquez and Edwards 1997), domestic and agricultural sludge (Garcia *et al.* 1994), coffee pulp, lignocellulosic residues and pruning (Frederickson *et al.* 1997; Vinceslas and Loquet 1994), dairy processing plant sludge (Kavian and Ghatnekar 1991; Gratelly *et al.* 1996; Elvira *et al.* 1998), vine fruit industry sludge (Atharasopoulous 1993), rice stubbles, mango leaves (Talashilkar *et al.* 1999), activated sludge (Hartenstein and Hartenstein 1981), textile mill sludge (Kaushik and Garg 2004; Garg *et al.* 2006), rice straw (Reddy and Ohkura 2004), tobacco crop residues (Dinesh *et al.* 2005), municipal solid waste (Sur *et al.* 2002; Kaviraj and Sharma 2003; Bharat 2007), household waste (Huhta and Haimi 1988; Gandhi *et al.* 1997; Sundberg *et al.* 2004), rubber leaf litter (Chaudhuri *et al.* 2003), forest litters (Manna *et al.* 2003), agro-industrial wastes (Kitturmath *et al.* 2007), in production of vermicompost. In India biomanagement of paper mill sludge, recycling of cattle dung, biogas effluent and water hyacinth have been reported in different studies using vermiculture (Balasubramanian 1995; Banu *et al*. 2001).

Selection of suitable species

The selection of appropriate species of earthworms for degrading organic waste to vermicompost is very important. The adaptability to waste, minimal gut transit time, fast growth rate and high reproductive potential are some of the important qualities to be present in earthworm species suitable for vermicomposting. At a global level *Eisenia foetida* is widely used for organic waste management whereas *Eudrilus eugeniae* is popular in subtropical and tropical countries. Sometimes polyculture of different species is also used for waste management (Kale 2005). Several epigeic earthworms, e.g., *Eisenia foetida* (Savigny), *Perionyx excavatus* (Perrier), and *Eudrilus eugeniae* Kinberg have been used for vermicomposting wastes from different sources (Kale *et al*. 1982: Garg and Kaushik 2005: Garg *et al*. 2006: Suthar 2007a, 2007b, 2007c, 2008a, 2008b: Suthar and Singh 2008a, 2008b).

This paper reviews the findings of work undertaken by different scientists (**Table 1**). Aalok (2009) has studied composting of leaf litters of tree species namely *Eucalyptus* hybrid, *Pinus roxburghii*, *Parthenium hysterophorus*, *Populus deltoids* and *Shorea robusta* and compared their nutrient status. Leaf litters of each of the species were mixed with municipal solid waste and the epigeic species *E. foetida* was used for composting process.

Horticulture and kitchen waste composting

Dickerson (2001) has worked on composting and vermicomposting of horticulture waste. Their results clearly indicate that vermicompost is superior to compost in nutrient contents. Ghosh (2004) experimented with solid vegetables and horticultural waste from nursery, hostels, canteen and residential complex. In his experiment, solid waste such as dry leaves, cowdung and garbage (vegetable waste) were taken in the ratio of 20-30 kg: 30-40 kg and 70-80 kg. Two types of composting processes were conducted, pit culture (large scale: size- 2 m × 0.5 m × 0.5 m) and pot culture (small scale: size – 1 ½ ft × 2 ½ ft × 1 ft). The pits and pots were inoculated with 1000 worms/sq. m., 400-1000 worms/ pot respectively to initiate vermicomposting process. The process of compost formation took 60-90 days. The results clearly indicate that nutrient quality of vermicompost is far better than prime organic manure source cowdung. The average nutrient status of some common organic manures and compost from agricultural residues, like poultry manure, rural compost, urban compost, water hyacinth compost and vermicompost has been reported by Gaur and Sadasivam (1993). Handreck (1986) has reported a detailed assessment of the ability of seven vermicomposts to supply nutrients to one test plant growing in soil-less medium. The substrates from which the vermicompost has been produced were sheep manure, cow manure, poultry manure, domestic waste, kitchen waste and pig waste. The vermicompost varied widely with respect to total nutrient content, particularly in K and P.

