Earthworms Vermicompost: A Powerful Crop Nutrient over the Conventional Compost & Protective Soil Conditioner against the Destructive Chemical Fertilizers for Food Safety and Security

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INTRODUCTION: VERMICOMPOST-THE MIRACLE PLANT GROWTH PROMOTER

Earthworms vermicompost is proving to be highly nutritive 'organic fertilizer' and more powerful 'growth promoter' over the conventional composts and a 'protective' farm input (increasing the physical, chemical & biological properties of soil, restoring & improving its natural fertility) against the 'destructive' chemical fertilizers which has destroyed the soil properties and decreased its natural fertility over the years. Vermicompost is rich in NKP (nitrogen 2-3%, potassium 1.85-2.25% and phosphorus 1.55-2.25%), micronutrients, beneficial soil microbes and also contain 'plant growth hormones & enzymes'. It is scientifically proving as 'miracle growth promoter & also plant protector' from pests and diseases. Vermicompost retains nutrients for long time and while the conventional compost fails to deliver the required amount of macro and micronutrients including the vital NKP to plants in shorter time, the vermicompost does.

PROTECTIVE COMPOST VERSUS THE DESTRUCTIVE CHEMICAL FERTILIZERS

Chemical fertilizers which ushered the 'green revolution' in the 1950-60's came as a 'mixed blessing' for mankind. It boosted food productivity, but at the cost of environment & society. It dramatically increased the 'quantity' of the food produced but decreased its 'nutritional quality' and also the 'soil fertility' over the years. It killed the beneficial soil organisms which help in renewing natural fertility. It also impaired the power of 'biological resistance' in crops making them more susceptible to pests & diseases. Over the years it has worked like a 'slow poison' for the soil with a serious 'withdrawal symptoms'. The excessive use of 'nitrogenous fertilizer' (urea) has also led to increase in the level of 'inorganic nitrogen' content in groundwater (through leaching effects) and in the human food with grave consequences for the human health. Chemically grown foods have adversely affected human health.

Organic farming systems with the aid of various nutrients of biological origin such as compost are thought to be the answer for the 'food safety and farm security' in future. Among them 'composts' made from biodegradation of organics of MSW (municipal solid waste) which is being generated in huge amount every day all over the world are most important. The organic fraction of the MSW (about 70-80%) containing plenty of nitrogen (N), potash (K) and phosphorus (P) is a good source of macro and micronutrients for the soil. Composts also contain plenty of 'beneficial soil microbes' which help in 'soil regeneration' & 'fertility improvement' and protect them from degradation while also promoting growth in plants (60 & 207). Composts also protect plants from pests and diseases (99 & 156).

Properties of farm soil using compost vis-a-vis chemical fertilizers: Suhane (182) studied the chemical and biological properties of soil under organic farming (using various types of composts) and chemical farming (using chemical fertilizers-urea (N), phosphates (P) and potash (K)). Results are given in Table 1.

All compost (including vermicompost), are produced from some 'waste materials' of society which is converted into a 'valuable resource'. It is like 'killing two birds in one shot'. More significant is that it is of biological origin i.e. a 'renewable resource' and will be readily available to mankind in future. Whereas, chemical fertilizers are made from petroleum products which are 'non-renewable' and a 'depleting' resource. While in the use of compost the environment is 'benefited' at all stages-from production (salvaging waste &

Table 1: Farm soil properties under organic farming and chemical farming

Chemical and biological properties of soil	Organic farming (Use of composts)	Chemical farming (Use of chemical fertilizers)
1) Availability of nitrogen (kg/ha)	256.0	185.0
2) Availability of phosphorus (kg/ha)	50.5	28.5
3) Availability of potash (kg/ha)	489.5	426.5
4) *Azatobacter* (1000/gm of soil)	11.7	0.8
5) Phospho bacteria (100,000/kg of soil)	8.8	3.2
6) Carbonic biomass (mg/kg of soil)	273.0	217.0

Source: Suhane (2007)

diverting them from landfills and reducing greenhouse gases) to application in farms (adding beneficial microbes to soil & improving biochemical properties), in the use of chemical fertilizers the environment is 'harmed' at all stages-from procurement of raw materials from petroleum industries to production in factories (generating huge amount of chemical wastes and pollutants) and application in farms (adversely affecting beneficial soil micro-organisms and soil chemistry).

COMPOSTS: THE MIRACLE PLANT GROWTH PROMOTER & PROTECTOR

Composts are aerobically decomposed products of organic wastes such as the cattle dung and animal droppings, farm and forest wastes and the municipal solid wastes (MSW). Bombatkar (42) called them as 'miracle' for plant growth. They supply balanced nutrients to plant roots and stimulate growth; increase organic matter content of the soil including the 'humic substances' that affect nutrient accumulation and promote root growth (49 & 165). They in fact improve the total physical and chemical properties of the soil. They also add useful micro-organisms to the soil and provide food for the existing soil micro-organisms and thus increase their biological properties and capacity of self-renewal of soil fertility (131 & 163). One ton of compost may contain 10 lbs of nitrogen (N), 5 lbs of phosphorus (P_2O_5) and 10 lbs of potash (K_2O). Compost made from poultry droppings contains highest nutrient level among all compost (42).

There are other agronomic benefits of composts application, such as high levels of soil-borne disease suppression and removal of soil salinity (99). Ayres (20) reported that mean root disease was reduced from 82% to 18% in tomato and from 98% to 26% in capsicum in soils amended with compost. Webster (206) reported that with application of compost in vineyards, levels of exchangeable sodium (Na) under vine were at least reduced to 50%. Treated vines produced 23% more grapes due to 18% increase in bunch numbers. The yield in grapes was worth additional AU $ 3,400/ha. Biological properties of soil were also improved with up to ten-fold increase in total microbial counts. Most significant was three-fold increase in the population of earthworms under the vine with long-term benefits to the soil.

All composts work as a 'slow-release fertilizer' whereas chemical fertilizers release their nutrients rather quickly in soil and soon get depleted. Nitrogen and phosphorus particularly are not all available to plant roots in the first year because N & P in organic matter are resistant to decay. Nitrogen is about one half effective as compared to chemical fertilizer, but phosphorus & potassium are as effective as chemical fertilizers. With continued application of compost the organic nitrogen tends to be released at constant rate from the accumulated 'humus' and the net overall efficiency of nitrogen over a period of years is considerably greater than 50% of that of chemical fertilizers. Availability of phosphorus is sometimes much greater (42 & 145). Moreover, significant amount of nitrogen is lost from soil due to oxidation in sunlight. Suhane (182) calculated that upon application of 100 kg urea (N) in farm soil, 40-50 kg gets oxidised and escapes as 'ammonia' (NH_3) into the air, about 20-25 kg leaches underground polluting the groundwater, while only 20-25 kg is available to plants.

VERMICOMPOST VIS -À-VIS CONVENTIONAL COMPOST & CHEMICAL FERTILIZERS

Conventional composting and vermicomposting are quite distinct processes particularly with respect to optimum temperatures for each process and the type of decomposer microbial communities that predominate

Table 2: Properties and nutrient value of compost produced from MSW

1.	Biological properties	
	(a) Total bacteria count/gm of compost	10^4
	(b) *Actinomycetes*/gm of compost	10^4
	(c) Fungi/gm of compost	10^6
	(d) *Azotobacter*/mg of compost	10^6
	(e) Root nodule bacteria (*Rhizobium*)	10^4
	(f) Phosphate solubilizers	10^6
	(g) *Nitrobacter*/gm of compost	10^2
2.	Chemical properties	
	(a) pH	7-8.2
	(b) Organic carbon	16.0%
	(c) Nitrogen	1.50-2.00%
	(d) Phosphorus	1.25%
	(e) Potassium	1.05-1.20%
	(f) Calcium	1-2%
	(g) Magnesium	0.7%
	(h) Sulphates	0.5%
	(i) Iron	0.6%
	(j) Zinc	300-700 ppm
	(k) Manganese	250-740 ppm
	(l) Copper	200-375 ppm

Source: Sinha (2004)

during active processing. While ‘thermophilic bacteria’ predominate in conventional composting, ‘mesophilic bacteria & fungi’ predominate in vermicomposting. Although the conventional composting process is completed in about 8 weeks, but additional 4 weeks is required for ‘curing’. Curing involves the further aerobic decomposition of some compounds, organic acids and large particles that remain after composting. Less oxygen and water is required during curing. Compost that has had insufficient curing may damage crops. Vermicomposting takes nearly half the time of conventional composting and vermicompost do not require any curing and can be used straightway after production (62). Vermicomposts have much ‘finer structure’ than ordinary compost and contain nutrients in forms that are readily available for plant uptake. Vermicomposts have outstanding chemical and biological properties with ‘plant growth regulators’ (lacking in other composts) and significantly larger and ‘diverse microbial populations’ than the conventional thermophilic composts (70; 73; & 193).

Atiyeh (16) found that the conventional compost was higher in ‘ammonium’, while the vermicompost tended to be higher in ‘nitrates’, which is the more available form of nitrogen. They also found that vermicompost has higher N availability than the conventional compost on a weight basis and the supply of several other plant nutrients e.g. phosphorus (P), potassium (K), sulfur (S) and magnesium (Mg), were significantly increased by adding vermicompost as compared to conventional compost to soil (17 & 18). Vermicompost retains nutrients for long time and while the conventional compost fails to deliver the required amount of macro and micronutrients including the vital NKP (nitrogen, potassium & phosphorus) to plants in shorter time, the vermicompost does (43; 94 & 180). This was verified by Bhatia (26 & 27), Sinha & Bharambe (175), Chauhan (51) and Valani (203).

