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Vermiculture for Organic Horticulture: Producing Chemical-Free, Nutritive & Health Protective Foods by Earthworms

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***A*bstract:**Earthworms have fed the world as ‘farm managers’ since mankind arrived on earth. Earthworm's vermicompost is scientifically proving to be an ‘extraordinary powerful growth promoters and protectors’ for crops (5-7 times over other bulky organic fertilizers and 20-40 % higher over chemical fertilizers). They are rich in NKP, micronutrients, beneficial soil microbes like ‘nitrogen-fixing’ and ‘phosphate solubilizing’ bacteria, ‘mycorrhizal fungi’, humus and growth hormones – auxins, gibberlins and cytokinins. It has very high ‘porosity’, ‘aeration’, ‘drainage’ and ‘water holding capacity’. It also protects plants against various pests and diseases either by suppressing or repelling them or by inducing biological resistance in plants. ‘Vermiwash’ (liquid from the body of worms) and the ‘vermicompost tea’ (solution of vermicompost) also work as very ‘powerful bio-pesticides’ eliminating the use of toxic chemical pesticides. Presence of live earthworms in soils has been found to significantly influence the development of quality of fruits in vegetable & fruit crops.

Earthworms and vermicompost can boost horticultural production without agrochemicals. It will provide several social, economic and environmental benefits to the society by way of producing ‘chemical-free’ safe, ‘nutritive and health protective’ (rich in minerals & antioxidants) foods (even against some forms of cancers) for the people; salvaging human wastes and replacing the dangerous ‘agrochemicals’ from the face of earth. Use of vermicompost in farms also ‘sequester’ huge amounts of atmospheric carbon (assimilated by green plants during photosynthesis) and bury them back into the soil improving the soil fertility, preventing erosion or compaction and also reducing greenhouse gas & mitigating global warming.

Keywords: Earthworms & Vermicompost Promotes High Crop Yield; Vermicompost Protects Plants from Pests & Diseases; Vermicompost Enhance Antioxidants in Fruits & Vegetables Protective Against Cancers & Heart Diseases; Use of Vermicompost Sequester Carbon in Soil & Mitigate Global Warming

1. Introduction

1.1 Agrochemicals & Chemically Produced Foods Slow Poison for Man & Environment

Agrochemicals 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 destroyed the ‘physical, chemical & the biological properties’ of soil over the years of use. 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 and diseases. Over the years it has worked like a ‘slow poison’ for the farm soil and the society.

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 all over the world. According to UNEP and WHO some 25 million farmers and agricultural workers are poisoned by pesticides every year and nearly 3 million people suffer from ‘acute pesticide poisoning’ and some 10 to 20 thousand people die every year from it in both the developed and the developing countries (Rangam, 2001).

Adverse effects of agro-chemicals on the health of farmers using them and the society consuming the chemically grown food have now started to become more evident all over the world. Fruits and vegetables are the foods that receive the highest doses of pesticides. US have some 600 pesticides in use today (Jones, 1999). US scientists predict that up to 20,000 Americans may die of cancer, each year, due to the low levels of ‘residual pesticides’ in the chemically grown food (UNEP / GEMS, 1992).

The US Agriculture Department showed that 73 % of the food grown by agrochemicals had residues from at least ‘one pesticide’ and were 6 times as likely as ‘organically grown foods’ to contain multiple pesticide residues. Jones (1999) reported 35 % of the food purchased in US has detectable pesticides levels, 1-3% above the legal tolerance levels. Heaton (2001) reported 48 % of the fruits and vegetables in UK have detectable pesticides residues. Many of these chemical residues remain on produce after washing and some are taken up by the entire plant and contaminate the entire flesh. Some 53 fruits and vegetables have been identified which have the most and least ‘pesticides residues after ‘washing and peeling’ as pesticides can even penetrate the skins. Apples top the list with 92 % containing two or more pesticides as more pesticides are used after the harvest for longer shelf life to fruits. Apples have been found to contain 13 times the average residue levels and carrots can have 29 times the average (Heaton, 2001).This is followed by Celery, Strawberries, Peaches, Spinach, Grapes, Potatoes and Lettuce. ’Exposures to these chemicals is linked with serious diseases and developmental disorders like ‘Nervous System Disorders’, ‘Immune System Suppression’, Breast and Other Cancers’ ‘Reproductive Damages’, ‘Impairment of Brain Development in Children’ and ‘Disruption of Hormonal Systems’ (Lloyd, 2011).

