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Full Length Research Paper

Embarking on a second green revolution for sustainable agriculture by vermiculture biotechnology using earthworms: Reviving the dreams of Sir Charles Darwin

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Vermiculture biotechnology promises to usher in the 'Second Green Revolution' by completely replacing the destructive agro-chemicals which did more harm than good to both the farmers and their farmland. Earthworms restore and improve soil fertility and significantly boost crop productivity. Earthworms excreta (vermicast) is a nutritive 'organic fertilizer' rich in humus, NKP, micronutrients, beneficial soil microbes - 'nitrogen-fixing and phosphate solubilizing bacteria' and 'actinomycets' and growth hormones 'auxins', 'gibberlins' and 'cytokinins'. Both earthworms and its vermicast and body liquid (vermiwash) are scientifically proving as both 'growth promoters and protectors' for crop plants. In the experiments with corn and wheat crops, tomato and egg-plants it displayed excellent growth performances in terms of height of plants, colour and texture of leaves, appearance of flowers and fruits, seed ears etc, as compared to chemical fertilizers and the conventional compost. There is also less incidences of 'pest and disease attack' and 'reduced demand of water' for irrigation in plants grown on vermicompost. Presence of live earthworms in soil also makes significant difference in flower and fruit formation in vegetable crops. Earthworms biomass, a byproduct of VBT is rich in 'high quality protein' and source of nutritive feed materials for fishery, poultry and dairy industries and also for human consumption.

Key words: Earthworms and vermicompost, plant growth promoter, plant protector, improve soil fertility, combat plant diseases, repel pest attack, earthworm biomass, protein feed, medicines.

INTRODUCTION

A revolution is unfolding in vermiculture studies for vermicomposting of diverse organic wastes by vermin-culture technology using waste eater earthworms into a nutritive 'organic fertilizer' and using them for production of 'safe food', both in quantity and quality without recourse to agro-chemicals. Heavy use of agro-chemicals since the 'green-revolution' of the 1960's boosted food productivity, with the cost of environment and society. It killed the beneficial soil organisms and destroyed their natural fertility, impaired the power of 'biological resistance' in crops to make them more susceptible to pests and diseases. Chemically grown foods have adversely affected human health. The scientific community all over the world is desperately looking for an 'economically viable, socially safe and environmentally sustainable' alternative to the agro-chemicals.

Vermiculture biotechnology promises to usher in the 'Second Green Revolution' by completely replacing the destructive agro-chemicals which did more harm than good to both the farmers and their farmland during the 'First Green Revolution' of the 1950 - 60's. Earthworms restore and improve soil fertility and boost crop

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productivity by the use of their excreta - 'vermicast'. They excrete beneficial soil microbes, and secrete polysaccharides, proteins and other nitrogenous compounds into the soil. They promote soil fragmentation and aeration, and bring about 'soil turning' and dispersion in farmlands. Worm activity can increase air-soil volume from 8 - 30%. One acre of land can contain up to 3 million earthworms, the activities of which can bring up to 8 - 10 tons of 'top soil' to the surface every year. Presence of worms improves water penetration in compacted soils by 50% (Kangmin and Peizhen, 2010; Ghabbour, 1996; Bhat and Kambhata, 1994). A study in India showed that an earthworm population of 0.2 - 1.0 million per hectare of farmlands can be established within a short period of three months. On an average 12 tons/ hectare/year of soil or organic matter is ingested by earthworms, leading to upturning of 18 tons of soil/year, and the world over at this rate it may mean a 2 inches of fertile humus layer over the globe (Bhawalkar and Bhawalkar, 1993; White, 1997).

Earthworms have over 600 million years of experience in waste and land management, soil improvement and farm production. No wonder, Charles Darwin called them as the 'unheralded soldiers of mankind and farmer's friend working day and night under the soil' (Martin, 1976; Satchell, 1983). Importance of earthworms in growth of pomegranate fruit plants was indicated by the ancient Indian scientist Surpala in the 10th Century A.D. in his epic 'Vrikshayurveda' (Science of Tree Growing) (Sadhale, 1996).

THE CONCEPT OF SUSTAINABLE AGRICULTURE

It is not enough to produce 'sufficient food' to feed the civilization but also to produce a 'high quality of nutritive food' which should be 'safe' (chemical free) and also 'protective' to human health and to produce it in a sustainable manner to ensure 'food security' for all, but most for the poor developing countries in the long term. 'Food Safety and Security' is a major issue everywhere in the world and this urgently needs a change in strategy of farm production.

The new concept of farm production against the destructive 'Chemical Agriculture' has been termed as 'Sustainable Agriculture'. This is about growing 'nutritive and protective foods' with the aid of biological based 'organic fertilizers' without recourse to agro-chemicals. This is thought to be the answer for the 'food safety and security' for the human society in future. The U.S. National Research Council (1989) defined sustainable agriculture as 'those alternative farming systems and technologies incorporating natural processes, reducing the use of inputs of off-farm sources, ensuring the long term sustainability of current production levels and conserving soil, water, energy and farm biodiversity'. It is a system of food production which avoids or largely excludes the use of systematically compounded chemical fertilizers and pesticides and use of environmentally friendly organic inputs.

A POWERFUL GROWTH PROMOTER AND PLANT PROTECTOR

Earthworms vermicompost is a highly nutritive organic fertilizer which is rich in humus, nitrogen (N, 2 - 3%), phosphorus (P, 1.55 - 2.25%), potassium (K, 1.85 - 2.25%), micronutrients, beneficial soil microbes like 'nitrogen-fixing bacteria' and mycorrhizal fungi. This organic fertilizer was scientifically proved as miracle plant growth promoters (Tiwary et al., 1989; Binet et al., 1998, Chaoui et al., 2003; Guerrero, 2010). Kale and Bano (1986) reports as high as 7.37% of nitrogen and 19.58% of phosphorus as P_2O_5 in worm's vermicast.

Furthermore, Suhane (2007) showed that exchangeable potassium (K) was over 95% higher in vermicompost compared with conventional compost. There are also over 60% higher amounts of calcium (Ca) and magnesium (Mg). Vermicompost has very high porosity, aeration, 'drainage' and water holding capacity. The more important is that it contains plant-available nutrients and appears to increase and retain the nutrients for longer period of time. Pajon (Undated) rated it as 4 - 7 times more powerful growth promoter than conventional compost. A matter of still greater agronomic significance is that worms and vermicompost increases biological resistance in plants (due to actinomycetes) and protect them against pest and diseases either by repelling or by suppressing them (Anonymous, 2001; Rodriguez et al., 2000; Edwards and Arancon, 2004). Many studies have shown that the presence of earthworm and its vermicompost resulted in advantages as explained below.