Arancon (13) studied the agronomic impacts of vermicompost and inorganic (chemical) fertilizers on strawberries when applied separately and also in combination. Vermicompost was applied @ 10 tons/ha while the inorganic fertilizers (nitrogen, phosphorus, potassium) @ 85 (N)-155 (P)-125 (K) kg/ha. While there was not much difference in the ‘dry shoot weight’ of strawberries, the ‘yield’ of marketable strawberries and the ‘weight’ of the 'largest fruit' was greater on plants in plots grown on vermicompost as compared to inorganic fertilizers in 220 days after transplanting. Also there were more 'runners' and 'flowers' on plants grown on vermicompost. Strawberries grown on inorganic fertilizers amended with vermicompost had significantly greater dry shoot weight, leaf areas and more number of flowers than grown exclusively on inorganics in 110 days after transplanting. Also, farm soils applied with vermicompost had significantly greater 'microbial biomass' than the one applied with inorganic fertilizers.

VERMICOMPOST: A SOIL CONDITIONER

Significantly, vermicompost works as a 'soil conditioner' and its continued application over the years lead to total improvement in the quality of soil and farmland, even the degraded and sodic soils. Experiments conducted in India at Shivri farm of 'U.P. Bhumi Sudhar Nigam' (U.P. Land Development Corporation) to reclaim 'sodic soils' gave very good results. Application of vermicompost @ 6 tons/ha resulted in reduction of 73.68 in sodicity (ESP) and increase of 829.33 kg/ha of available nitrogen (N) leading to significant improvement in soil quality (174).

VERMICOMPOST: THE MIRACLE PLANT GROWTH PROMOTER & PROTECTOR

Vermicompost is a nutritive 'organic fertilizer' rich in NKP (nitrogen 2-3%, potassium 1.85-2.25% and phosphorus 1.55-2.25%), micronutrients, beneficial soil microbes like 'nitrogen-fixing bacteria' and 'mycorrhizal fungi' and are scientifically proving as 'miracle growth promoters & protectors' (177). Kale and Bano (108) reports as high as 7.37% nitrogen (N) and 19.58% phosphorus as P_2O_5 in worms vermicast. Suhane (182) showed that exchangeable potassium (K) was over 95% higher in vermicompost. There are also good amount of calcium (Ca), magnesium (Mg), zinc (Zn) and manganese (Mn). Additionally, vermicompost contain enzymes like amylase, lipase, cellulase and chitinase, which continue to break down organic matter in the soil (to release the nutrients and make it available to the plant roots) even after they have been excreted. (50; 121 & 188). Annual application of adequate amount of vermicompost also lead to significant increase in soil enzyme activities such as 'urease', 'phosphomonoesterase', 'phosphodiesterase' and 'arylsulphatase'. The soil treated with vermicompost has significantly more electrical conductivity (EC) and near neutral pH. (188).

Vermicompost has very 'high porosity', 'aeration', 'drainage' and 'water holding capacity'. They have a vast surface area, providing strong absorbability and retention of nutrients. They appear to retain more nutrients for longer period of time. Study showed that soil amended with vermicompost had significantly greater 'soil bulk density' and hence porous & lighter and never compacted. Increase in porosity has been attributed to increased number of pores in the 30-50 µm and 50-500 size ranges and decrease in number of pores greater than 500 µm (121 & 128).

There have been several reports that worm worked waste and their excretory products (vermicast) can induce excellent plant growth (14; 15; 16; 17; 18; 19; 21; 22; 26; 49; 73;115; 144;154; 194 & 210). It has been found to influence on all yield parameters such as-improved seed germination, enhanced rate of seedling growth, flowering and fruiting of major crops like wheat, paddy, corn, sugarcane, tomato, potato, brinjal, okra, spinach, grape and strawberry as well as of flowering plants like petunias, marigolds, sunflowers, chrysanthemums and poinsettias. In all growth trials the best growth responses were exhibited when the vermicompost constituted a relatively small proportion (10%-20%) of the total volume of the container medium. Surprisingly, greater proportions of vermicomposts in the plant growth medium have not always improved plant growth (180).

Suhane (182) asserts that vermicompost is at least 4 times more nutritive than cattle dung compost. In Argentina, farmers who use vermicompost consider it to be seven (7) times richer than conventional composts in nutrients and growth promoting values (Pajon (Undated); Munroe (124). Suhane (183) reported that exclusive application of vermicompost @ 25 quintal/ha in farm wheat crops supported yield better than chemical fertilizers. It was 40 quintal/ha on vermicompost and 34.2 Q/ha on chemicals. And when same amount of agrochemicals were supplemented with vermicompost the yield increased to about 44 Q/ha which is over 28% and nearly 3 times over control. On cattle dung compost applied @ 100 Q/ha (4 times of vermicompost) the yield was just over 33 Q/ha. Application of vermicompost had other agronomic benefits. It significantly reduced the demand for irrigation by nearly 30-40%. Test results indicated better availability of essential micronutrients and useful microbes in vermicompost applied soils. Most remarkable observation was significantly less incidence of pests and disease attacks in vermicompost applied crops.

Sinha & Bharmbe (175); Chauhan (51) & Valani (203) also reported extraordinarily good growth of potted corn & wheat crops on vermicompost as compared to conventional composts and chemical fertilizers. Singh (167) reported good yields in farmed wheat crops grown on vermicompost (comparable with chemical fertilizers) which increased upon successive applications of same amount of vermicompost. (They have all been discussed later in the chapters).

SOME SIGNIFICANT PROPERTIES OF VERMICOMPOST OF GREAT AGRONOMIC VALUES

a) High levels of bio-available nutrients for plants: Vermicompost contains most nutrients in plant-available forms such as 'nitrates' (N), 'phosphates' (P), 'soluble' potassium (K), & magnesium (Mg) and 'exchangeable' phosphorus (P) & calcium' (Ca) (70 & 73). Vermicomposts have large particulate surface areas that provides many micro-sites for microbial activities and for the strong retention of nutrients (13 & 14).

b) High level of beneficial soil microorganisms promoting plant growth: Vermicomposts are rich in 'microbial populations & diversity', particularly 'fungi', 'bacteria' and 'actinomycetes' (45; 50; 154; 166 & 188). Teotia (187) and also Parle (134) reported bacterial count of 32 million per gram in fresh vermicast compared to 6-9 million per gram in the surrounding soil. Scheu (154) reported an increase of 90% in respiration rate in fresh vermicast indicating corresponding increase in the microbial population. Suhane (182) found that the total bacterial count was more than 10^{10} per gram of vermicompost. It included *Actinomycetes, Azotobacter, Rhizobium, Nitrobacter* & phosphate solubilizing bacteria which ranged from 10^2-10^6 per gm of vermicompost. The PSB has very significant role in making the essential nutrient phosphorus (P) 'bio-available' for plant growth promotion (147). Although phosphates are available in soils in rock forms but are not available to plant roots unless solubilized.

Pramanik (138) studied the microbial population in vermicompost prepared from cow dung and municipal solid wastes (MSW) as substrates (raw materials) and found that it was in highest abundance in cow dung vermicompost. The total bacterial count was 73 x 10^8, the cellulolytic fungi was 59 x 10^6 and the nitrogen-fixing bacteria was 18 x 10^3. It was least in vermicompost obtained from MSW. The total bacterial count was 16 x 10^8, the cellulolytic fungi were 21 x 10^6 and the nitrogen-fixing bacteria were 5 x 10^3. Application of lime in the substrate enhanced the population of all above mentioned microbes irrespective of the substrates used for vermicomposting.

Plant growth promoting bacteria (PGPB) directly stimulates growth by nitrogen (N) fixation, solubilization of nutrients, production of growth hormones such as 1-aminocyclopropane-1-carboxylate (ACC) deaminase and indirectly by antagonising pathogenic fungi by production of siderophores, chitinase, ß-1,3-glucanase, antibiotics, fluorescent pigments and cyanide (95).

There is also substantial body of evidence to demonstrate that microbes, including bacteria, fungi, actinomycetes, yeasts and algae, also produce 'plant growth regulators' (PGRs) such as 'auxins', 'gibberellins', 'cytokinins', 'ethylene' and 'ascorbic acids' in appreciable quantities and as their population is significantly boosted by earthworms large quantities of PGRs are available in vermicompost (79).

c) Rich in growth hormones: Biochemical stimulating total plant growth: Researches show that vermicompost further stimulates plant growth even when plants are already receiving 'optimal nutrition'. Vermicompost has consistently improved seed germination, enhanced seedling growth and development and increased plant productivity much more than would be possible from the mere conversion of mineral nutrients into plant-available forms. Arancon (12) found that maximum benefit from vermicompost is obtained when it constitutes between 10 to 40% of the growing medium. Neilson (126 & 127) and Tomati (192) have also reported that vermicompost contained growth promoting hormone 'auxins', 'cytokinins' and flowering hormone 'gibberellins' secreted by earthworms. It was demonstrated by Grappelli (90) & Tomati (190;191 & 192) that the growth of ornamental plants after adding aqueous extracts from vermicompost showed similar growth patterns as with the addition of auxins, gibberellins and cytokinins through the soil.

d) Rich in humic acids: Biochemical promoting root growth & nutrient uptake: Atiyeh (17; 18 & 19) speculates that the growth responses of plants from vermicompost appears more like 'hormone-induced activity' associated with the high levels of humic acids and humates in vermicompost rather than boosted by high levels of plant-available nutrients. This was also indicated by Canellas (49) who found that humic acids isolated from vermicompost enhanced root elongation and formation of lateral roots in maize roots. Pramanik (138) also reported that humic acids enhanced 'nutrient uptake' by the plants by increasing the permeability of root cell membrane, stimulating root growth and increasing proliferation of 'root hairs'.

e) Vermicompost is free of pathogens: Nair (125) studied that 21 days of a combination of thermocomposting and vermicomposting produced compost with acceptable C:N ratio and good homogenous consistency of a fertilizer. The study also indicated that vermicomposting leads to greater reduction of pathogens after 3 months upon storage. Whereas, the samples which were subjected to only thermofilic composting, retained higher levels of pathogens even after 3 months.