Studies indicate that there is significant amount of ‘residual pesticides’ contaminating our food stuff long after they are taken away from farms for human consumption. American studies found detectable levels of DDT in 17 % of carrots tested 20 years after this pesticide was banned in US (Heaton, 2001). In an Indian study vegetable samples were contaminated 100% with HCH and 50 % with DDT. Bhatnager and Sharma (1993) reported pesticide residues in wheat flour samples. Contamination with HCH was 70%, Heptachlor 2 was 45%, Aldrin 45% and DDT 91%. 60% of water samples were found to be contaminated with Aldrin and 50% with DDT. They were all higher than permissible limits of WHO. In India 41 out of 70 samples of crops contained insecticidal residues of *Phosphamidon, DDVP, Methyl parathion, Malathion, Chlorpyriphos* and three different *Pyrethroids* (Sinha *et al,* 2009 a). Rao (1993) also reported residues of pesticides in meat, fish, eggs, butter, milk including in mother’s milk and human fat in India. The contamination was 100% with HCH, 69% with DDT and 43% with aldrin. In human fat DDT residue ranged from 1.8 ppm in

Lucknow to 22.4 ppm in Ahmedabad; HCH ranged from 1.6 ppm in Bombay to 7 ppm in Bangalore.

1.2 Decline in Nutritional Value of Food

Also, there have also been serious decline in the 'nutritional values' of food produced by agrochemicals in the wake of 'green revolution'. More concerning is that there is significant increase in some undesirable constituents like 'nitrates' and 'free amino acids' in chemically grown crops. Nitrates can potentially endanger health. Davis *et al*. (2004) compared the nutritive contents of 43 garden crops from 1950 to 1999 and found that there were reliable decline in 6 nutrients viz. proteins, calcium, potassium, iron, riboflavin and vitamin C ranging from 6 % in proteins to 38 % in riboflavin. Significantly lower 'carotene' was found in all vegetable crops produced by chemical fertilizers as compared to the organically grown crops (Shankar and Sumathi, 2008).

2. Resolving the Problem: Embarking on Organic Farming

To resolve the various problems related to 'human food safety, nutritional quality and environmental security' a global movement is going on to scientifically revive the traditional 'Organic Farming' systems (Lampkin, 1990). Organic farming largely avoids the use of agrochemicals and high aggressive tillage, use various nutrients of biological origin, employs various methods of biological control of pests and diseases' with restoration of biologically active 'disease-suppressive' fertile soils that can also 'protect plant health' & promote plant growth. Organic foods are significantly rich in 'antioxidants', 'proteins', 'vitamins' and essential 'minerals' & 'protective' to human health even against 'colon cancer' and 'breast cancer' (Olsson, 2006).

Earthworms vermicompost give very 'high food productivity' comparable to or even better than the chemical fertilizers with significantly 'higher nutritional quality' while also improving the physical, chemical and biological properties of soil. Vermicompost is rich in NKP, micronutrients, beneficial soil microbes and also contain plant growth hormones and enzymes secreted by earthworms. It retains nutrients for long time and also 'protects crops from pests and diseases'. It has high 'moisture holding capacity' and hence also reduces the use of water for farm irrigation by 40-50 %. The 'vermiwash' (liquid produced during vermicomposting) and 'vermicompost tea' (fermented solution of vermicompost produced in water) are highly effective 'bio-pesticides' with 100 % control of crop pests and diseases. Ironically, the ancient Indian scientist Surpala (10th Century A.D.) in *Vrikshayurveda* (Science of Tree Growing) also recommended to add earthworms in soil of pomegranate plants to get good quality fruits.