Tripathi and Bhardwaj (2004) in their study used epigeic worm *E. foetida* and aneceic worm *Lampito mauritii* in order to evaluate the composting potential of both these species under tropical conditions. In the kitchen waste + cowdung bedding treatment, both *E. foetida* and *L. mauritii* increased N, P and K (g/kg) as well as decreasing C/N and C/P ratio after 150 days of vermicomposting. *E. foetida* produced a faster change in the kitchen waste + cowdung vermicompost with moderate mineralization and higher decomposition rates and moderate breeding. In contrast, *L. mauritii* produced moderate mineralization and moderate decomposition rates having moderate breeding. Both worm species differed in rates of decomposition and mineralization but not in the trend of decomposition.

Bamane *et al.* (2004) in their paper discussed the applicability of an expert or knowledge based approach to hotel waste management system and concluded that the prototype expert system developed can serve as a tool for selecting the best alternative for the purpose. Their results show that normal heterotrophic organisms are responsible for the degradation of the hotel waste. The earthworms help in speeding up the process.

Weed composting

Gajalakshmi *et al.* (2002) have worked with different wastes such as water hyacinth, paper waste neem leaves and mango leaves. They have experimented with four species of earthworms namely *E. eugeniae*, *Drawida willsi*, *L. mauritii*, and *P. excavatus*. Their study was an attempt to develop a system with which the aquatic weed water hyacinth can be economically processed to generate vermicompost in large quantities. The composting process was completed in 20 days and the composted weed was found to be vermicomposted three times as rapidly as uncomposted water hyacinth.

Investigations have been carried out by Channappagoudar *et al.* (2007) to find out the influence of composts prepared from the various weed species viz., *Parthenium hysterophorus*, *Cassia serecia*, *Chromolaena odorata* and *Portulaca oleracea* on growth and yield of sorghum crop. The results clearly indicated that compost prepared from the weed species specially *Parthenium* and *Cassia* at pre-flowering stage was far superior in nutrient content than FYM as well as vermicompost and were comparable with poultry manure. *Parthenium* followed by *Chromolaena* and *Cassia* weeds can be successfully used for preparing organic manure and used in increasing the crop productivity as an alternative source FYM.

Industrial waste composting

Industrial wastes rich in organic matter and free from toxic substances or ions could be suitable substrates for vermicomposting. Suthar (2006) has reported vermicomposting of guar gum industrial waste using *P. excavatus*. Suthar (2008c) have also reported the vermiconversion of distillery sludge mixed with cow dung using *E. foetida* and the results show that distillery sludge mixed with cow dung could be utilized as an efficient soil conditioner for sustainable land restoration practices, at low-imput basis. According to Kaushik *et al.* (2008), textile mill waste can be vermicomposted if it is mixed in the range of 20-30% with cow dung. Sangwan *et al.* (2009) have studied the vermicomposting of sugar mill sludge mixed with biogas plant slurry using *E. foetida*. Their results demonstrate that if press mud is vermicomposted after mixing with 30-50% biogas plant slurry, its manorial value can be increased.

Parthasarathi *et al.* (1999) have determined the total NPK contents in the vermicasts produced by *L. mauritii*, *E. eugeniae*, *P. excavatus* and *E. foetida* adopting monoculture and polyculture techniques while they vermicompost pressmud. Two month old, dried pressmud (control) was used as feed for the mature earthworms under following two types of experiments: 1. Monoculture – 500 worms of each species were left in separate pits (150 × 90 × 120 cm) each containing 500 kg of pressmud. 2. Polyculture – 125 worms of each species left in a pit (150 × 90 × 120 cm) containing 500 kg of pressmud.

Total N, P, K contents of pressmud vermicasts produced by mono and polyculture of earthworms show that N is enhanced 2-3 times, P – 1.3-1.6 times and K – 1.9 – 2.8 times in the casts of individual as well as casts of polyculture. Casts produced by *E. eugeniae* followed by polyculture are the most efficient ways of vermicomposting pressmud.

Kaushik and Garg (2004) studied the ability of *E. foetida* to transform textile mill sludge mixed with cow dung and/or agricultural residues into vermicompost. The maximum growth and reproduction was obtained in 100% cowdung, but worms grew and reproduced favorably in 80% cowdung + 20% solid textile mill sludge and 70% cowdung + solid textile mill sludge also. Vermicomposting resulted in significant reduction in C:N ratio and increase in total nitrogen, total P, total K and total calcium after 77 days of worm activity in all the feeds.