High levels of bio-available nutrients for plants

Earthworms mineralize the nitrogen (N), phosphorus (P), and all essential organic and inorganic elements in the compost to make it bio-available to plants as nutrients (Buchanan et al., 1988). They recycle N in soil in very short time, ranging from 20 - 200 kg N/ha/year and increase nitrogen contents by over 85% (Patil, 1993). After 28 weeks the soil with living worms contained 75 ppm of nitrate nitrogen (N), compared with the controlled soil which had only 45 ppm (Barley and Jennings, 1959). Worms increase nitrogen levels in soil by adding their metabolic and excretory products (vermicast), mucus, body fluid, enzymes and decaying tissues of dead worms (Dash and Patra, 1979; Whalen et al., 1999). Lee (1985) suggested that the passage of organic matter through the gut of worm results in phosphorus (P) converted to more bio-available forms. This is done by both worm's gut enzyme ‘phosphatases’ and by the phosphate solubilizing microorganisms in the worm cast (Satchell and Martin, 1984).

High level of beneficial and biologically active soil microorganisms

Among beneficial soil microbes stimulated by earthworms are nitrogen-fixing and phosphate solubilizing bacteria, the actinomycetes and mycorrhizal fungi. Suhane (2007) found that the total bacterial count was more than 10^{10}/gr of vermicompost. It included Actinomycetes, Azotobacter, Rhizobium, Nitrobacter and Phosphate Solubilizing Bacteria, ranging from 10^2 - 10^6 per g of vermicompost.

Humus

Vermicompost contains ‘humus’ excreted by worms which makes it markedly different from other organic fertilizers. It takes several years for soil or any organic matter to decompose to form humus while earthworms secrete humus in its excreta. Without humus plants cannot grow and survive. The humic and fulvic acids in humus are essential to plants in four basic ways: 1). Enables plant to extract nutrients from soil; 2). Help dissolve unresolved minerals to make organic matter ready for plants to use; 3). Stimulates root growth; and 4). Helps plants overcome stress. Presence of humus in soil even helps chemical fertilizers to work better (Kangmin, 1998; Kangmin and Peizhen, 2010). This was also indicated by Tomati et al. (1985) and Canellas et al. (2002) found that humic acids isolated from vermicompost enhanced root elongation and formation of lateral roots in maize roots. Humus in vermicast extracts ‘toxins’, ‘harmful fungi and bacteria’ from soil and protects plants.

Plant growth hormones

Edwards and Burrows (1988) and Atiyeh et al. (2000) speculated that the growth responses of plants from vermicompost appeared more like ‘hormone-induced activity’ associated with the high levels of nutrients, humic acids and humates in vermicompost. Researches show that vermicompost use further stimulates plant growth even when plants are already receiving ‘optimal nutrition’. It consistently improved seed germination, enhanced seedling growth and development, and increased plant productivity significantly much more than would be possible from the mere conversion of mineral nutrients into plant-available forms. Neilson (1965), Tomati et al. (1987, 1995) and Suhane (2007) have also reported that vermicompost contained growth promoting hormone ‘auxins’, ‘cytokinins’ and flowering hormone ‘gibberlins’ secreted by earthworms.

Soil enzymes

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 (Tiwary et al., 1989; Chaoui et al., 2003). They also increase the levels of some important soil enzymes like dehydrogenase, acid and alkaline phosphatases and urease. Urease play a key role in N-cycle as it hydrolyses urea and phosphates bioconvert soil phosphorus into bio-available form for plants.

CONTROLLING PEST AND DISEASE WITHOUT PESTICIDES

Earthworms are both ‘plant growth promoter and protector’. There has been considerable evidence in recent years regarding the ability of earthworms and its 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. Furthermore, the actinomycetes fungus excreted by the earthworms in their vermicast produce chemicals that kill parasitic fungi, such as *Pythium* and *Fusarium* (Edward and Arancon, 2004). Yardim et al. (2006) reported that application of vermicompost reduced the damage by stripted cucumber beetle (*Acalymma vittatum*), spotted cucumber beetle (*Diabotrica undecimpunctata*) and larval hornworms (*Manduca quinquemaculata*) on tomatoes in both green-house and field experiments. There are several plant protection abilities of earthworms. Recently, Newington et al. (2004) have implicated earthworms as influencing the abundance of above-ground herbivores and their natural enemies (crop pests) which they devour.

Ability to 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 (Singh, 1983; Suhane, 2007).

Ability to repel crop pests

There seems to be strong evidence that worms varmicastings sometimes repel hard-bodied pests (Anonymous, 2001). Edwards and Arancon, (2004) 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 (Munroe, 2007).

Ability to suppress plant disease

Arancon et al. (2002) reported that vermicompost application suppressed 20 - 40% infection of insect pests that is, aphids (*Myzus persicae*), mearly bugs (*Pseudococcus spp*.) and cabbage white caterpillars (*Peiris brassicae)* on pepper (*Capiscum annuum*), cabbage (*Brassica oleracea*) and tomato (*Lycopersicum esculentum*).

Furthermore, Edwards and Arancon (2004) have found that the use of vermicompost in crops inhibited the soil-born fungal diseases. They also found significant suppression of plant-parasitic nematodes in field trials with pepper, tomatoes, strawberries and grapes. The 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 that is, by starving them and also by blocking their excess to plant roots by occupying all the available sites. This concept is based on soil food-web studies (http://www.soilfoodweb.com).

In addition, Edwards and Arancon (2004) also reported the disease suppressing effects of applications of 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'.

Meanwhile, Edwards et al. (2007) reported considerable suppression of root knot nematode (*Meloidogyne incognita*) and drastic suppression of spotted spider mites (*Tetranychus* spp.) and aphid (*M. persicae*) in tomato plants after application of vermicompost teas (vermiwash liquid). They are serious pests of several crops.