2.1 Organic Farming Produce Nutritive and Health Protective Food for Society

Organically grown fruits & vegetables have been found to be highly nutritious, rich in 'antioxidants' than their chemically grown counterparts and can be highly beneficial for human health (Sinha *et al*., 2011 c). Organic foods have elevated antioxidants levels in about 85 % of the cases studied with average levels being 30% higher compared to chemically grown foods (Anonymous, 2000; Benbrook, 2005; Bourne and Prescott, 2006). Smith (1993) reported high mineral contents in organic foods. Antioxidant vitamins in vegetables are some of the nutrients besides vitamins, minerals, flavonoids and phytochemicals, which contribute greatly to human health protection. Studies indicate that organic foods are high in 'organic acids' and 'poly-phenolic compounds' many of which have potential health benefits like antioxidants (Winter and Davis, 2006) (See table 1). A Japanese study indicated that organic vegetables had 30 % to 10 times higher levels of 'flavonoids' as compared to chemical grown counterparts and with very high 'anti-mutagenic activity'. This is of great significance in preventing some deadly diseases leading to tremendous health benefits (Ren *et. al.*, 2001). The greatest anti-mutagenic activity was found in organic spinach.

Table 1. Nutrients in horticultural crops grown organically

Food Products	Nutrients Studied	Results
Cabbage, Spinach & Onion	Flavonoids	Higher levels of flavonoids
Peach & Pear	Polyphenoloxidase Enzyme Activity, Total Phenolics & Organic Acids	Both had higher levels of phenolic & polyphenoloxidase; organic peach had higher citric & ascorbic acids
Corn & Strawberry	Phenolics & Ascorbic Acids	Higher levels of phenolics & ascorbic acids
Tomatoes	Vitamin C, Carotenoids & Polyphenols	Higher levels of vitamin C Carotenoids & polyphenols
Grapes	Polyphenoloxidase &Diphenolase Enzymes	Polyphenoloxidase did not differ; diphenolase activity was 2 times higher
Apples	Phenolics	Higher phenolics in pulps

Source: Winter & Davis (2006)

Leclerc *et al*., (1991) found that carrot and celeriac roots grown organically were higher in ‘ascorbic acids’ and ‘β –carotene’ contents. Organic potatoes also had significantly high ‘ascorbic acids’ than those produced chemically. In a ten-year comparative study Mitchell (2007) reported levels of flavonoids ‘quercetin’ and ‘kaempferol’ in organic tomatoes were 79 % and 97 % higher than those in chemically grown tomatoes. The levels of flavonoids increased over time. Ismail *et al*. (2003) analyzed β-carotene, vitamin C and riboflavin contents and found that swamp cabbage grown organically was highest in β -carotene, vitamin C and riboflavin contents among the entire samples studied. Worthington (2001) reviewed 41 organic crops and found 27% more vitamin C, 21.1 % more iron (Fe), 29.3 % more magnesium (Mg), and 13.6% more phosphorus (P) in them as compared to chemically grown crops. There was higher iron (Fe), calcium (Ca), magnesium (Mg), phosphorus (P) content in organically grown spinach, tomato, turnip, apple, cabbage, carrots, beetroots, celery, lentil, lettuce, pepper, potato and pears. In addition, organic products had 15.1% less nitrates than their chemical counterparts. Heaton (2001) found 14 studies showing average 50 % lower nitrates in organically grown crops. Shankar & Sumathi (2008) reported significantly higher ‘nitrates’ in chemically grown tomatoes. Nitrates in food is linked with ‘gastric cancer’ (as it can be transformed into nitrosamines in stomach) and ‘infantile methaemoglobinaemia (blue baby syndrome) and may affect DNA alkylation and transcription, teratogenesis (McKnight *et al*.1999).

Schuphan (1974) reported results of 12 years of experiment on vegetables grown organically on ‘Stable Manure’ and ‘Biodynamic Compost’ compared with NPK. The dry matter increased by 23 %, relative protein by 18 %, ascorbic acids (vitamin C) by 28 %, total sugars by 19 %. Among the minerals potassium (K) increased by 18 %, calcium (Ca) by 10 %, phosphorus (P) by 13 % and iron (Fe) by 77 % (in spinach). The undesired constituents in organic crops diminished – nitrates by 93 % (in spinach), free amino acids by 42 % and sodium (Na) by 12 %. He also studied increase of proteins by 4-6 % in spinach, 33-40 % in savoy, 15-24 % in lettuce, 24-37 % in celeriac, 21-25 % in carrots and slightly in potatoes. The reduction in ‘free amino acids’ by organic fertilizers is beneficial for crops. Aphids feeding on plants use this as a source of protein.