f) Vermicompost is free of toxic chemicals: Several studies have found that earthworms effectively bio-accumulate or biodegrade several organic and inorganic chemicals including 'heavy metals', 'organochlorine pesticide' and 'polycyclic aromatic hydrocarbons' (PAHs) residues in the medium in which it inhabits.

g) Vermicompost protects plants against various pests and diseases: There has been considerable evidence in recent years regarding the ability of vermicompost to protect plants against various pests and diseases either by suppressing or repelling them or by inducing biological resistance in plants to fight them or by killing them through pesticidal action (3 & 5).

i) Induce biological resistance in plants: Vermicompost contains some antibiotics and actinomycetes which help in increasing the 'power of biological resistance' among the crop plants against pest and diseases. Pesticide spray was significantly reduced where earthworms and vermicompost were used in agriculture.(168 & 182).

ii) Repel crop pests: There seems to be strong evidence that worms varmicastings sometimes repel hard-bodied pests (3 & 12). Edwards & Arancon (74) reports statistically significant decrease in arthropods (aphids, buds, mealy bug, spider mite) populations and subsequent reduction in plant damage, in tomato, pepper and cabbage trials with 20% and 40% vermicompost additions. George Hahn, doing commercial vermicomposting in California, U.S., claims that his product repels many different insects pests. His explanation is that this is due to production of enzymes 'chitinase' by worms which breaks down the chitin in the insect's exoskelton (124).

iii) Suppress plant disease: Edwards & Arancon (74) have found that use of vermicompost in crops inhibited the soil-born fungal diseases. They also found statistically significant suppression of plant-parasitic nematodes in field trials with pepper, tomatoes, strawberries and grapes. The scientific explanation behind this concept is that high levels of agronomically beneficial microbial population in vermicompost protects plants by out-competing plant pathogens for available food resources i.e. by starving them and also by blocking their excess to plant roots by occupying all the available sites. This concept is based on 'soil-foodweb' studies pioneered by Dr. Elaine Ingham of Corvallis, Oregon, U.S. (http://www.soilfoodweb.com). Edwards and Arancon (74) reported the agronomic effects of small applications of commercially produced vermicompost, on attacks by fungus *Pythium* on cucumber, *Rhizoctonia* on radishes in the greenhouse, by *Verticillium* on strawberries and by *Phomposis* and *Sphaerotheca fulginae* on grapes in the field. In all these experiments vermicompost applications suppressed the incidence of the disease significantly. They also found that the ability of pathogen suppression disappeared when the vermicompost was sterilized, convincingly indicating that the biological mechanism of disease suppression involved was 'microbial antagonism.

Szczech (186), Orlikowski (130) Rodriguez (148) and Zaller (213) also found that the aqueous extracts of vermicomposts depress soil-borne pathogens and pests. They found in their field experiment that only half as many plants of tomatoes sprayed with aqueous extract of vermicompost were infected with Phytopthora infestans (that cause 'late-blight' disease) as those of control ones.

FACTORS DETERMINING THE NUTRITIONAL QUALITY OF VERMICOMPOST

The nutritional quality of vermicompost is determined primarily by the type of the substrate (raw materials) and species of earthworms used for composting, along with microbial inoculants, liming, aeration, humidity, pH and temperature. Cattle dung has been found to yield most nutritive vermicompost when composted by *Eisinea fetida*. Pramanik (138) found that application of lime @ 5 gm/kg of substrate and 'microbial inoculation' by suitable 'cellulolytic', 'lignolytic' and 'N-fixing' strains of microbes not only enhance the rate of vermicomposting but also results into nutritionally better vermicompost with greater enzymatic (phosphatase & urease) activities. Kaushik and Garg (113) found that inoculation with N-fixing bacteria significantly increased the 'nitrogen' (N) content of the vermicompost. Liming generally enhance earthworm activities as well as microbial population. Earthworms after ingesting microbes into its gut proliferate the population of microbes to several times in its excreta (vermicast). It is therefore advantageous to use beneficial microbial inoculants whose population is rapidly increased for rapid composting and also better compost quality.

Pramanik (138) studied the vermicomposting of four (4) substrates viz. cow dung, grass, aquatic weeds and municipal solid wastes (MSW) to know the 'nutritional status & enzymatic activities' of the resulting vermicomposts in terms of increase in total nitrogen (N), total phosphorus (P) & potassium (K), humic acid contents and phosphatase activity.

Total Nitrogen: They found that cow dung recorded maximum increase in nitrogen (N) content (275%) followed by MSW (178%), grass (153%) and aquatic weed (146%) in their resulting vermicomposts over the initial values in their raw materials. And this was even without liming and microbial inoculation. Application of lime without microbial inoculation, however, increased N content in the vermicompost from 3% to 12% over non-limed treatment, irrespective of substrates used.

Total Phosphorus & Potassium: Similarly, the vermicompost prepared from cow dung had the highest total phosphorus (12.70 mg/g) and total potassium (11.44 mg/g) over their initial substrate followed by those obtained from aquatic weeds, grasses and MSW. This was also irrespective of lime application and microbial inoculation. Among the microbes inoculated for vermicomposting, *Bacillus polymyxa* a free-living N-fixing bacterium was most effective in increasing total phosphorus (11-22%) in the vermicompost after liming.

Humic Acid: It was highest in vermicompost prepared from cow dung (0.7963 mg/g), followed by those from grasses (0.6147 mg/g), aquatic weeds (0.4724 mg/g) and MSW (0.3917 mg/g). And this was without liming and microbial inoculation. However, microbial inoculation again increased humic acid contents in vermicompost from 25% to 68% depending upon the substrate used. Inoculation by *Phanerochaete chrysoporium* recorded highest humic contents without liming as compared to other inoculants. But under limed condition, inoculation by *B. polymyxa* was most effective in increasing humic acid contents irrespective of substrates used for vermicomposting.

Phosphatase Activity: Vermicompost obtained from cow dung showed the highest 'acid phosphatase' (200.45 µg *p*-nitrophenol/g/h) activities followed by vermicompost from grasses (179.24 µg *p*-nitrophenol/g/h), aquatic weeds (174.27 µg *p*-nitrophenol/g/h) and MSW (64.38 µg *p*-nitrophenol/g/h). The 'alkaline phosphatase' activity was highest in vermicompost obtained from aquatic weeds (679.88 µg *p*-nitrophenol/g/h) followed by cow dung (658.03 µg *p*-nitrophenol/g/h), grasses (583.28 µg *p*-nitrophenol/g/h) and MSW (267.54 µg *p*-nitrophenol/g/h). This was irrespective of lime application and microbial inoculation. However, when inoculated by fungi all showed maximum phosphatase activities under both limed and non-limed conditions. This was also indicated by Vinotha (204).

Studies by Agarwal (4) also found that the NPK value of vermicompost processed by earthworms from the same feedstock (cattle dung) significantly increases by 3 to 4 times. It also enhances several micronutrients.

Table 3: NPK value of vermicompost compared with conventional cattle dung compost made from cattle dung

	Nutrients	Cattle dung compost	Vermicompost
1	N	0.4-1.0%	2.5-3.0%
2	P	0.4-0.8%	1.8-2.9%
3	K	0.8-1.2%	1.4-2.0%

Source: Agarwal (1999); Ph. D Thesis, University of Rajasthan, India

Table 4: Important nutrients present in vermicompost vis-à-vis conventional composts prepared from the same feed stock 'food and garden wastes' (In mg/g)

Nutrients	Vermicompost	Aerobic compost	Anaerobic compost
1) Nitrogen (N)	9.500	6.000	5.700
2) Phosphorus (P)	0.137	0.039	0.050
3) Potassium (K)	0.176	0.152	0.177
4) Iron (Fe)	19.730	15.450	17.240
5) Magnesium (Mg)	4.900	1.680	2.908
6) Manganese (Mn)	0.016	0.005	0.006
7) Calcium (Ca)	0.276	0.173	0.119

Source: Singh (2009); Master's Degree Project Report, Griffith University, Australia

Similar was findings of Singh (166). Vermicompost processed by earthworms showed higher values of important plant nutrients as compared to those available in composts made from the same feed stock 'food & garden wastes 'by aerobic & anaerobic methods.

IMPORTANT FEEDBACKS FROM FARMERS USING VERMICOMPOST IN BIHAR (INDIA)

Sinha interviewed some farmers in India using vermicompost for agriculture. Most of them asserted to have switched over to organic farming by vermicompost completely eliminating the use of chemical fertilizers in the last 3-4 years with very encouraging results, benefiting both, their economy (reduced cost of inputs and significantly high outputs from good crop production, sale of vermicompost and worms) and the environment (reduced use of chemical pesticides, improved physical, chemical & biological properties of farm soil). Some of them asserted to have harvested three (3) different crops in a year (reaping 2-3 times more harvest) due to their rapid growth & maturity and reduced harvest cycle. Several villages have become 'BIO-VILLAGE' using only vermicompst in crop production and completely giving up chemical agriculture.