Vermiwash - A growth promoting and plant protecting

The brownish-red liquid which collects in all vermcomposting practices is also 'productive' and 'protective' for farm crops. This liquid partially comes from the body of earthworms (as worm's body contain plenty of water) and is rich in amino acids, vitamins, nutrients like nitrogen, potassium, magnesium, zinc, calcium, iron and copper and some growth hormones like 'auxins', 'cytokinins'. It also contains plenty of nitrogen-fixing and phosphate solubilising bacteria (nitrosomonas, nitrobacter and actinomycetes). Vermiwash has great 'growth promoting' as well as 'pest killing' properties. Buckerfield at al. (1999) reported that weekly application of vermiwash increased radish yield by 7.3%. Thangavel et al. (2003) also observed that both growth and yield of paddy increased with the application of vermiwash and vermicast extracts.

Farmers from Bihar in North India reported growth promoting and pesticidal properties of this liquid. They used it on brinjal and tomato with excellent results. The plants were healthy and bore bigger fruits with unique shine over it. Spray of vermiwash effectively controlled all incidences of pests and diseases significantly reduced the use of chemical pesticides and insecticides on vegetable crops and the products were significantly different from others with high market value (Suhane et al., 2008; Sinha et al., 2009).

George (2007) studied the use of vermiwash for the management of 'Thrips' (*Scirtothrips dorsalis*) and 'Mites' (*Polyphagotarsonemus latus*) on chilli amended with vermicompost to evaluate its efficacy against thrips and mites. Vermiwash was used in three different dilutions e.g. 1:1, 1:2 and 1:4 by mixing with water both as 'seedling dip' treatment and 'foliar spray'. Six rounds of vermiwash sprays were taken up at 15 days interval commencing at two weeks after transplanting. Among the various treatments, application of vermicompost at the rate of 0.5 ton/ ha with 6 sprays of vermiwash at 1:1 dilution showed significantly lower incidence of thrips and mites attack. The treatment resulted in very low mean population of thrips and mites, namely 0.35 and 0.64 per leaf, respectively. In addition, the application of vermicompost gave a highest yield (2.98 quintal/ha). Giraddi et al. (2003) also reported significantly lower pest population in chilli applied with vermiwash (soil drench 30 days after transplanting, and foliar spray at 60 and 75 days after transplanting) as compared to untreated crops.

Suthar (2010 a) has reported hormone like substances in vermiwash. He studied its impact on seed germination, roots and shoots length in *Cyamopsis tertagonoloba* and compared with urea solution (0.05%). Maximum germination was 90% on 50% vermiwash as compared to 61.7% in urea solution. Maximum root and shoot length was 8.65 and 12.42 cm on 100% vermiwash as compared to 5.87 and 7.73 on urea. The seedlings with 100% vermiwash foliar spray showed the maximum level of total protein and soluble sugars in their tissues.

STUDIES ON THE ROLE OF VERMICULTURE BIOTECHNOLOGY

There have been several reports that earthworms and their excretory products (vermicast) can induce excellent plant growth and enhance crop production:

a) Baker et al. (1997) found that the earthworms (*Aporrectodea trapezoids*) increased growth of wheat crops (*Triticum aestivum*) by 39%, grain yield by 35%, lifted protein value of the grain by 12% and also resisted crop diseases as compared to the control. Baker et al. (2006) also reported that in Parana, Brazil invasion of earthworms significantly altered soil structure and water holding capacity. The grain yields of wheat and soybean increased by 47 and 51%, respectively, Palainsamy (1996) reported that earthworms and its vermicast improve the growth and yield of wheat by more than 40%. Bhatia et al. (2000), Sharma (2001) and Suthar (2005, 2010b) also reported better yield and growth in wheat crops applied with vermicompost in soil.
b) Kale et al. (1992) who studied on the agronomic impacts of vermicompost on rice crops (*Oryza sativa*) reported that greater population of nitrogen fixers, actinomycetes and mycorrhizal fungi inducing better nutrient uptake by crops and better growth. Jeyabal and Kuppuswamy (2001) studied the impact of vermicompost on rice-legume cropping system in India. They showed that the integrated application of vermicompost, chemical fertilizer and biofertilizers (*Azospirillum* and phosphor-bacteria) increased rice yield by 15.9% over chemical fertilizer used alone. Guerrero and Guerrero (2008) also reported good response of upland rice crops grown on vermicompost.
c) Buckerfield and Webster (1998) found that worm-worked waste (vermicompost) boosted grape yield by two-fold as compared to chemical fertilizers. Treated vines with vermicompost produced 23% more grapes due to 18% increase in bunch numbers. Furthermore, a study on grapes carried out on 'eroded wastelands' in Sangli district of Maharashtra, India, treated with vermicasting at the rate of 5 tons/ha showed that the grape harvest was normal with improvement in quality, taste and shelf life. The soil analysis showed that within one year pH came down from 8.3 - 6.9 and the value of potash increased from 62.5 - 800 kg/ha. There was also marked improvement in the nutritional quality of the grape fruits (Sinha et al., 2009).
d) Arancon et al. (2004) studied the agronomic impacts of vermicompost and inorganic (chemical) fertilizers on strawberries (*Fragaria ananasa*) when applied separately and also in combination. Significantly, the 'yield' of marketable strawberries and the 'weight' of the 'largest fruit' was 35% greater on plants grown on vermicompost as compared to inorganic fertilizers in 220 days after transplanting. Also, there were 36% more 'runners' and 40% more 'flowers' on plants grown on vermicompost. Also, farm soils applied with vermicompost had significantly greater 'microbial biomass' than the one applied with inorganic fertilizers. Singh et al. (2008) also reported that vermicompost increased the yield of strawberries by 32.7% and also drastically reduced the incidence of physiological disorders like albinism (16.1 - 4.5%), fruit malformations (11.5 - 4%), grey mould (10.4 - 2.1%) and diseases like Botrytis rot. By suppressing the nutrient related disorders, vermicompost application increased the yield and quality of marketable strawberry fruits up to 58.6%.
e) Webster (2005) studied the agronomic impact of vermicompost on cherries and found that, it increased yield of 'cherries' for three (3) years after 'single application' inferring that the use of vermicompost in soil builds up fertility and restore its vitality for long time and its further use can be reduced to a minimum after some years of application in farms.
f) Studies on the production of important vegetable crops like tomato (*L. esculentus*), eggplant (*Solanum melangona*) and okra (*Abelmoschus esculentus*) have yielded very good results (Guerrero and Guerrero, 2006; Gupta et al., 2008; Sinha et al., 2009). Agarwal et al. (2010) studied growth impacts of earthworms (with feed materials), vermicompost, cow dung compost and chemical fertilizers on okra (*A. esculentus*). Worms and vermicompost promoted excellent growth in the vegetable crop with more flowers and fruits development. But the most significant observation was drastically less incidence of 'Yellow Vein Mosaic', 'Color Rot' and 'Powdery Mildew' diseases in worm and vermicompost applied plants. Meena et al. (2007) studied the growth impacts of organic manure (containing earthworm casts) on garden pea (*Pisum sativum*) and compared with chemical fertilizers. It produced higher green pod plants, higher green grain weight per plant, higher percentage of protein content and carbohydrates and higher green pod yield (24.8 - 91%) as compared to chemical fertilizer.
g) Baker et al. (2006) reported a study of earthworms on soil properties and herbage production in a mined field micro-plot experiment in Ireland. The presence of earthworms had little effect on herbage production in the first year. But total herbage yield was 25% greater in the second year and 49% greater in the third year in plots receiving annual topdressing of cattle slurry with earthworms compared to similarly-treated plots with cattle slurry but without earthworms. The conclusion drawn from such study is that earthworms in soil are paramount in plant productivity. In the first year, it took the worm to restore and condition the mined soil. By second year, enough nutritive 'vermicast' got accumulated in soil and improved soil fertility which promoted higher herbage yield (25 %). In the third year, the worm population in soil increased significantly leading to higher excretion of vermicast, higher soil fertility and higher plant production (49%). In a bucket experiment they found that the cumulative herbage yields over a period of 20 months was 89% higher in buckets with earthworms added with cattle manure as compared to those without earthworms but only with cattle manure, and only 19% higher in buckets receiving exclusive chemical fertilizers.