Organic fertilizers unequivocally increase one of the most important essential amino acids ‘methionine’ which plays key role in the biological value of proteins. Plant breeders are keen to increase these amino acids genetically.

3. Review of Literature

3.1 Studies on the Impact of Earthworms and Vermicompost on Nutritional & Health Protective Values of Food Produced

Studies made at CSIRO Australia found that the presence of earthworms (*Aporrectodea trapezoids*) in soil lifted protein value of the grain of wheat crops (*Triticum aestivum*) by 12 % (Baker & Amato, 2011). Shankar and Sumathi, (2008) reported significantly higher vitamin C in spinach, tomato, turnip, apple, cabbage, carrots, beetroots, celery, lentil, lettuce, pepper, potato and pears grown on vermicompost. They also studied that tomato grown on vermicompost had significantly higher total antioxidants, total carotene, iron (Fe), zinc (Zn), crude fibre and lycopene content than the other organically grown tomatoes. Vermicompost applied tomato also registered significantly higher 'shelf-life' when stored at room temperature.

3.2 Organically Grown Fruits & Vegetables Reduces the Risk of Some Cancers

More significantly, *in vitro* studies indicate that organically grown fruits & vegetables can reduce the risks of 'cancer' in humans. The 'anti-mutagenic' properties of organic foods carry great significance in this respect (Ren *et. al.*, 2001; Ferguson *et al*., 2004a). A wide range of studies show that antioxidant plant phenolic compounds are 'anti-proliferative' and can prevent or slow tumour progression. Flavonoids can interfere with several steps in the development of cancers. They can protect DNA from oxidative damage that leads to abnormal cell proliferation. They can inhibit 'cancer promoters' and activate 'carcinogen-detoxification system' (Galati and O'Brien, 2004; Galati *et al*., 2004). Recent research has confirmed a specific mechanism leading to the anti-cancer activities of the flavonoids 'resveratrol'. It starves cancer cells by inhibiting the actions of a key protein that helps feed cancer cells (Benbrook, 2005).

Studies of flavonoids extracted from 'cranberries' have revealed significant impacts on a number of human cancer cell lines. It is suggested that flavonoids extracts from 'cranberries' might someday find application as a novel 'anti-cancer' drug (Ferguson *et al.*, 2004b). Extracts from organic strawberries showed higher 'anti-proliferative' activity against 'colon cancer' and 'breast cancer' cells than did the extracts from conventional strawberries (Olsson *et al*., 2006). European study found that the carrot antioxidant 'falcarinol' satisfied six criteria suggested for food intake of antioxidants to reduce the risk of cancers (Benbrook, 2005). Tomato is one of the most 'protective food' due to excellent source of balanced mixture of minerals and antioxidants, including vitamin C, total carotene and lycopene. Lycopene has been found to have preventive effects on 'prostate cancer' in human beings. Lumpkin (2005) reported significantly higher lycopene in tomato grown organically. A potent antioxidant in canola oil has recently been discovered which has 'anti-mutagenic', 'anti-proliferative' and 'anti-bacterial impacts' (Kuwahara *et al*., 2004).

3.3 Protection from Cardiovascular Diseases by Organic Fruits & Vegetables Rich in Antioxidants

A number of studies have suggested that antioxidants vitamins, especially 'vitamin E' and 'beta-carotene' (precursor of vitamin A) may prevent the initiation and progression of cardiovascular diseases. A Japanese study indicated significant protection from coronary heart diseases in women to the relatively high dietary intake of 'quercetin' and 'isoflavones'. The organic foods contain significantly high amounts of both these antioxidant vitamins and flavonoids. Possible importance of 'lycopene' (found in significantly high amounts in organic tomatoes) has also been suggested for protection from cardiovascular diseases (Benbrook, 2005).