MSW composting

A comparative study between exotic and local (epigeic- *E. foetida* and aneceic- *L. mauritii*, respectively) species of earthworms for the evaluation of their efficacy in their vermicomposting of municipal solid waste for 42 days resulted in significant difference between the two species in their performance measured as loss in total organic carbon, carbon-nitrogen ratio (C:N) and increased in total Kjeldahl N, electrical conductivity and total K and weight loss of MSW. The change in pH and increase in number of earthworms and cocoons and weight of earthworms were non significant (Kaviraj and Sharma 2003).

A better quality of compost from MSW could be generated using the vermicomposting technique (Bharat 2007). Sur *et al.* (2002) studied the aerobic composting of municipal solid waste for seven weeks. Significant improvement was seen in some physical and chemical properties during composting. There was reduction in availability and solubility of some potentially toxic metals like Cd, Cr, Pb, Ni and Zn. Composting of MSW can thus provide an environmentally safe product which can be used for soil.

Different organic wastes, viz. cow dung, grass, aquatic weeds and MSW with lime and microbial inoculants affect the chemical and biochemical properties of vermicompost (Pramanik *et al.* 2007). Cow dung was reported the best substrate for vermicomposting.

Garg *et al.* (2006) conducted a study to assess the potential of *E. foetida* in composting the different types of organic substrates (i.e., textile sludge, textile fibre, institutional waste, kitchen waste, and agro-residues) and quality of vermicompost thus produced. The results show that vermicomposting significantly modified the physical and chemical properties of different feed mixtures tested. Total Kjeldahl N content of the compost increased significantly with time in all the substrates in the presence of earthworms. Increase in N content in the final product in the form of mucus, nitrogenous excretory substances, and growth stimulatory hormones and enzymes from earthworms have also been reported (Tripathi and Bhardwaj 2004). The efficiency of vermicomposting process using *E. foetida* on the basis of nutrient content (N and P) of the compost was found maximum for industrial waste followed by institutional waste, agro-residues and kitchen waste.

Castings of *E. foetida* from sheep manure alone and mixed with cotton wastes were analyzed for their properties and chemical composition and compared with the same manures in the absence of earthworms (Albanell *et al.* 1988). The results showed that earthworms accelerated the mineralization rate and converted the manures into castings with a higher nutritional value and degrees of humification. The castings obtained from manure mixed with cotton wastes exhibited good agronomic quality, suggesting that this kind of industrial residue may be used in vermicomposting.

Leaf litter composting

Kadam *et al.* (2008) have studied the effect of precomposting of Tendu (*Diospyros melanoxylon*) leaf residues on growth and cocoon production of *E. eugeniae.* The leaf residue was precomposted for a period of 15, 20, 25, 30, 35, 40, 45 and 50 days before subjecting it to vermicomposting. Maximum growth and cocoon production rate was seen in the residue precomposted for 45 days. This suggests that if the wastes with higher C: N ratio are fed directly to earthworms, it may prove to be detrimental. One of the reasons for this is the intolerance of the worms to the heat generated during decomposition of these materials (Bhiday 1995; Abbasi and Ramasamy 1999). Such wastes must be, therefore, precomposted before vermicomposting (Bhiday 1995; Edwards 1995).

Suthar (2009) carried out a study to examine the growth and fecundity of *Perionyx excavatus* and *Perionyx sansibaricus* using partially decomposed cow dung mixed with leaf litter of *Mangifera indica*. *P. sansibaricus* proved to be more efficient than *P. excavatus* in terms of cattle mineralization rate.

In the study by Aalok (2009), with leaf litter of plant species namely *Eucalyptus* hybrid, *Pinus roxburghii*, *Parthenium hysterophorus*, *Populus deltoids* and *Shorea robusta*, the results show that parthenium vermicompost had higher

Table 1 Chemical composition of different types of compost and vermicompost.