h). Ansari (2008) studied the production of potato (*S. tuberosum*) by application of vermicompost in a reclaimed sodic soil in India. With good potato growth, the sodicity (ESP) of the soil was also reduced from initial 96.74 - 73.68 in just about 12 weeks. The average available nitrogen (N) content of the soil increased from initial 336.00 - 829.33 kg/ha.

i) Sinha et al. (2009) reported that farmers at Phaltan in Satara district of Maharashtra, India, applied live earthworms to their sugarcane crop grown on saline soils irrigated by saline ground water. The yield was 125 ton/ha of sugarcane and there was marked improvement in soil chemistry. Within a year, there was 37% more nitrogen, 66% more phosphates and 10% more potash. The chloride content was less by 46%.

EXPERIMENTAL STUDIES TESTIFYING THE VALIDITY OF VERMICULTURE BIOTECHNOLOGY

Study 1: Potted corn crops (Griffith University, Australia)

The trial tested three treatments with three replicates, namely (1) worms only, (2) chemical fertilizers, and (3) 200 gm vermicompost with 25 worms. Soluble chemical fertilizers 'Thrive' was used. Approximately, 8 gm of chemicals was dissolved in 4.5 L of water. It had total nitrogen of 15%, phosphorus of 4%, potassium of 26%, and a combination of essential micronutrients. Three applications were made during entire growth period, while the worms and vermicompost was applied only once. The plastic pots containing 7 kg of soil were used to grow the plants (Photo 1). They were all done in flower pots with 7 kg soil. Results are shown in Table 1 and Figure 1.

The results showed that corn plants with worms, and vermicompost and those on chemical fertilizers exhibited parallel growth for some weeks after which those on vermicompost picked up faster. While, those on chemicals grew only 5 cm in 7 weeks (week 12 - 19) those on vermicompost grew by 15 cm within the same period. Once the worms build up the soil fertility, it enhances growth rapidly. Earthworms alone (without feed) in soil could not promote growth well. They need feed materials to produce growth promoting metabolic products which are vermicast and humus containing rich NKP and micronutrients and more significantly 'growth hormones' auxins and gibberlins). It takes several years to form 'soil humus' through slow disintegration of organic matters but the earthworms excrete them in their cast (Sinha et al., 2009).

Study 2: Potted corn crops (Griffith University, Australia)

It had 3 treatments with 3 replicas of each. The dose of vermicompost and number of worms were 'doubled' (400 gm and 50 Nos.). Conventional compost (cow manure) was used. Feed materials (crushed dry leaves) were added with worms) (Photo 2). Only one application of each compost was made. Results are shown in Table 2 and Figure 2.

KEY OBSERVATIONS, FINDINGS AND DISCUSSION

Corn plants on vermicompost achieved rapid and excellent growth and attained maturity very fast. Between weeks 6 - 11, there was massive vegetative growth with broad green leaves. Significantly, corn plants with worms and feed were more green and healthy than those on conventional compost and superseded them finally in the 14th week. Addition of feed material increased the metabolic activities of worms producing vermicast, humus and growth hormones which reinforced growth. Also, plants grown on vermicompost matured faster and there was appearance of 'male reproductive structure' within the period of study (Sinha et al., 2009).

Study 3: Potted wheat crops (Griffith University, Australia)

It had three treatments with two replicas of each and a control. Treatment 1 had chemical fertilizers (NPK+ Mg+ S+ Fe + B + Zn), treatment 2 conventional compost (cow manure) and treatment 3 vermicompost. They were all done in flower pots (Photo 3) with 7 kg soil. Results are shown in Table 3 and Figure 3.

Wheat crops maintained very good growth on vermincompost and earthworms from the very beginning and achieved maturity in 14 weeks. The striking rates of seed germination were very high; nearly 48 h (2 days) ahead of others and the numbers of seed germinated were also high by nearly 20%. Plants were greener and healthier over others, with large numbers of tillers and long seed ears were formed at maturity (Photo 4). Seeds were healthy and nearly 35 - 40% more as compared to plants on chemical fertilizers. What they achieved in just 5 weeks was achieved by others in 10 weeks. More significant was that the pot soil with vermicompost was very soft and porous and retained more moisture. Pot soil with chemicals were hard and demanded more water frequently (Chauhan and Valani, 2008; Sinha et al., 2009).

Study 4: Farmed wheat crops (Rajendra Agriculture University, India)

This study was made in India under collaborative research program. Cattle dung compost made on farms was used as conventional compost. Vermicompost was also prepared on farm from food and farm wastes including cattle dung. The results are shown in Table 4 and Figure 4.

