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'.

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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.
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