Type of waste	Compost/ vermicompost	N (%)	P (%)	K (%)	References
Garden waste	Compost	0.80	0.35	0.48	Dickerson 2001
	Vermicompost	1.94	0.47	0.70	Dickerson 2001
		1.45	0.88	0.66	Ghosh 2004
		0.99	0.1	0.95	Ghosh 2004
		1.92	1.30	0.40	Harris *et al*. 1990
		1.60	2.20	0.67	Gaur and Sadasivam 1993
Farm yard manure	Compost	0.5	0.2	0.5	Gaur *et al*. 1995
		0.8	0.41	0.71	Gaur and Sadasivam 1993
		0.73	0.18	0.71	Ghosh *et al*. 2004
		0.75	0.26	0.34	Purakayastha and Bhatnagar 1997
		0.54	0.17	0.55	Channappagoudar *et al*. 2007
Town waste	Compost	1.5	1.0	1.5	Gaur *et al*. 1995
		1.24	1.92	1.07	Gaur and Sadasivam 1993
MSW	Compost	1.45	0.38	1.2	Caravaca *et al*. 2003
	Vermicompost	3.0	0.6	0.78	Levy and Taylor 2003
Water hyacinth	Compost	2.0	1.0	2.3	Gaur *et al*. 1995
Poultry waste	Compost	2.87	2.93	2.35	Gaur and Sadasivam 1993
	Vermicompost	2.02	1.60	1.42	Channappagoudar *et al*. 2007
		2.4	2.4	0.14	Handreck 1986
		3.03	2.63	1.40	Gaur *et al*. 1995
Sheep waste	Compost	3.0	1.0	2.0	Handreck 1986
	Vermicompost	2.7	1.9	0.17	Handreck 1986
Sludge	Vermicompost	0.7	0.026	0.069	Garg *et al*. 2006
		1.5-3.5	0.75-4.0	0.3-0.6	Gaur *et al*. 1995
Fibre	Vermicompost	0.52	0.06	0.247	Garg *et al*. 2006
Institutional	Vermicompost	0.73	0.087	0.072	Garg *et al*. 2006
Kitchen	Vermicompost	2.5	0.89	0.58	Tripathi and Bhardwaj 2004
		1.10	0.18	0.436	Garg *et al*. 2006
Agricultural	Vermicompost	1.1	0.3	0.31	Handreck 1986
		0.88	0.10	0.263	Garg *et al*. 2006
Food	Vermicompost	1.3	2.7	9.2	Arancon *et al*. 2004
Paper	Vermicompost	1.0	2.7	6.2	Arancon *et al*. 2004
Pressmud	Vermicompost	2.81	3.31	2.31	Parthasarathi *et al*. 1999
Cow manure	Compost	1.057	0.917	0.657	Aalok 2009
	Vermicompost	1.5	0.7	0.74	Handreck 1986
		1.473	1.087	0.753	Aalok 2009
Domestic waste	Vermicompost	2.1	1.0	1.18	Handreck 1986
Hotel waste	Vermicompost	2.00-2.50	2.00-2.50	3.20-3.40	Bamane *et al*. 2004
Parthenium	Compost	2.95	0.82	1.39	Channappagoudar *et al*. 2007
Eucalyptus leaf litter +	Compost	1.013	0.663	0.870	Aalok 2009
MSW	Vermicompost	1.333	1.003	1.127	Aalok 2009
Pine leaf litter +MSW	Compost	0.730	0.517	0.517	Aalok 2009
	Vermicompost	1.077	0.757	0.633	Aalok 2009
Parthenium leaf litter	Compost	1.397	0.610	1.520	Aalok 2009
+MSW	Vermicompost	1.823	0.717	1.673	Aalok 2009
Poplar leaf litter +MSW	Compost	0.960	0.543	0.427	Aalok 2009
	Vermicompost	1.260	0.660	0.580	Aalok 2009
Sal leaf litter +MSW	Compost	0.607	0.480	0.290	Aalok 2009
	Vermicompost	0.870	0.530	0.363	Aalok 2009

nutrients than the other vermicomposts (**Table 1**). No earthworm mortality was observed in any of the wastes during the study period. The nutrient values of compost and vermicomposts is evidence enough that organic matter which passes through the gut of earthworms and deposited on or in soil in the form of casts possessed higher amounts of nutrient than that of the substrates or soil on which the earthworms feed (Edwards and Burrows 1988; Reddy *et al.* 1997). The nutrient contents of casts or vermicompost vary greatly depending on the organic matter on which the earthworms feed (Reddy and Ohkura 2004).

The studies so far undertaken by various scientists lead to the conclusion that forest wastes and weeds are a rich source of nutrients and organic matter and therefore there is an urgent need to generate awareness on this issue. Vermicomposting of leaf litter and weeds will provide an effective solution to waste and weed management in the forest and urban areas. On a sustainable basis and will also generate the much needed organic fertilizer.

Effect of vermicompost on plant growth

The unused biological waste material can be effectively used in vermicomposting, using earthworms. The compost produced by the vermicomposting of organic wastes, could be added to agricultural land to improve soil structure and fertility, for the growth of plants (Rampal and Sharma 2002).