Some of the important revelation by farmers were:

- Reduced use of 'water for irrigation' as application of vermicompost over successive years improved the 'moisture holding capacity' of the soil;
- Reduced 'pest attack' (by at least 75%) in crops applied with vermicompost. Cauliflowers grown on vermicompost remains 95% 'disease free'. Late Blight (fungal disease) in banana was almost reduced by over 95%;
- Reduced 'termite attack' in farm soil especially where worms were in good population;
- Reduced 'weed growth';
- Faster rate of 'seed germination' and rapid seedlings growth and development;
- Greater numbers of fruits per plant (in vegetable crops) and greater numbers of seeds per ear (in cereal crops), heavier in weight-better in both, quantity and quality as compared to those grown on chemicals;
- Fruits and vegetables had 'better taste' and texture and could be safely stored up to 6-7 days, while those grown on chemicals could be kept at the most for 2-3 days;
- Wheat production increased from 35 to 40%;
- Fodder growth was increased by nearly 50% @ 30 to 40 quintal/hectare;
- Flower production (commercial floriculture) was increased by 30-50% @ 15-20 quintal/hectare. Flower blooms were more colorful and bigger in size;

CONCLUSIONS AND REMARKS

Earthworms vermicompost work as a 'slow-release fertilizer' and also 'protect plants' against pest & diseases. With their continued application the 'organic nitrogen' & other nutrients in compost tends to be

A B

Photo showing disease resistance in cauliflower induced by vermicompost
(A). Cauliflower grown on chemical fertilizers (Susceptible to diseases)
(B). Cauliflower grown on vermicompost (Resistant to diseases)
(Hazipur, Bihar, India. December 2008)

released at constant rate from the accumulated 'humus' and the net overall efficiency of NPK over a period of years is considerably greater than 50% of that of chemical fertilizers. Availability of phosphorus is sometimes much greater. Vermicompost will also be a 'recipe' to restore the 'degenerated & chemically contaminated soils' of world agricultural ecosystems resulting from the heavy use of agrochemicals in the wake of green revolution. Use of vermicompost would significantly reduce or even replace the use of 'dangerous agrochemicals', reduce the demand of water for irrigation and pest & disease control, thus benefiting the farmers and the economy and ecology of the nation in every way.

It also appears that vermicompost functions more effectively when covered by mulch. Mulch keep them moist and allows the worm 'cocoons' to germinate faster into baby worms and the beneficial microbes to multiply and act faster. Apparently, it is both earthworms and its excreta (vermicast) that plays combined role in growth promotion. Worms & microbes secrete growth promoting plant hormones 'gibberlins', 'auxins' and 'cytokinins', help mineralise the nutrients and make them 'bioavailable'. In a glasshouse trial, Buckerfield (47 & 48) found that the 'stimulatory effect' of vermicompost on plant growth was apparently destroyed when it was 'sterilized'.

REFERENCES & FURTHER READINGS

1. Anonymous, 1980. Report and Recommendations on Organic Farming-Case Studies of 69 Organic Farmers in USA; Pub. of US Board of Agriculture, USA.
2. Anonymous, 1998. Sustainable Agriculture; People and the Planet; Vol: 7(1).
3. Anonymous, 2001. Vermicompost as Insect Repellent; Biocycle, Jan. 01: 19.
4. Agarwal, Sunita, 1999. Study of Vermicomposting of Domestic Waste and the Effects of Vermicompost on Growth of Some Vegetable Crops. Ph. D Thesis Awarded by University of Rajasthan, Jaipur, India. (Supervisor: Rajiv K. Sinha)
5. Al-Dahmani, J.H., P.A. Abbasi, S.A. Miller and H.A.J. Hoitink, 2003. Suppression of bacterial spot of tomato with foliar sprays of compost extracts under greenhouse and field conditions. Plant Disease, 87: 913-919.
6. Alam, M.N., M.S. Jahan, M.K. Ali, M.A. Ashraf and M.K. Islam, 2007. Effect of Vermicompost and Chemical Fertilizers on Growth, Yield and Yield Components of Potato in Barind Soils of Bangladesh. Journal of Applied Sciences Research, 3 (12): 1879-1888.
7. Anderson, N.C., 1983. Nitrogen Turnover by Earthworms in Arable Plots Treated With Farmyard Manure and Slurry; J.E. Satchell (Ed.) Earthworm Ecology: from Darwin to Vermiculture; Chapman and Hall, London, pp. 139-150.
8. Ansari, Abdullah A., 2008. Effect of Vermicompost on the Productivity of Potato (Solanum tuberosum). Spinach (Spinacia oleracea) and Turnip (Brassica campestris). World Journal of Agricultural Sciences, 4 (3): 333-336.
9. Appelhof, Mary, 1997. Worms Eat My Garbage; 2nd (Ed.). Flower Press, Kalamazoo, Michigan, U.S. (http://www.wormwoman.com).
10. Appelhof, Mary, 2003. Notable Bits; In WormEzine, Vol: 2 (5). (Available at (http://www.wormwoman.com).
11. Arancon, N.Q., C.A. Edwards, P. Bierman, J.D. Metzger, S. Lee and C. Welch, 2003. Effects of vermicomposts on growth and marketable fruits of field-grown tomatoes, peppers and strawberries. Pedobiologia, 47: 731-735.
12. Arancon, Norman, 2004. An Interview with Dr. Norman Arancon; In Casting Call, Vol: 9 (2). (http://www.vermico.com).
13. Arancon, N.Q., C.A. Edwards, P. Bierman, C. Welch and J.D. Metzger, 2004. Influences of vermicomposts on field strawberries-1: Effects on growth and yields; Bioresource Technology, 93: 145-153.
14. Arancon, N.Q., C.I. Edwards and P. Bierman, 2006: Influences of vermicomposts on field strawberries-2: Effects on soil microbiological and chemical properties; Bioresource Technology, 97: 831-840.
15. Arancon, N.Q., C.A. Edwards, A. Babenko, J. Cannon, P. Galvis and J.D. Metzger, 2008. Influences of vermicomposts, produced by earthworms and microorganisms from cattle manure, food waste and paper waste, on the germination, growth and flowering of petunias in the greenhouse; Applied Soil Ecology, 39: 91-99.
16. Atiyeh, R.M., J. Dominguez, S. Sobler and C.A. Edwards, 2000a. Changes in biochemical properties of cow manure during processing by earthworms (Eisenia andrei) and the effects on seedling growth; Pedobiologia, 44: 709-724.
17. Atiyeh, R.M., S. Subler, C.A. Edwards, G. Bachman, J.D. Metzger and W. Shuster, 2000b. Effects of Vermicomposts and Composts on Plant Growth in Horticultural Container Media and Soil; In Pedobiologia, 44: 579-590.
18. Atiyeh, R.M., N.Q. Arancon, C.A. Edwards and J.D. Metzger, 2000c. Influence of earthworm processed pig manure on the growth and yield of greenhouse tomatoes. J. of Bioresource Technology, 75: 175-180.
19. Atiyeh, R.M., C.A. Lee Edward, N.Q. Arancon and J.D. Metzger, 2002. The influence of humic acids derived from earthworm-processed organic wastes on plant growth; Bioresource. Technology, 84: 7-14.
20. Ayres, Mathew, 2007. Supression of Soil-Borne Plant Diseases Using Compost; Paper Presented at 3rd National Compost Research and Development Forum; Organized by COMPOST Australia, Murdoch University, Perth.

21. Azarmi, R., P. Sharifi and M.R. Satari, 2008. Effect of vermicompost on growth, yield and nutrition status of tomato (*Lycopersicum esculentum*) (In Press).
22. Azarmi, R., Mousa Torabi Giglou and Rahim Didar Taleshmikail, 2008. Influence of vermicompost on soil chemical and physical properties in tomato (*Lycopersicum esculentum*) field; African Journal of Biotechnology, 7 (14): 2397-2401.
23. Bajsa, O., J. Nair, K. Mathew and G.E. Ho, 2004. Pathogen Die-Off in Vermicomposting Process; Paper presented at the International Conference on 'Small Water and Wastewater Treatment Systems', Perth, Australia.
24. Bhat, J.V. and P. Khambata, 1994. Role of earthworms in agriculture; Indian Council of Agriculture Research (ICAR), New Delhi, India, Series No. 22: 36.
25. Bhatanagar, P. and Mamta Sharma, 1993. Monitoring of organochlorine pesticide residuesin wheat and drinking water samples from Jaipur (Raj.), AEB Symp. on 'Toxicity Evaluation in Biosystems, Indore, India, Nov. 7-9, 1993.
26. Bhatia, Sonu, 2000. Earthworm and Sustainable Agriculture: Study of the Role of Earthworm in Production of Wheat Crop. Ph.D Thesis Awarded by University of Rajasthan, Jaipur, India. (Supervisor: Rajiv K. Sinha).
27. Bhatia, Sonu, K. Rajiv Sinha and Reena Sharma, 2000. Seeking Alternatives to Chemical Fertilisers for Sustainable Agriculture: A Study on the Impact of Vermiculture on the Growth and Yield of Potted Wheat Crops (Triticum aestivum Linn). International J. of Environmental Education & Information, University of Salford, UK, 19 (4): 295-304.
28. Baker, Geoff and Vicki Barrett, 1994. Earthworm Identifier; Publication of Council of Scientific and Industrial Research Organization (CSIRO), Division of Soil & Land Management, Australia.
29. Bansal, S. and K.K. Kapoor, 2000. Vermicomposting of crop residues and cattle dung with Eisenia foetida. J. of Bioresource Technology, 73: 95-98.
30. Barley, K.P., 1959. The Influence of Earthworm on Soil Fertility II: Consumption of Soil and Organic Matter by the Earthworms. Australian Journal of Agricultural Research, 10: 179-185.
31. Barley, K.P. and A.C. Jennings, 1959. Earthworms and Soil Fertility III; The Influence of Earthworms on the Availability of Nitrogen. Australian Journal of Agricultural Research, 10: 364-370.
32. Beetz, Alice, 1999. Worms for Composting (Vermicomposting); ATTRA-National Sustainable Agriculture Information Service, Livestock Technical Note, June 1999.
33. Bettolo, Marini, 1987. Towards a Second Green Revolution; Elsevier Science Publishers, U.K.
34. Bhardwaj, K.K.R. and A.C. Gaur, 1985. Recycling of Organic Wastes; Pub. of Indian Council of Agricultural Research, New Delhi, India, pp: 54-58.
35. Bhawalkar, V.U. and U.S. Bhawalkar, 1993. Vermiculture: The Bionutrition System; National Seminar on Indigenous Technology for Sustainable Agriculture, I.A.R.I, New Delhi, March 23-24, pp: 1-8.
36. Bhawalkar, U.S., 1995. Vermiculture Eco-technology; Publication of Bhawalkar Earthworm Research Institute (BERI), Pune, India.
37. Bhiday, M.H., 1995. Wealth from Waste: Vermiculturing; Publication of Tata Energy Research Institute (TERI), New Delhi, India; ISBN 81-85419-11-6.
38. Binet, F., L. Fayolle and M. Pussard, 1998. Significance of earthworms in stimulating soil microbial activity. Biology and Fertility of Soils, 27: 79-84.
39. Bogdanov, Peter, 1996. Commercial Vermiculture: How to Build a Thriving Business in Redworms; VermiCo Press, Oregon, pp: 83.
40. Bogdanov, Peter, 2004. The Single Largest Producer of Vermicompost in World; In P. Bogdanov (Ed.), 'Casting Call', Vol. 9 (3), October 2004. (http://www.vermico.com)
41. Butt, K.R., 1999. Inoculation of Earthworms into Reclaimed Soils: The U.K. Experience. Journal of Land Degradation and Development; 10: 565-575.
42. Bombatkar, Vasanthrao, 1996. The Miracle Called Compost; The Other India Press, Pune, India.
43. Bonkowski, M. and M. Schaefer, 1997. Interactions between earthworms and soil protozoa: A trophic component in the soil food web. J. of Soil Biology and Biochemistry, 291: 499-502.