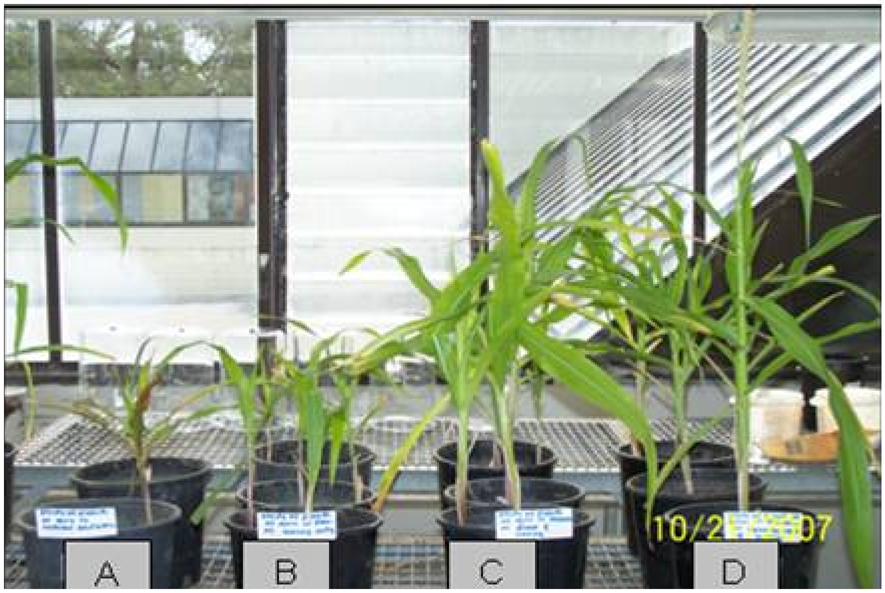

Photo 1. Growth of corn plants after 12 Weeks, Vermicompost vis-à-vis chemical fertilizers. (A) Control, (B) Earthworms Only (25 Nos.), (C) Chemical Fertilizers, (D) Vermicompost (200 gm) and Earthworms (25 Nos.).

Table 1. Growth of corn plants promoted by earthworms, worms with vermicompost and chemical fertilizers (EW = 25 Nos.; VC 200 gm; CF = 8 gm in 4.5 L water; pot soil 7 kg; Av. growth in cm).

Treatment	Week 4	Week 6	Week 12	Week 15	Week 19
Control	31	44	46	48 (P and NL)	53
EW (Only)	40	47	53	53 (G and NL)	56
CF	43	61	87 (G and BL)	88	92
VC + EW	43	58	90 (DG and BL)	95 (AM)	105

EW = Earthworms; VC = vermicompost; CF = chemical fertilizers; G = green; DG = deep green; BL= broad leaves; P= pale ; NL = narrow leaves; AM= achieved maturity. Growth was studied in terms of health and height of plants, color and texture of leaves maturity and appearance of reproductive structures which was best in plants grown on vermicompost with worms).

Exclusive application of vermicompost @25 quintal/ha boosted yield 18% higher over the chemical fertilizers. On conventional compost applied @ 100 Q/ha (4 times more than vermicompost) the yield was 17% less than that on vermicompost. The requirement of irrigation was also reduced in vermicompost applied farm plots by 30 - 40%. Test results indicated better availability of essential micronutrients and useful microbes in vermicompost applied soils. Most remarkable was the significantly reduced (nearly 75%) incidences of ‘pest and disease attack’ on vermicompost grown crops (Sinha et al., 2009).

Study 5: Potted tomato plants (Griffith University, Australia)

It had four treatments and a control with three replicas of each. Treatment 1 had chemical fertilizers (NPK + Mg + S + Fe + B + Zn), treatment 2 conventional compost (composted cow manure), treatment 3 vermicompost and treatment 4 vermicompost with earthworms (Photo 5). They were all done in flower pots with 7 kg soil. Results are shown in Table 5.

Tomato plants on vermicompost and vermicompost with worms maintained very good growth from the very beginning. Number of flowers and fruits per plant were also significantly high as compared to those on agrochemicals and conventional compost. Presence of earthworms in soil made a significant difference in ‘flower and fruit formation’ in tomato plants. Very disappointing was the results of composted cow manure obtained from the market. It could not compete with vermicompost (indigenously prepared from food waste) even when applied in ‘double dose’.

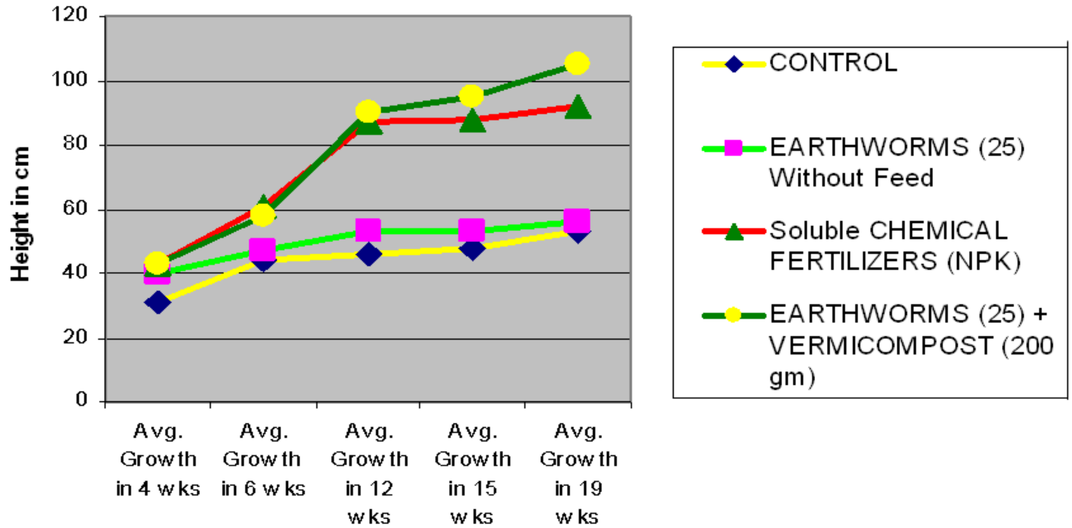

Figure 1. Graph showing growth performances of corn crops by earthworms, worms with vermicompost and the chemical fertilizers in 19 weeks period.