Arancon *et al.* (2004) have assessed the effects of the application of different types and rates of vermicomposts on the growth and yields of field-grown strawberries, under field conditions independent of nutrients. Commercially produced food waste and paper-based vermicomposts were used in the trials and applied to 4.5 m^2 field plots, under high plastics hoop tunnels, at rates of 5 to 10 ha^{-1}. Vermicompost applications increased the strawberry growth and yields significantly including increases of up to 37% in leaf areas, 37% in plant shoot biomass, 40% in number of flowers, 36% in number of plant runners and 35% in marketable fruit weights.

The preparation and benefits of vermicompost on the plants have been explained by Purakayastha and Bhatnagar (1997). They have given the average nutrient contents of vermicompost, which is much higher than commonly used farm yard manure (FYM).

The capacity of composts made from three different combinations of organic wastes (horse manure and bedding, mink farm wastes, MSW and sewage sludge) along with clarifier solids from a chemo-thermo mechanical pulp mill, to enhance the growth of tomato (*Lycopersicum esculentum* L.) seedlings grown in nutrient-poor organic potting soil was studied by Levy and Taylor (2003). Mink farm compost and horse manure compost stimulated root and shoot growth of tomato seedlings but MSW compost and pulp mill solids were strongly inhibitory. Municipal solid waste (MSW) compost and unamended potting soil also inhibited seedling emergence and pulp mill solids produced stunting and deformities in radish and cress seedlings. Both toxic constituents and nutrient imbalances may be responsible for the growth-inhabiting effects of these amendments. Application of pulp mill solids to agricultural soil without composting may lead to deleterious effects on vegetable crops.

A field experiment was conducted in a silt-loam soil from a degraded semiarid Mediterranean area to evaluate the effect of the addition of composted urban residues on soil aggregate stability, bulk density and chemical properties and on the establishment of *Pistacia lentiscus* and *Retama sphaerocarpa* seedlings. The addition of composted residue significantly increased the soil aggregate stability by about 22% for both shrub species. The beneficial effect of the composted residue on soil quality still persisted 18 months after addition. Composted residue addition to soil can be considered an effective preparation method of a degraded area for carrying out successful revegetation programs with Mediterranean shrubs under semiarid conditions (Caravaca *et al*. 2003).

Campitelli and Ceppi (2008) in their study have analyzed a set of twenty-eight different compost and vermicompost through nineteen chemical, physical and biological parameters. Results showed a wide variation total organic carbon, germination index (GI), pH, total N, and water soluble carbon (WSC), which depends on the characteristics of each process.

The magnitude of the transformation of P from the organic to inorganic state, and thereby into available forms was found to be considerably higher in the case of earthworm-inoculated organic wastes, showing that vermicomposting may prove to be an efficient technology for providing better P nutrition from different organic wastes (Ghosh *et al*. 1999).

Tests were conducted to see the effect of the earthworm *E. foetida* on decomposing organic residues. A wormless sludge + bark mixture in the laboratory remained in a compact clump, while a well managed garden compost was considered humidified and aerated in three months. Thus "vermicompost" could be considered superior to ordinary compost with regard to its physical structure (Haimi and Huhta 1988).

Peyvast *et al.* (2007) reported the effects of different amount of vermicompost (0, 10, 20 and 30%) on growth, yield and chemical characteristics of spinach (*Spinacia oleracea* L.) cv 'Virofly'. The results showed that an addition of vermicompost to soil can increase plant heights and number of leaves significantly.

The use of vermicompost at different points in the production cycle of tomato, marigold, pepper, and cornflower were investigated by Bachman and Metzger (2008). 20% (v/v) pig manure vermicompost when applied, enhanced shoot and root weight, leaf area, and shoot: root ratios of both tomato and French marigold seedlings; however, amendment with vermicompost had little influence on pepper and cornflower seedling growth.

Gutiérrez-Miceli *et al.* (2007) reported the effects of sheep-manure vermicompost on the growth, productivity and chemical characteristics of tomatoes (*Lycopersicum esculentum*) (cv. 'Rio Grande') in a greenhouse experiment. Sheep-manure vermicompost as a soil supplement increased plant heights significantly increased tomato yields and soluble, insoluble solids and carbohydrate concentrations. Likely, Zaller (2007) also reported that vermicompost amendments significantly influenced emergence and elongation of tomato seedlings.