44. Bradley, Peggy, 2000. Agriculture in the New Millennium; Bradley Hydroponics, Oregon, U.S. (Email: carbonq@peak.org).
45. Brown, G.G., 1995. How do earthworms affect microfloral and faunal community diversity? Journal of Plant and Soil, 170: 209-231.
46. Buchanan, M.A., E. Russell and S.D. Block, 1988. Chemical characterization and nitrogen mineralization potentials of vermicomposts derived from different organic wastes. In: Edwards, C.A. and E.F. Neuhauser (Eds.). Earthworms in Environmental and Waste Management'; S.P.B Acad. Publ., The Netherlands, pp: 231-239.
47. Buckerfield, J.C. and K.A. Webster, 1998. Worm-Worked Waste Boost Grape Yield: Prospects for Vermicompost Use in Vineyards; The Australian and New Zealand Wine Industry Journal, 13: 73-76.
48. Buckerfield, J.C., T.C. Flavel, K.E. Lee and K.A. Webster, 1999. Vermicompost in Solid and Liquid Forms as a Plant-Growth Promoter; Pedobiologia, 43: 753-759.
49. Canellas, L.P., F.L. Olivares, A.L. Okorokova and R.A. Facanha, 2000. Humic Acids Isolated from Earthworm Compost Enhance Root Elongation, Lateral Root Emergence and Plasma Membrane H^+-ATPase Activity in Maize Roots. In J. of Plant Physiology, 130: 1951-1957.
50. Chaoui, H.I., L.M. Zibilske and T. Ohno, 2003. Effects of earthworms casts and compost on soil microbial activity and plant nutrient availability. Soil Biology and Biochemistry, 35 (2): 295-302.
51. Chauhan, Krunal, 2009. A Comprehensive Study of Vermiculture Technology: Potential for its Application in Solid Waste and Wastewater Management, Soil Remediation and Fertility Improvement for Increased Crop Production; Report of 40 CP Honours Project for the Partial Fulfillment of Master of Environmental Engineering Degree; Griffith University, Australia (Supervisors: Dr. Rajiv K. Sinha and Dr. Sunil Heart).
52. Christensen, O., 1987. The Effect of Earthworms on Nitrogen Cycling in Arable Soil; Proceedings of the 9th International Colloquium on Soil Zoology, Nauka, Moscow, pp: 106-118.
53. Christensen, O., 1988. The Direct effects of Earthworms on Nitrogen Turnover in Cultivated Soils. Ecological Bulletins. Copenhagen, Denmark, 39: 41-44.
54. Clarholm, M., 1981. Protozoan grazing of bacteria in soil: Impact and importance. J. of Microbiology and Ecology, 7: 343-350.
55. Cohen, S. and H.B. Lewis, 1949. The nitrogen metabolism of the earthworm. J. of Biological Chemistry, 180: 79-92.
56. Conway, R. Godon, 1989. The Challenge of Sustainable Agriculture. Proc. Of the 3rd International Conf. of Environmental Education and Sustainable Development, New Delhi (Ed. Deshbandhu Harjit Singh and A.K. Mitra).
57. Dash, M.C., 1978. Role of Earthworms in the Decomposer System. In: Singh, J.S. and B. Gopal (Eds.). Glimpses of Ecology; India International Scientific Publication, New Delhi, pp: 399-406.
58. Darwin, Charles, 1881. The Formation of Vegetable Moulds Through the Action of Worms. Murray Publications, London.
59. Datar, M.T., M.N. Rao and S. Reddy, 1997. Vermicomposting: A Technological Option for Solid Waste Management. J. of Solid Waste Technology and Management, 24 (2): 89-93.
60. De Brito Alvarez, M.A., S. Gagne and H. Antoun, 1995. Effect of compost on rhizosphere microflora of the tomato and on the incidence of plant-growth promoting rhizobacteria. J. of Applied and Environmental Microbiology, 61: 194-199.
61. Devliegher, W. and W. Verstraete, 1997. The effect of Lumbricus terrestris on soil in relation to plant growth: Effect of Nutrient Enrichment Process (NEP) and gut-associated processes (GAP). J. of Soil Biology and Biochemistry, 29: 341-346.
62. Dominguez, J., C.A. Edwards and S. Subler, 1997. A comparison of vermicomposting and composting, BioCycle, 28: 57-59.
63. Domínguez, J., 2004. State of the Art and New Perspectives on Vermicomposting Research; In Edwards, C.A., (Ed.). Earthworm Ecology, CRC Press; Boca Raton, FL, USA, pp: 401-424.
64. Dynes, R.A., 2003. EARTHWORMS, Technology Info to Enable the Development of Earthworm Production, Rural Industries Research and Development Corporation (RIRDC), Govt. of Australia, Canberra, ACT.

65. Edwards, C.A. and J.R. Lofty, 1972. Biology of Earthworms; Chapman and Hall, London, pp: 283.
66. Edwards, C.A., I. Burrows, K.E. Fletcher and B.A. Jones, 1985. The Use of Earthworms for Composting Farm Wastes. In JKR Gasser (Ed.) Composting Agricultural and Other Wastes; Elsevier, London and New York, pp: 229-241.
67. Edwards, C.A. and K.E. Fletcher, 1988. Interaction Between Earthworms and Microorganisms in Organic Matter Breakdown. Agriculture Ecosystems and Environment; 24: 235-247.
68. Edwards, C.A., 1988. Breakdown of Animal, Vegetable and Industrial Organic Wastes by Earthworms. In Edward, C.A. and E.F. Neuhauser (Ed.). Earthworms in Waste and Environmental Management, SPB Academic Publishing, The Hague, The Netherlands; ISBN 90-5103-017-7, pp: 21-32.
69. Eastman, B.R., P.N. Kane, C.A. Edwards, L. Trytek, B.A.L. Gunadi and J.R. Mobley, 2001. The Effectiveness of Vermiculture in Human Pathogen Reduction for USEPA Biosolids Stabilization. J. of Compost Science and Utilization, 9 (1): 38-41.
70. Edwards, C.A. and I. Burrows, 1988. The Potential of Earthworms Composts as Plant Growth Media. In Edward, C.A. and E.F. Neuhauser (Eds.). Earthworms in Waste and Environmental Management. SPB Academic Publishing, The Hague, The Netherlands; ISBN 90-5103-017-7, pp: 21-32.
71. Edwards, C.A. and P.J. Bohlen, 1996. Biology and Ecology of Earthworms (3rd Ed.), Chapman and Hall, London, U.K.
72. Edwards, C.A., 1998. The Use of Earthworms in the Breakdown and Management of Organic Wastes. In Edwards, C.A. (Ed.). Earthworm Ecology; CRC Press, Boca Raton, FL, USA, pp: 327-354.
73. Edwards, C.A., J. Domínguez and N.Q. Arancon, 2004. The influence of vermicomposts on plant growth and pest incidence. In Shakir, S.H. and W.Z.A. Mikhail (Eds.). Soil Zoology for Sustainable Development in the 21st Century, Self-Publisher; Cairo, Egypt, pp: 397-420.
74. Edwards, C.A. and N. Arancon, 2004. Vermicompost Supress Plant Pests and Diseases Attacks. In REDNOVA NEWS: http://www.rednova.com/display/ ?id =55938
75. Evans, A.C. and W.J. Guild and L. Mc. 1948. Studies on the Relationship Between Earthworms and Soil Fertility IV. On the Life Cycles of Some British Lumbricidae, Annals of Applied Biology, 35 (4): 471-84.
76. Evans, A.C., 1948. Some effects of earthworms on soil structure, Annals of Applied Biology, 35: 1-13.
77. FAO, 2001. Food Security and the Environment, Fact sheet prepared for the World Food Summit, FAO, Rome, Italy.
78. FAO, 2004. The State of the Food and Agriculture 2003-2004. FAO Publication, Rome, Italy.
79. Frankenberger, Jr., W.T. and M. Arshad, 1995. Phytohormones in Soils: Microbial Production and Function. Marcel and Deckker Pub., New York, pp: 503.
80. Fraser-Quick, G., 2002. Vermiculture-A Sustainable Total Waste Management Solution. What's New in Waste Management? 4 (6): 13-16.
81. Frederickson, J., K.R. Butt, R.M. Morris and C. Daniel, 1997. Combining Vermiculture With Traditional Green Waste Composting Systems. J. of Soil Biology and Biochemistry, 29: 725-730.
82. Frederickson, J., 2000. The Worm's Turn, Waste Management Magazine, August, UK.
83. Gallardo-Lara, F. and R. Nogales, 1987. Effect of the application of town refuse compost on the soil-plant system: a review. J. of Biological Wastes, 19: 35-62.
84. Garg, K. and N. Bhardwaj, 2000. Effect of Vermicompost of Parthenium on Two Cultivars of Wheat. Indian. J. Ecology, 27: 177-180.
85. Gaur, A.C. and G. Singh, 1995. Recycling of rural and urban wastes through conventional composting and vermicomposting. In: Tandon, H.L.S. (Ed.). Recycling of Crop, Animal, Human and Industrial Waste in Agriculture. Fertilizer Development and Consultation Organisation, New Delhi, India, pp: 31-49.
86. GEORG, 2004. Feasibility of Developing the Organic and Transitional Farm Market for Processing Municipal and Farm Organic Wastes Using Large-Scale Vermicomposting; Pub. Of Good Earth Organic Resources Group, Halifax, Nova Scotia, Canada. (Available on http://www.alternativeorganic.com).
87. Ghabbour, S.I., 1996. Earthworm in Agriculture: A Modern Evaluation; Indian Review of Ecological and Biological Society, 111 (2): 259-271.
88. Graff, O., 1970. Phosphorus Contents of Earthworms Casts (In German), Landbauforchung Volkenrode, 20: 33-36.