4. Earthworms & Vermicompost: The Great Soil Conditioners

Use of vermicompost in farm soil eventually leads to generation of huge population of 'earthworms' from their cocoons in the vermicompost. Sir Charles Darwin believed that soil could not be present on earth until earthworms evolved and flourished. Humus in vermicompost excreted by worms is of great agronomic value for the soils. It takes several years for soil organic matter (SOM) or ordinary composts to decompose to form humus while earthworms secrete humus in its excreta (vermicasts). Without humus plants cannot grow and survive. The 'humic acids', 'fulvic acids' and 'humins' in humus are essential to soil and plants in several ways.

4.1 Vermicompost Increase 'Soil Organic Matter' (SOM): Vital for Crop Growth

Application of vermicompost increase the soil organic matter (SOM) i.e. soil carbon to more sustainable levels, above 3-5 % and improve fertility. Organic carbon in soil plays a central and fundamental role in soil structure, quality and fertility. SOM acts as a 'glue' to bind 'soil particles' into aggregates thus improving soil structure, infiltration, air porosity, water & nutrient holding capacity. Soil quality and fertility reduces over time as carbon is continually removed from farm soil through grain harvesting, cutting of hay and stubble fed to cattle and also through oxidation as greenhouse gas 'carbon dioxide'. Application of composts 'replenishes the SOM' adds the lost soil carbon and helps to sustain the soil quality and fertility and maximise production over time. As the SOM decomposes over time it results in the development of more stable carbon compound called 'humus' which is essential for plant growth especially 'roots formation'.

4.2 Increase Beneficial Soil Microbes, Microbial Activity & Essential Nutrients

Vermicompost is rich in microbial diversity. Earthworms further proliferates useful microbes in billions & trillions in soil. Soil organic matter (SOM) is also the food source of beneficial soil microbes and helps in improving microbial population and diversity. Microbes are responsible for transforming, releasing and cycling of nutrients and essential elements. Microbes are also essential for converting nutrients into their 'plant available forms' and also for 'facilitating nutrients uptake' by plants. Soil microbes also create the 'glue' that sticks soil particles together, creating soil crumbs and pore spaces that make good soil structure decreasing 'soil hardness'.

Suhane (2007) studied the chemical and biological properties of soil under organic farming (using vermicompost) and chemical farming (using chemical fertilizers-urea (N), phosphates (P) and potash (K) (See table 2).

Table 2. Farm soil properties under organic and chemical farming

Chemical and biological properties of soil	Organic farming (Use of vermicompost)	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: *Vermicompost*; Suhane (2007)

With continued application of vermicompost the organic nitrogen (N) 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 (P) is sometimes much greater than that from inorganic fertilizers.

4.3 Remove Soil Sodicity & Salinity

Farmers at Phaltan in Maharashtra, India, applied live earthworms to their sugarcane crop grown on saline soils irrigated by saline ground water. The yield was 125 tonnes/hectare 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%. In another study there was good production of potato (*Solanum tuberosum*) by application of vermicompost in a reclaimed sodic soil in India. The sodicity (ESP) of the soil was also reduced from initial 96.74 to 73.68 in just about 12 weeks. The average available nitrogen (N) content of the soil increased from initial 336.00 kg/ha to 829.33 kg/ha (Sinha *et al*., 2009 a; Nelson and Rangarajan, 2011).

4.4 Increase Water Holding Capacity of Soil

Addition of vermicompost to soils increases water holding capacity, maintain evaporation losses to a minimum and works as a 'good absorbent' of atmospheric moisture due to the presence of colloidal materials – the 'earthworm mucus'. The worm vermicast works as 'micro-dams' storing hygroscopic and gravitational water (Bhandari *et al*, 1967; Munnoli *et al*. 2002; Munnoli and Bhonsle, 2011). Stockdrill and Lossens (1966) reported that the earthworms increased the water holding capacity of New Zealand soils by 17 %.

This is of great agronomic significance as agriculture use nearly 85 % of world freshwater. About 3 million litres of water is needed to produce 1 hectare of corn; about 12-20 million litres to produce 1 ha of rice and about 250 litres to produce 1 kg of wheat. With the use of chemical fertilizers the demand for irrigation of chemically grown crops has further increased substantially.