Singh *et al.* (2008) reported that vermicompost application increased the strawberry plant spread, leaf area, dry matter, and total fruit yield. Vermicompost substitution also drastically reduced nutrient-related disorders and disease like *Botrytis* rot. Beneficial effects of vermicompost application have also been reported by Padmavathiamma *et al.* (2008). Their results have shown that vermicompost-amended acid-agriculture-soil significantly improved the yield, biometric character and quality of banana, cassava and cowpea. In a field study by Karmegam and Daniel (2008), all the growth and yield parameters in Hyacinth Bean, *Lablab purpureus* (L.) Sweet were significantly higher in vermicompost, chemical fertilizer and vermicompost + chemical fertilizer mixture than in the control plots.

Vermiwash

Organic manure like vermicompost and vermiwash, when added to soil, augment crop growth and yield (Lalitha *et al.* 2000). Organic amendments like vermicompost and vermiwash promote humification, increased microbial activity and enzyme production, which, in turn, bring about the aggregate stability of soil particles, resulting in better aeration (Tisdale and Oades 1982; Dong *et al.* 1983; Haynes and Swift 1990; Perucci 1990).

Laboratory studies by researchers at the Central Plantation Crops Research Institute (CPCRI), Kasaragod in Kerala have proved that coconut leaf vermiwash improves the germination percentage of the seeds and seedling vigour of seeds such as cowpea and paddy crops. Prabhu (2006) reported that the application of vermiwash has resulted in better shoot growth and more leaf production in nutmeg, clove, pepper and vanilla Vermiwash application stimulated the number of microorganisms particularly the free-living nitrogen fixing bacteria in the soil especially at the root region of the crops. Experiments conducted on bhendi (ladies' finger) showed that gall formation, a common infestation, was greatly controlled by regular application of vermiwash.

Shivsubramanian and Ganeshkumar (2004) tested the effect of vermiwash on the growth and productivity of marigold. George *et al.* (2007) reported the effect of vermiwash spray on significantly maximum dry chilli yield. Buckerfield *et al.* (1999) reported that weekly applications of vermiwash increased radish yield by 7.3% and Thangavel (2003) observed that both growth and yield of paddy increased with the application of vermiwash and vermicast extracts.

Zambare *et al.* (2008) tested the effect of vermiwash on growth of cowpea plant on soil extract agar medium at laboratory scale experiments. Vermiwash supplemented medium showed high cowpea plant growth as compared to without supplementation. Vermiwash was found to contain enzyme cocktail of proteases, amylases, urease and phosphatase. Microbiological study of vermiwash revealed that it contains nitrogen-fixing bacteria like *Azotobacter* sp., *Agrobacterium* sp. and *Rhizobium* sp. and some phosphate solublizing bacteria.

Experiments were conducted to assess the impact of vermicompost and vermiwash (soil application) in combination on vegetable crops like spinach (*Spinacia oleracea*), onion (*Allium cepa*) and potato (*Solanum tuberosum*) in reclaimed sodic soils to study the productivity levels through such organic farming packages to be offered to the farmers (Ansari 2008). The results showed that the yield of spinach significantly increased in plots treated with verminwash (1: 5 v/v in water), the yield of onion significantly increased in plots treated with vermiwash (1: 10 v/v in water), whereas the average weight of onion bulbs was significantly greater in plots amended with vermicompost and vermiwash (1: 5 v/v in water). The yield of potato and the average weight of potato tubers were significantly higher in plots treated with vermicompost.

CONCLUSION

There is no doubt that in India, where on one side pollution is increasing day by day due to accumulation of organic waste and on the other side there is a great shortage of organic manure, which could increase the fertility and productivity of the land and produce nutritive and safe food, the scope for vermicomposting is enormous (Ramesh *et al.* 2005). Waste management is one of the major necessities that should be fully understood for the future of both the earth and humanity. In recent years interest has arisen concerning the possibility of using decomposer organisms, mainly earthworms to process waste materials by clean technologies that minimize environmental pollution. Vermitechnology is a promising technique that has shown its potential in certain challenging areas like augmentation of food production, waste recycling, management of solid wastes, etc. and can play an important role in providing so many valuable properties from the agronomic and environmental point of view. It is therefore, imperative to follow its evolution both quantitatively and qualitatively.

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