89. Graff, O., 1981. Preliminary experiment of vermicomposting of different waste materials using Eudrilus eugeniae Kingberg. In: Appelhof, M. (Ed.). Proc. of the workshop on 'Role of Earthworms in the Stabilization of Organic Residues'; Malanazoo Pub. Michigan, USA, pp: 179-191.
90. Grappelli, A., V. Tomati, E. Galli and B. Vergari, 1985. Earthworm Casting in Plant Propagation. Horticultural Science, 20: 874-876.
91. Guild, W.J., 1955. Earthworms and Soil Structure. In D.K. Mc and E. Kevan (Ed.). 'Soil Zoology' (Butterworths: London.).
92. Gunathilagraj, K., 1996. Earthworm: An Introduction, Indian Council of Agricultural Research Training Program. Tamil Nadu Agriculture University, Coimbatore.
93. Gunathilagraj, K. and T. Ravignanam, 1996. Vermicomposting of Sericultural Wastes. Madras Agricultural Journal. Coimbatore, India, pp: 455-457.
94. Hammermeister, A.M., P.R. Warman, E.A. Jeliakova and R.C. Martin, 2004. Nutrient Supply and Lettuce Growth in Response to Vermicomposted and Composted Cattle Manure. J. of Bioresource Technology, (Quoted in Munroe, 2007).
95. Han, J., L. Sun, X. Dong, Z. Cai, H. Yang, Y. Wang and W. Song, 2005. Characterization of a novel plant growth-promoting bacteria strain Delftia tsuruhatensis HR4 both as a diazotroph and a potential bio-control agent against various pathogens. Syst. Applied Microbiology, 28: 66-76.
96. Hand, P., 1988. Earthworm Biotechnology. In: Greenshields, R. (Ed.). Resources and Application of Biotechnology: The New Wave; MacMillan Press Ltd. US.
97. Hartenstein, R. and M.S. Bisesi, 1989. Use of Earthworm Biotechnology for the Management of Effluents from Intensively Housed Livestock. Outlook on Agriculture, USA, 18: 72-76.
98. Hati, Daksha, 2001. 1000 Wriggling Worms and Rural Women. The Deccan Herald, 26th June, 2001, India.
99. Hoitink, H.A.J. and P.C. Fahy, 1986. Basis for the control of soil-borne plant pathogens with composts. Annual Review of Phytopathology, 24: 93-114.
100. Hopp, H., 1946. Earthworms fight erosion too. J. of Soil Conservation; 11: 252-254.
101. Hopp, H. and C.S. Slater, 1949. The Effect of Earthworms on the Productivity of Agricultural Soils. J. of Agricultural Research, 78: 325-339.
102. Horrigan, L., R.S. Lawrence and P. Walker, 2002. How Sustainable Agriculture Can Address the Environmental and Human Health Harms of Industrial Agriculture; Environmental Health Perspectives; 110 (5): 445-456.
103. Ireland, M.P., 1983. Heavy Metals Uptake in Earthworms. Earthworm Ecology, Chapman and Hall, London.
104. Ismail, S.A., 2005. The Earthworm Book. Other India Press, Apusa, Goa, pp: 101.
105. Jensen, J., 1998. Worm Farm Take on New Challenge; Biocycle, 39 (1): 56-57.
106. Jordao, C.P., C.C. Nascentes, P.R. Cecon, R.L.F. Fontes and J.L. Pereira, 2006. Heavy metal availability in soil amended with composted urban solid wastes. Environmental Monitoring and Assessment, 112: 309-326.
107. Joshi, N.V. and B.V. Kelkar, 1952. The role of earthworms in soil fertility. Indian J. of Agricultural Science, 22: 189-96.
108. Kale, R.D. and K. Bano, 1986. Field Trials With Vermicompost. An Organic Fertilizer; In Proc. of National Seminar on 'Organic Waste Utilization by Vermicomposting'. GKVK Agricultural University, Bangalore, India.
109. Kale, R.D., S.N. Seenappa and J. Rao, 1993. Sugar factory refuse for the production of vermicompost and worm biomass. V International Symposium on Earthworms; Ohio University, USA.
110. Kale, R.D. and N.S. Sunitha, 1995. Efficiency of Earthworms (E. Eugeniae) in Converting the Solid Waste from Aromatic Oil Extraction Industry into Vermicompost. Journal of IAEM, 22 (1): 267-269.
111. Kale, R.D., 1998. Earthworms: Nature's Gift for Utilization of Organic Wastes; In C.A. Edward (Ed.). 'Earthworm Ecology'; St. Lucie Press, NY, ISBN 1-884015-74-376.
112. Kale, R.D., 1998. Earthworm Cinderella of Organic Farming. Prism Book Pvt Ltd, Bangalore, India, pp: 88.
113. Kaushik, P. and V.K. Garg, 2004. Dynamics of biological and chemical parameters during vermicomposting of solid textile mill sludges mixed with cow dung and agricultural residues. J. of Bioresource Technology, 4: 203-209.

114. Kaviraj, Sharma, 2003. Municipal solid waste management through vermi-composting employing exotic and local species of earthworms. J. of Bioresource Technology, 90: 169-173.
115. Krishnamoorthy, R.V. and S.N. Vajranabhaiah, 1986. Biological Activity of Earthworm Casts: An Assessment of Plant Growth Promoter Levels in the Casts. Proc. of Indian Academy of Sciences (Animal Science), 95: 341-351.
116. Lakshmi, B.L. and G.S. Vizaylakshmi, 2000. Vermicomposting of Sugar Factory Filter Pressmud Using African Earthworms Species (Eudrillus eugeniae). Journal of Pollution Research, 19 (3): 481-483.
117. Lavelle, P. and A. Martin, 1992. Small-scale and large-scale effects of endogeic earthworms on soil organic matter dynamics in soils of the humid-tropics. J. of Soil Biology and Biochemistry, 12: 1490-1498.
118. Lee, K.E., 1985. Earthworms, their Ecology and Relationships with Soil and Land Use. Academic Press, Sydney, pp: 411.
119. Loehr, R.C., J.H. Martin, E.F. Neuhauser and M.R. Malecki, 1984. Waste Management Using Earthworms-Engineering and Scientific Relationships. Project Report ISP-8016764, National Science Foundation, Washington DC.
120. Lotzof, M., 2000. Vermiculture: An Australian Technology Success Story. Waste Management Magazine, February 2000, Australia.
121. Lunt, H.A. and H.G. Jacobson, 1994. The chemical composition of earthworm casts. Soil Science, 58: 367-75.
122. Martin, J.P., 1976. Darwin on Earthworms: The Formation of Vegetable Moulds; Bookworm Publishing, ISBN 0-916302-06-7.
123. Morgan, M. and I. Burrows, 1982. Earthworms/Microorganisms interactions. Rothamsted Exp. Stn. Rep.
124. Munroe, Glenn, 2007. Manual of On-farm Vermicomposting and Vermiculture; Pub. of Organic Agriculture Centre of Canada, pp: 39.
125. Nair, Jaya., Kuruvilla Mathew and Goen, Ho, 2007. Earthworms and composting worms-Basics towards composting applications. Paper at 'Water for All Life-A Decentralised Infrastructure for a Sustainable Future'; March 12-14, 2007, Marriott Waterfront Hotel, Baltimore, USA.
126. Neilson, R.L., 1951. Earthworms and Soil Fertility; In Proc. Of 13^{th} Conf. Of Grassland Assoc., New Plymouth, US, pp: 158-167.
127. Neilson, R.L., 1965. Presence of Plant Growth Substances in Earthworms, Demonstrated by the Paper Chromatography and Went Pea Test, Nature, (Lond.), 208: 1113-1114.
128. Nighawan, S.D. and J.S. Kanwar, 1952. Physico-chemical properties of earthworm castings. Indian J. of Agricultural Sciences, 22: 357-375.
129. OECD, 1998. Agriculture and the Environment: Issues and Policies; Report of OECD, Paris.
130. Orlikowski, L.B., 1999. Vermicompost extract in the control of some soil borne pathogens. International Symposium on Crop Protection, 64: 405-410.
131. Ouédraogo, E., A. Mando and N.P. Zombré, 2001. Use of compost to improve soil properties and crop productivity under low input agricultural system in West Africa. J. of Agricultural Ecosystems and Environment, 84: 259-266.
132. Pajon, Silvio (Undated): 'The Worms Turn-Argentina', Intermediate Technology Development Group, Case Study Series 4, (Quoted in Munroe, 2007). (http://www.tve.org./ho/doc.cfm?aid=1450&lang=English).
133. Palanisamy, S., 1996. Earthworm and Plant Interactions; Paper presented in ICAR Training Program; Tamil Nadu Agricultural University, Coimbatore.
134. Parle, J.N., 1963. A microbiological study of earthworm casts. J of General Microbiology, 31: 13-23.
135. Parmelle, R.W. and Jr.D.A. Crossley, 1988. Earthworm Production and Role in the Nitrogen Cycle of a no-tillage agro-ecosystem on the Georgia Piedmont. Pedobiologia, 32: 353-361.
136. Patil, B.B., 1993. Soil and Organic Farming, In Proc. of the Training Program on 'Organic Agriculture'. Institute of Natural and Organic Agriculture, Pune, India.
137. Pierre, V., R. Phillip, L. Margnerite and C. Pierrette, 1982. Anti-bacterial activity of the haemolytic system from the earthworms Eisinia foetida Andrei. Invertebrate Pathology, 40: 21-27.
138. Pramanik, P., G.K. Ghosh, P.K. Ghosal and P. Banik, 2007. Changes in organic-C, N, P and K and enzyme activities in vermicompost of biodegradable organic wastes under liming and microbial inoculants. J. of Bioresource Technology, 98: 2485-2494.