Photo 2. Growth of corn plants after 6 weeks, vermicompost vis-à-vis conventional compost. (A) EW (50 Nos.) + Feed (400 gm), (B) CC (400 gm), (C) VC (400 gm).

Table 2. Growth of corn crops promoted by earthworms with feed material, vermicompost and conventional compost (EW = 50 Nos.; VC = 400 gm; CC = 400 gm; Pot Soil 7 Kg; Av. Growth in cm).

Treatment	Week 3	Week 4	Week 6	Week 9	Week 14
EW + F	41	49	57 (G and NL)	64	82 (DG, BL and AM)
CC	42	57	70 (P and NL)	72.5	78 (LG and AM)
VC	53	76	104 (DG and BL)	120 (AM)	135

EW = Earthworms; F = feed material; CC = conventional compost; VC = vermicompost; G = green; P = pale; NL= narrow leaves; DG = deep green; LG = light green; BL = broad leaves; AM = achieved maturity; (Growth was studied in terms of health and height of plants, color and texture of leaves, maturity and appearance of reproductive structures which was best in plants grown on vermicompost).

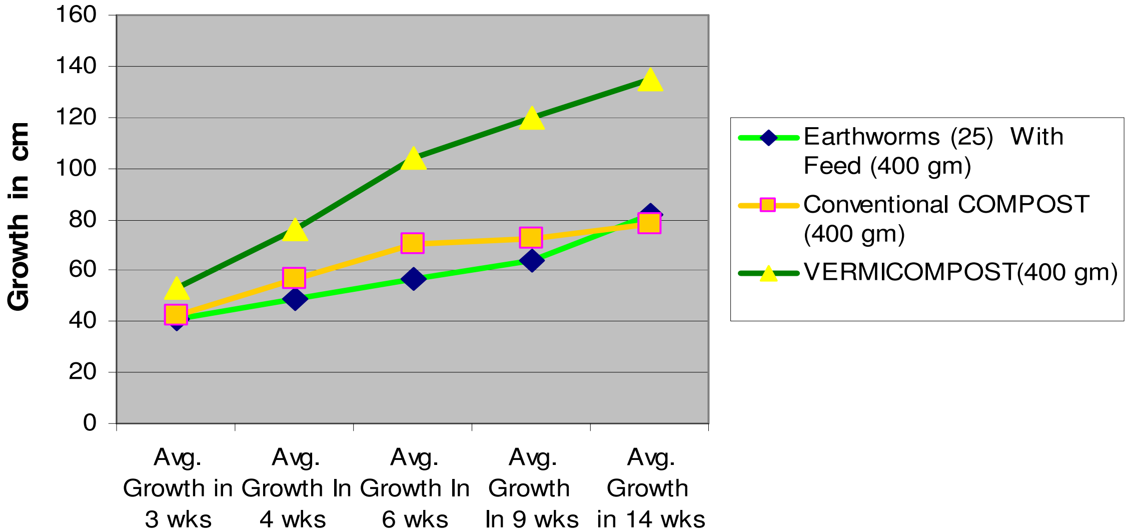

Figure 2. Graph showing growth performances of corn crops by earthworms, vermicompost and the conventional compost in 14 weeks period.

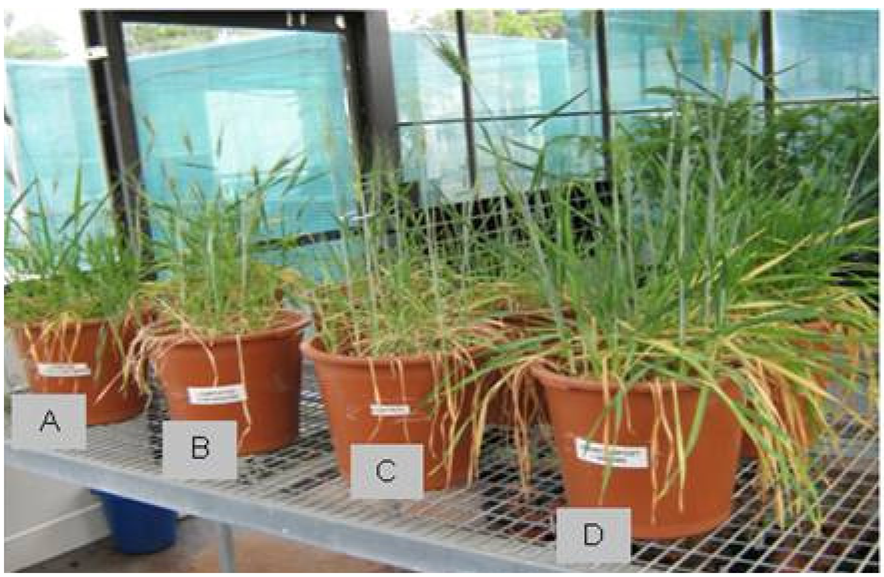

Photo 3. Growth of wheat plants after 12 Weeks. (A) CF (5 gm × 3), (B) CC (500 gm), (C) Control, (D) VC (500 gm) + earthworms (25).

Table 3. Growth of wheat crops promoted by vermicompost, conventional compost and chemical fertilizers (VC 500 gm, EW 25 Nos., CC 500 gm, CF 5 gm × 3 times, Av. Growth in cm).

Treatment	Week 1	Week 5	Week 10	Week 12
Control	17	22	26	26
CC	17	31(LG)	32	32 (AM)
CF	16	36 (DG)	39	43 (AM)
VC + EW	19	39 (DG)	43 (HT and AM)	47 (LSE)

CC = Conventional compost; CF = chemical fertilizer; VC = vermicompost; EW = earthworms; LG = light green; DG = deep green; HT = high tillers; AM = achieved maturity; LSE = long seed ears (Growth was studied in terms of germination of seeds and seedling formations, health and height of plants, color and texture of leaves, number of tillers, maturity and appearance of reproductive structures which was best in plants grown on vermicompost with worms).