139. Pretty N. Jules, 1995. Regenerating Agriculture: Polices and Practices for Sustainability and Self-Reliance, Earthscan Pub. Limited, London.
140. Pretty, N. Jukes, 1996. Sustainable Agriculture: Impact on Food Production and Challenges for Food Security. International Institute of Environment and Development, IIED, London.
141. Puh, P.C., 1941. Beneficial influence of earthworms on some chemical properties of the soil. Publication of Science Society of China (Division of Zoology), 15: 147-155.
142. Ramesh, P.T., Alfred, Sagaya and K. Gunathilagraj, 1997. Population Density of Earthworms Under Different Crop Ecosystem. In Proceeding of Training Program on Vermiculture at ICAR, New Delhi.
143. Rao, B. Narsimha, 1993. Pollution problems caused by pesticides. Symposium on Toxicity Evaluation in Biosystem; Academy of Environmental Biology (AEB), Indore, Nov. 7-9, 1993.
144. Reddy, M.V., 1988. The effect of casts of Pheretima alexandri on the growth of Vinca rosea and Oryza sativa. In: Edwards, C.A. and E.F. Neuhauser (Eds.). Earthworms in Environmental and Waste Management; SPB Bakker, The Netherlands, pp: 241-248.
145. Reganold, John P., Papendick, Robert I. Parr and F. James, 1990. Sustainable Agriculture, Scientific American.
146. Reinecke, A.J., S.A. Viljioen and R.J. Saayman, 1992. The suitability of Eudrilus eugeniae, Perionyx excavatus and Eisenia fetida (Oligochaete) for vermicomposting in Southern Africa in terms of their temperature requirements. J. of Soil Biology and Biochemistry, 24: 1295-1307.
147. Rodriguez, H. and R. Fraga, 1999. Phosphate solubilizing bacteria and their role in plant growth promotion. J. of Biotechnological. Advancement, 17: 319-339.
148. Rodríguez, J.A., E. Zavaleta, P. Sanchez and H. Gonzalez, 2000. The effect of vermicompost on plant nutrition, yield and incidence of root and crown rot of Gerbera (Gerbera jamesonii H Bolus), Fitopathologia, 35: 66-79.
149. Russell, E.J., 1910. The Effect of Earthworms on Soil Productiveness. J. of Agriculture Science, 3: 246-57.
150. Sadhale, Nailini, 1996. Recommendation to Incorporate Earthworms in Soil of Pomogranate to obtain high quality fruits. In Surpala's Vrikshayurveda, Verse 131. The Science of Plant Life by Surpala, 10th Century A.D. Asian Agri-History Bulletin; No. 1. Secunderabad, India.
151. Satchell, J.E., 1983. Earthworm Ecology-From Darwin to Vermiculture; Chapman and Hall Ltd., London, pp: 1-5.
152. Satchel, J.E. and K. Martin, 1984. Phosphatase Activity in Earthworm Feces. J. of Soil Biology and Biochemistry; 16: 191-194.
153. Saxena, M., A. Chauhan and P. Asokan, 1998. Flyash Vemicompost from Non-friendly Organic Wastes. Pollution Research, 17 (1): 5-11.
154. Scheu, S., 1987. Microbial Activity and Nutrient Dynamics in Earthworms Casts. J. of Biological Fertility Soils, 5: 230-234.
155. Scheu, S., 1993. There is an Earthworm Mobilizable Nitrogen Pool in Soil. Pedobiologia; 37: 243-249.
156. Scheuerell, S. and W. Mahaffee, 2002. Compost Tea: Principles and Prospects for Plant Disease Control. Compost Science and Utilization, 10: 313-338.
157. Seenappa, S.N. and R. Kale, 1993. Efficiency of earthworm Eudrillus eugeniae in converting the solid wastes from the aromatic oil extraction units into vermicompost. Journal of IAEM, 22: 267-269.
158. Seenappa, S.N., J. Rao and R. Kale, 1995. Conversion of distillery wastes into organic manure by earthworm Eudrillus euginae. Journal of IAEM, 22 (1): 244-246.
159. Senapati, B.K., 1992. Vermitechnology: An option for Recycling Cellulosic Waste in India. In: New Trends in Biotechnology. Oxford and IBH Publications Pvt. Co. Ltd. Calcutta, pp: 347-358.
160. Senesi, N., 1989. Composted Materials as Organic Fertilizers. The Science of Total Environment, 81/82: 521-542.
161. Sharma, Reena, 2001. Vermiculture for Sustainable Agriculture: Study of the Agronomic Impact of Earthworms and their Vermicompost on Growth and Production of Wheat Crops. Ph.D. Thesis, submitted to the University of Rajasthan, Jaipur, India (Supervisor: Dr. Rajiv K. Sinha).
162. Sharpley, A.N. and J.K. Syers, 1976. Potential Role of Earthworms Casts for Phosphorus Enrichment of Run-Off Waters. Soil Biology and Biochemistry; 8: 341-346.

163. Shiralipour, A., D.B. McConnell and W.H. Smith, 1992. Uses and Benefits of MSW Compost: A Review and Assessment. J. of Biomass and Bioenergy , 3: 267-279.
164. Shrikhande, J.G. and A.N. Pathak, 1948. Earthworms and insects in relation to soil fertility. Current Science, 17: 327-328.
165. Siminis, C.I., M. Loulakis, M. Kefakis, T. Manios and V. Manios, 1998. Humic substances from compost affect nutrient accumulation and fruit yield in tomato. Acta Horticulturae, 469: 353-358.
166. Singh, Kulbaivab, 2009. Microbial and Nutritional Analysis of Vermicompost, Aerobic and Anaerobic Compost. 40 CP Honours Project for Master in Environmental Engineering; Griffith University, Brisbane, Australia; (Supervisors: Dr. Rajiv K. Sinha & Dr. Sunil Heart).
167. Singh, Pancham K., K. Rajiv Sinha, Sunil Herat, K. Ravindra Suhane and Sunita Kushwaha, 2009. Studies on Earthworms Vermicompost as a Sustainable Alternative to Chemical Fertilizers for Production of Wheat Crops. Collaborative Research on Vermiculture Studies, College of Horticulture, Noorsarai, Bihar, India and Griffith University, Brisbane, Australia.
168. Singh, R.D., 1993. Harnessing the Earthworms for Sustainable Agriculture. Institute of National Organic Agriculture, Pune, India, pp: 1-16.
169. Singleton, D.R., B.F. Hendrix, D.C. Coleman and W.B. Whitemann, 2003. Identification of uncultured bacteria tightly associated with the intestine of the earthworms Lumricus rubellus. Soil Biology and Biochemistry; 35: 1547-1555.
170. Sinha, Rajiv, K., 1998. Embarking on the second green revolution for sustainable agriculture in India: A judicious mix of traditional wisdom and modern knowledge in ecological farming. Journal of Agricultural and Environmental Ethics, Kluwer Acad. Pub., The Netherlands, 10: 183-197.
171. Sinha, Rajiv K., Sunil Herat, Sunita Agarwal, Ravi Asadi and Emilio Carretero, 2002. Vermiculture Technology for Environmental Management: Study of Action of Earthworms Elsinia fetida, Eudrilus euginae and Perionyx excavatus on Biodegradation of Some Community Wastes in India and Australia. The Environmentalist, U.K., 22 (2): 261-268.
172. Sinha, Rajiv K., 2008. Organic Farming: An Economic Solution for Food Safety and Environmental Security; Green Farming-International J. of Agricultural Sciences, 1 (10-11): 42-49.
173. Sinha, Rajiv K., Sunil Herat, Gokul Bharambe & Ashish Brahambhatt, 2009. Vermistabilization of Sewage Sludge (Biosolids) by Earthworms: Converting a Potential Biohazard destined for Landfill Disposal into a Pathogen Free, Nutritive and Safe Biofertilizer for the Farms. Journal of Waste Management Research, Verona (Accepted for Publication).
174. Sinha, Rajiv K., Jaya Nair, Gokul Bharambe, Swapnil Patil and P.D. Bapat, 2008. Vermiculture Revolution. In James I. Daven and Robert N. Klein (Eds.). Progress in Waste Management Research; NOVA Science Publishers, NY, USA, Invited Paper, pp: 157-227.
175. Sinha, Rajiv K. and Gokul Bharambe, 2007. Studies on Agronomic Impacts of Vermicompost Vis-à-vis Conventional Compost and Chemical Fertilizers on Corn Crops. CESR Sponsored Project; Griffith University, Brisbane, Australia.
176. Sinha, Rajiv K., Sunil Herat, Ravindra K. Suhane, Pancham K. Singh, Krunal Chauhan and Dalsukh Valani, 2009. Embarking on a Second Green Revolution for Sustainable Agriculture by Earthworms and Vermicompost: The Miracle Plant Growth Promoters and Protectors; The Environmentalist, U.K. (Communicated).
177. Sinha, Rajiv K., Sunil Herat, Gokul Bharambe, Swapnil Patil, P.D. Bapat, Kunal Chauhan and Dalsukh Valani, 2009. Vermiculture Biotechnology: The Emerging Cost-effective and Sustainable Technology of the 21st Century for Multiple Uses from Waste and Land Management to Safe and Sustained Food Production, Environmental Research Journal, NOVA Science Publishers, NY, USA, Invited Paper, Vol: 3 (2/3).
178. Spain, A.V., P. Lavelle and A. Mariotti, 1992. Stimulation of Plant Growth by Tropical Earthworms, Soil Biol. Biochem., 24 (12): 1629-1633.
179. Stinner, B.R., D.A. McCartney, J.M. Blair, R.W. Parmelee and M.F. Allen, 1997. Earthworm Effects on Crop and Weed Biomass and Nitrogen (N) content in Organic and Inorganic Fertilized Agro-ecosystems. Soil Biology and Biochemistry, 29: 423-426.
180. Subler, Scott., Edwards Clive and Metzger James, 1998. Comparing Vermicomposts and Composts. Biocycle, 39: 63-66.