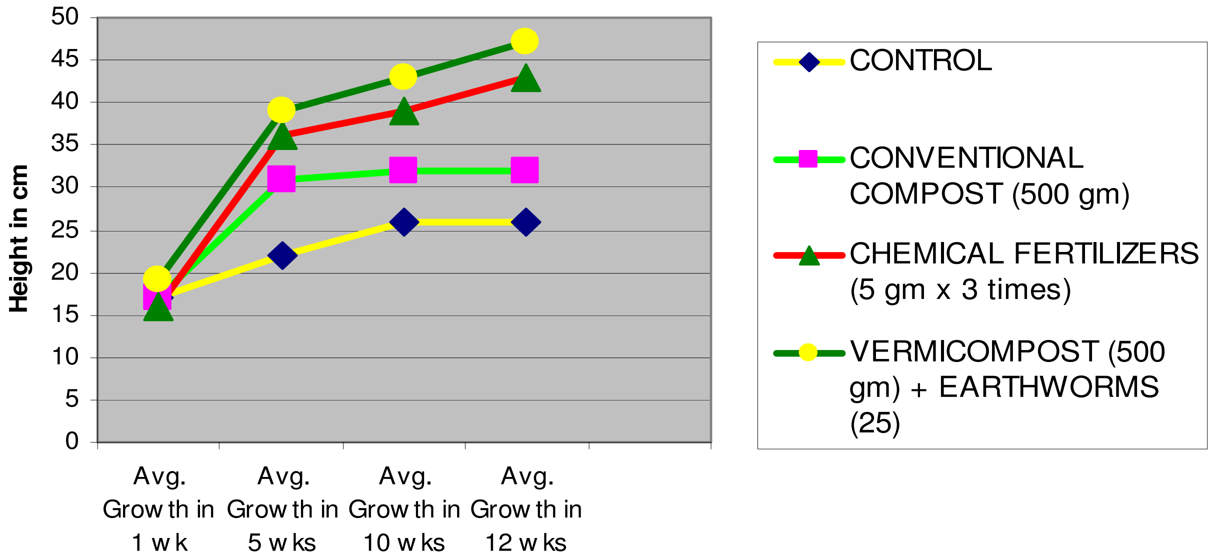

Figure 3. Graph showing growth performances of wheat crops by vermicompost and earthworms, conventional compost and chemical fertilizers in 12 weeks period.

Photo 4. Development of seeds in ears after 14 weeks. (A).Vermicompost and worms, (B) Chemical fertilizers (C) Conventional Compost, (D) Control.

Study - 6: Potted egg-plants (Griffith University, Australia)

All treatments were like tomato plants (Photo 6). Results are shown in Table 6.

Egg-plants on vermicompost and vermicompost with live worms maintained very good growth from the beginning and achieved more than 40% growth over

Table 4. Yield of farmed wheat crops promoted by vermicompost, conventional compost and chemical fertilizers in exclusive applications and in combinations.

Treatment	Input / hectare	Yield per hectare (Q / ha)
Control	(No Input)	15.2
Vemicompost (VC)	25 Quintal VC / ha	40.1
Conventional compost (CC)	100 Quintal CC / ha	33.2
Chemical fertilizers (CF)	NPK (120:60:40) kg / ha	34.2
CF + VC	NPK (120:60:40) kg / ha + 25 Q VC / ha	43.8
CF + CC	NPK (120:60:40) kg / ha + 100 Q CC / ha	41.3

Source: Suhane et al. (2008); Sinha et al. (2009): N = Urea; P = Phosphate; K = Potash (In Kg / ha).

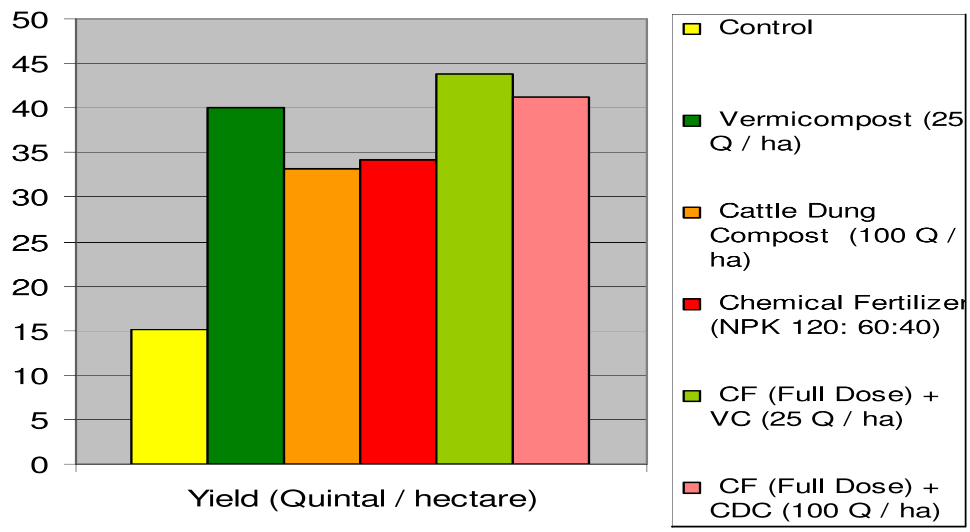

Figure 4. Yield of farmed wheat crops promoted by vermicompost, conventional compost and chemical fertilizers in exclusive applications and in combinations.

Photo 5. Growth and development of tomato plants after 10 weeks. (A) Control, (B) Chemical Fertilizers, (C) Conventional Compost, (D) Vermicompost.

Table 5. Growth of tomato plants promoted by vermicompost, vermicompost with earthworms, conventional compost (composted cow manure) and chemical fertilizers (All seedlings measured 5 cm; average growth in cm).

Parameters studied	Control fertilizers (5 gm × 3 times)	Chemical cow manure (500 gm)	Composted (250 gm)	Vermicompost (250 gm)	Vermicompost (250 gm) + Earthworms (50)
Avg. growth in 2 Wks.	10	16	16	18	19
Avg. growth in 4 Wks.	30	49	35	60	60
Number of flowers (Wk.5)	8	17	10	27	31
Avg. growth in 6 Wks.	40	70	51	118	125
Avg. growth in 8 Wks.	48	108	53	185	188
Number of fruits (Wk. 9)	4	16	6	22	27
Avg. growth after 10 Wks.	50	130	53	207	206

Photo 6. Growth and development of egg-plants after 10 weeks. (A) Control, (B) Chemical fertilizer, (C) Conventional Compost, and (D) Vermicompost.

Table 6. Growth of egg-plants promoted by vermicompost, vermicompost with earthworms, conventional compost (composted cow manure) and chemical fertilizers (All seedlings measured 3.5 cm; Average growth, size of leaf and fruit in cm).