181. Sudha, B. and K.K. Kapoor, 2000. Vermicomposting of Crop Residues and Cattle Dung with Eisinia fetida. J. of Bioresource Technology, Vol: 73.
182. Suhane, R.K., 2007. Vermicompost (In Hindi); Pub. Of Rajendra Agriculture University, Pusa, Bihar; pp: 88 (www.kvksmp.org) (Email: info@kvksmp.org).
183. Suhane, Ravindra K., K. Sinha, Rajiv and K. Singh, Pancham, 2008. Vermicompost, Cattle-dung Compost and Chemical Fertilizers: Impacts on Yield of Wheat Crops; Communication of Rajendra Agriculture University, Pusa, Bihar, India.
184. Sukumaran, N., 2008. Vermitechnology for Increasing Crop Yield; School of Life Sciences. Vels University, Pallavaram, Chennai, India (sukumaran06@gmail.com). Published in The HINDU.
185. Syers, J.K. and J.A. Springett, 1984. Earthworm and soil fertility. J. of Plant and Soil, 76: 93-104.
186. Szczech, M., W. Rondomanski, M.W. Brzeski, U. Smolinska and J.F. Kotowski, 1993. Suppressive effect of commercial earthworm compost on some root infecting pathogens of cabbage and tomato. Biological Agriculture and Horticulture, 10: 47-52.
187. Teotia, S.P., F.L. Duley and T.M. McCalla, 1950. Effect of stubble mulching on number and activity of earthworms. Agricultural Experiment Research Station Bulletin, University of Nebraska College of Agriculture, Lincoln, N.E., pp: 165.
188. Tiwari, S.C., B.K. Tiwari and R.R. Mishra, 1989. Microbial populations, enzyme activities and nitrogen-phosphorus-potassium enrichment in earthworm casts and in surrounding soil of a pineapple plantation. J. of Biology and Fertility of Soils; 8: 178-182.
189. Tobey, James A. and Henri Smets, 1996. The Polluter Pay Principle in the Context of Agriculture and the Environment. The World Economy, Blackwell Publishers, Vol: 19 (1).
190. Tomati, V., A. Grappelli and E. Galli, 1983. Fertility Factors in Earthworm Humus. In Proc. of International Symposium on 'Agriculture and Environment: Prospects in Earthworm Farming; Rome, pp: 49-56.
191. Tomati, V., A. Grappelli and E. Galli, 1987. The Presence of Growth Regulators in Earthworm-Worked Wastes. In Proceeding of International Symposium on 'Earthworms'; Italy; 31 March-5 April, 1985; pp: 423-436.
192. Tomati, V., A. Grappelli and E. Galli, 1988. The Hormone like Effect of Earthworm Casts on Plant Growth. Biology and Fertility of Soils, 5: 288-294.
193. Tomati, V. and E. Galli, 1995. Earthworms, Soil Fertility and Plant Productivity. Acta Zoologica Fennica, 196: 11-14.
194. Tomar, V.K., R.K. Bhatnagar and R.K. Palta, 1998. Effect of Vermicompost on Production of Brinjal and Carrot. Bhartiya Krishi Anusandhan Patrika (Indian Agricultural Research Bulletin), 13 (3-4): 153-156.
195. UNDP, 1994. Sustainable Human Development and Agriculture; UNDP Guide Book Series, NY.
196. UNEP/GEMS, 1992. The Contamination of Food. UNEP/GEMS Environment Library No. 5, Nairobi, Kenya.
197. UNEP, 1996. Food for All: The World Food Summit. Our Planet; November 1996 (Jacques Diouf).
198. UNEP, 1998. Sustainable Agriculture; People and the Plant; Pub. of United Nation Environment Program, Vol: 7 (1).
199. UNEP-DTIE, 1999. Sustainability and the Agri-Food Industry. Industry and Environment, Pub. of United Nation Environment Program, Division of Technology Industry and Economics; Paris, Cedex 15, France.
200. UNSW, ROU, 2002a. Vermiculture in Organics Management-The Truth Revealed, (Seminar in March 2002) University of New South Wales Recycling Organics Unit, Sydney, NSW, Australia.
201. UNSW, ROU, 2002b. Best Practice Guidelines to Managing On-Site Vermiculture Technologies, University of New South Wales Recycling Organics Unit, Sydney, NSW, Australia; (Viewed in December 2004) www.resource.nsw.gov.au/data/Vermiculture%20BPG.pdf
202. USDA-ARS, 1997. Preparing Agriculture for a Changing World. Agricultural Research; July 1997, 4-17, US Dept. of Agriculture.
203. Valani, Dalsukh, 2009. Study of Aerobic, Anaerobic and Vermicomposting Systems for Food and Garden Wastes and the Agronomic Impacts of Composts on Corn and Wheat Crops; Report of 40 CP Honours Project for the Partial Fulfillment of Master of Environmental Engineering Degree, Griffith University, Australia (Supervisors: Dr. Rajiv K. Sinha and Dr. Sunil Herat).

204. Vinotha, S.P., K. Parthasarathi and L.S. Ranganathan, 2000. Enhanced phosphatase activity in earthworm casts is more of microbial origin. Current Science, 79: 1158-1159.
205. Visvanathan, *et al*., 2005. Vermicomposting as an Eco-tool in Sustainable Solid Waste Management, Asian Institute of Technology, Anna University, India.
206. Webster, Katie, A., 2005. Vermicompost Increases Yield of Cherries for Three Years after a Single Application, EcoResearch, South Australia, (www.ecoresearch.com.au).
207. Weltzien, H.C., 1989. Some effects of composted organic materials on plant health. Agriculture Ecosystems and Environment, 27: 439-446.
208. Whalen, J.K., W. Robert Parmelee, A. David McCartnney, Jessica L. Vanarsdale, 1999. Movement of Nitrogen (N) from Decomposing Earthworm Tissue to Soil. Microbial and Nitrogen Pools, Soil Biology and Biochemistry, 31: 487-492.
209. White, S., 1997. A Vermi-adventure in India. J. of Worm Digest, 15 (1): 27-30.
210. Wilson, D.P. and W.R. Carlile, 1989. Plant growth in potting media containing worm-worked duck waste. Acta Horticulture; 238: 205-220.
211. Winding, A., R. Ronn and N.B. Hendriksen, 1997. Bacteria and protozoa in soil microhabitats as affected by earthworms. Biological Fertility of Soils, 24: 133-140.
212. Yvan, Capowiez, Stephane Cadoux, Pierre Bouchand, Jean Roger-Estrade, Guy Richard and Hubert Boizard, 2009. Experimental Evidence for the Role of Earthworms in Compacted Soil Regeneration Based on Field Observations and Results from a Semi-field Experiment. Soil Biology and Biochemistry, 41: 711-717.
213. Zaller, J.G., 2006. Foliar Spraying of Vermicompost Extracts: Effects on Fruit Quality and Indications of Late-Blight Suppression of Field-Grown Tomatoes. Biological Agriculture and Horticulture, 24: 165-180.
214. Zhang, B.-G., G.-T. Li, T.-S. Shen, J.-K. Wang and Z. Sun, 2000. Changes in microbial biomass C, N and P and enzyme activities in soil incubated with the earthworm Metaphire guillelmi or Eisenia fetida. J. of Soil Biology and Biochemistry, 32: 2055-2062.

Useful websites on vermiculture studies

http://www.alternativeorganic.com (Good Earth People, Canada).
http://www.kvksmp.org (Farmers Training on Vermicomposting at RAU, Bihar, India).
http://www.rirdc.gov.au (Australian Govt. Pub. On EARTHWORMS).
http://www.vermitech.com (Australian Company in Vermiculture Business).
http://www.vermitechnology.com (U.S. Company in Vermiculture Business).
(http://www.wormwoman.com (Mary Appelhof: Author of Classic Book 'Worms Eat My Garbage-Sold over 3500 copies).
http://www.wormdigest.org ('Worm Digest'-A Quarterly Magazine).
http://www.wormresearchcentre.co.uk (Earthworm Research Center in UK).

Relevant Books by Dr. Rajiv K. Sinha

1. Sinha, Rajiv K and Rohit Sinha, 2008. Environmental Biotechnology (Role of Plants, Animals and Microbes in Environmental Management) (pages 315), Aavishkar Publishers, India; ISBN 978-81-7910-229-9.
2. Sinha, Rajiv K., 2007. Sustainable Development (Striking a Balance between Economy & Ecology), (pages 340), Pointer Publisher, India; ISBN 978-81-7132-499-6.
3. Sinha, Rajiv K., 2003. Sustainable Agriculture: Embarking on the Second Green Revolution, (pages 350), Surabhee Publisher, India; ISBN 81-86599-60-6.