Parameters studied	Control	Chemical fertilizers (5 gm × 3 times)	Composted cow manure (500 gm)	Vermicompost (250 gm)	Vermicompost (250 gm) + Earthworms (50)
Avg. growth in 2 wks.	6	8	8	10	10
Avg. growth in 4 wks.	10	20	18	28	26
Avg. growth in 6 wks.	16	48	40	72	65
No. of flowers(After wk 6)	0	1	1	3	4
Av. size of leaf	6 × 10	10 × 13	8 × 11	15 × 22	13 × 18
Avg. growth in 8 wks.	28	60	50		
Avg. growth after 10 wks.	32	76	70		
Number of fruits (wk. 10)	0	1	1	3	4
Size of Av. fruit	0	3 × 5	3 × 4	6 × 8	12 × 7

Source: Sinha and Valani (2009).

chemicals and conventional compost. Number of flowers and fruits per plant by week 10 were not much but definitely more than agrochemicals and conventional compost. However, the vermicompost and the presence of live earthworms in soil made significant difference in the 'size' of fruits and leaves in egg-plants. Again, very disappointing was the results of composted cow manure even when applied in 'double dose' than the vermicompost.

ADVANTAGES OF VERMICULTURE BIOTECHNOLOGY IN FARM PRODUCTION

There are several economic and environmental advantages of the use of vermiculture over chemical agriculture in farm production. Besides increasing yield, it produces chemical-free organic foods and also restores the natural fertility of soil over the years. It also significantly reduces the need of water for irrigation and use of chemical pesticides as plants become more resistant to pests and diseases. The cost of food production is also significantly reduced for farmers. It benefits both the 'producers' and the 'consumers' of food.

Can replace destructive chemical fertilizers from farm production

Vermicompost has potential to replace the destructive chemical fertilizers from farm production. It can alone produce food over 30 - 40% higher than those produced by chemical fertilizers. It is at least 75% cheaper than the chemical fertilizers which are produced in factories from varnishing petroleum products generating huge waste and pollution. Vermicompost is produced from 'waste' which is in plenty all over the world.

Produce nutritive, chemical-free farm products with greater storage value

The biggest advantage of great social significance is that the food produced is completely organic 'safe and chemical-free' and also more 'nutritive'. Use of vermicompost enhances size, color, smell, taste, flavour and keeping quality (storage value) of flowers, fruits, vegetables and food grains.

Restore natural fertility of farmland soil

Upon successive years of application, vermicompost build-up the soils 'natural fertility' improving its total physical (porous), chemical (rich in nutrients) and biological (beneficial soil microbes) properties. It also regenerates a rich population of worms in the farm soil from the cocoons which further help improve soil fertility and subsequently lesser amount of vermicompost is required to maintain a good yield and productivity. On the contrary, with the continued application of chemical fertilizers over the years the 'natural fertility of soil is destroyed' and it becomes 'addict'. Subsequently, greater amount of chemicals are required to maintain the same yield and productivity of previous years.

Reduces water for farm irrigation

Vermicompost has very 'high porosity', 'aeration', 'drainage' and 'water holding capacity' and thus, its application in soil reduces the requirement of water for irrigation by 30 - 40%.

Kills pests without pesticides

Another big advantage of great social and environmental significance of VBT is that vermicompost 'suppress/ eradicate plant pests and disease' in crops including the soil-born fungal diseases. In field trials with pepper, tomatoes, strawberries and grapes significant suppression of plant-parasitic nematodes has been found. There is also significant decrease in arthropods (aphids, buds, mealy bug, and spider mite) populations with 20 and 40% vermicompost additions (Edwards and Arancon, 2004). Humus in vermicast extracts 'toxins', 'harmful fungi and bacteria' from soil and protects plants. Actinomycetes in vermicast induce 'biological resistance' in plants against pests and diseases. As such, use of vermicompost significantly reduces the need for 'chemical pesticides'. These studies indicated over 75%.

EARTHWORM BIOMASS: AS VALUED BY-PRODUCTS OF VBT

In any vermiculture practice, earthworms biomass comes as a valuable by-product and they are good source of nutritive 'worm meal'. They are rich in proteins (65%) with 70 - 80% high quality essential amino acids 'lysine' and 'methionine' and are being used as feed material to promote 'fishery' and 'poultry' industry and even for manufacture of 'protein food' for human consumption. They are also finding new uses as a source of 'life-saving medicines' for treatment of cardiovascular diseases and some forms of cancer from their enzymes (lumbrokinase) and for production of 'antibiotics' from their ceolomic fluid which has anti-pathogenic properties. The biological compounds from earthworms are also finding new uses as source for production of rubbers, lubricants, cosmetics and detergents. They are all biodegradable and hence environmentally sustainable (Sinha, 2010; Sinha et al., 2010 a).

CONCLUSIONS AND REMARKS

Earthworms and its vermicompost works like 'miracle growth promoter' and is nutritionally superior to the conventional compost and chemical fertilizers. Reduced incidence of 'pest and disease attack', and 'better taste of organic food products especially 'fruits and vegetables' grown with vermiculture are matter of great socio-economic and environmental significance (Hand, 1988; Lee, 2003). Presence of earthworms in soil particularly makes a big difference in growth of flowering and fruit crops and significantly aid in fruit development. The 18% increase in yield of wheat crops over chemical fertilizers in their farm studies made in India has great economic and agronomic significance.

Use of vermicompost over the years build up the soil's physical, chemical and biological properties restoring its natural fertility. Subsequently, reduced amount of vermi-compost is required to maintain productivity. VBT will truly bring in 'economic prosperity' for the farmers, 'ecological security' for the farms and 'food security' for the people. With the growing global popularity of 'organic foods' which became a US $ 6.5 billion business every year by 2000, there will be great demand for earthworms and vermicompost in future (Sinha et al., 2010b).

The 'natural control of crop pests' influenced by earthworms seems particularly fruitful research area to be pursued. More study is required to develop the potential of 'vermiwash' as a sustainable, non-toxic and environ-mentally friendly alternative to the 'chemical pesticides'. Earthworms are justifying the beliefs and fulfilling the dreams of Charles Darwin who called earthworms as 'friends of farmers' and that of Anatoly Igonin of Russia who said 'Earthworms create soil and improve soil's fertility and provides critical biosphere's functions: disinfecting, neutralizing, protective and productive'.

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