4.5 Create & Restore Disease Suppressive Soils

Earthworms act as 'vector' for dispersal of 'disease-suppressive' useful microbes in soils (Compant *et al*., 2005). Earthworms gut act as a 'microbial factory' and it proliferates the microbial community and diversity in millions and trillions in soils in short time (Binet *et al*., 1998). Increasing the population of mixed species of earthworms in soil can proliferate the population and distribution of these 'bio-control microbial agents' in farm soil in billions and trillions. For example *A. trapezoids* spread the bio-control bacterium *Pseudomonas corrugata* (which is highly effective against *G. graminis* var. *tritici* on wheat) to a depth of 9 cm in soil after surface inoculation in pots compared to a depth of only 3 cm in soil without earthworms (controls).

4.6 Significantly Improves and Rapidly Recycles Nitrogen in Soils

Barley and Jennings (1959) reported that worms significantly contribute nitrogen (N) contents to soil by over 85%. Earthworms can contribute between 20 to 40 kg nitrogen/ha/year in soil, in addition to other mineral nutrients and plant growth regulators and increase soil fertility and plant growth by 30-200% (Darwin, 1881). Earthworms recycle nitrogen in the soil in very short time and the quantity recycled is significant ranging from 20 to 200 kg N/ha/year. After 28 weeks soil with living worms contained 75 ppm of nitrate nitrogen compared to the control soil without worms which contained 45 ppm. Worms increase nitrogen levels in soil by adding their metabolic & excretory products (vermicast), mucus, body fluid, enzymes and decaying tissues of dead worms. They also contribute nitrogen indirectly through fragmentation of organic materials and grazing on soil microorganisms.

Earthworm tissues contain about 7.9 % N on a dry weight basis. Living worms release nitrogen from their bodies and after death it is rapidly decomposed in about 4 days releasing all nitrogen into the soil. In a study with potted ryegrass, over 70 % of the N^{15} added was incorporated into plant shoots after 16 days. Study found that 50% of the N in dead worm tissues was mineralized in 7 days while 70% in 10-20 days and the N was converted to NO_3-N which is bio-available form on nitrogen to crop roots. The release of mineral N after death of earthworms could be significant since worm biomass can turn over up to 3 times a year in farm soil. Study estimated direct flux of nitrogen through earthworm biomass in farm soils ranging from 10-74 kg N/ha/year. In corn field mortality and decomposition of dead earthworms could contribute 23.5 kg N /ha/year. In case of inorganic fertilizer-treated farm soil it is only 15 .9 kg/ha/year.

4.7 Control Soil Born Plant Diseases

Earthworms have also been found to be directly involved in suppression of soil-borne plant diseases Genus *Aporrectodea* have been found to reduce the symptoms of several soil-borne plant diseases. Presence of *A. rosea* and *A. trapezoids* in soils were correlated with a reduction in the symptoms of diseases caused by *Rhizoctonia solani* in wheat crops in an Australian farm soil. These earthworm species were also associated with suppression of crop diseases caused by *Gaeumannomyces graminis* var. *tritici* on wheat (Elmer, 2009). Elmer (2009) also reported that when the population of earthworms *Lumbricus terrestris* was augmented in soils infested with soil-borne pathogens it significantly reduced the diseases of susceptible cultivars of asparagus (*Asparagus officinalis*), eggplant (*Solanum melongena*) and tomato (*Solanum lycopersicum*). Earthworms activity was also associate with increase in plant growth and plant weights were increased 60-80 %.

5. Earthworms Vermicompost Promote High Plant Growth & Yield

In general the land inhabited by earthworms for 3 years will become high yielding farmland. Earthworms loosen the soil as they move through it. Air and water can penetrate soil through earthworm tunnels. One square meter of healthy soil contains 1,000 earthworms. According to the estimate of an American researcher, 1,000,000 (one million) earthworms in a garden plot provide the same benefit as three gardeners working 8 hours in shifts all year round, and moreover having 10 tons of manure applied in the plot (Xu Kuiwu and Dai Xingting, 1998).

There have been several reports that earthworms and their excretory products (vermicast) can induce excellent plant growth. 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 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 (Subler *et al.*, 1998). Arancon *et al.*, (2003) also found that maximum benefit from vermicompost is obtained when it constitutes between 10% to 40% of the growing medium.

5.1 High Levels of Bio-Available Nutrients for Plants

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 and protectors’ with significantly higher agronomic impacts (5-7 times) over all the conventional composts. Kale and Bano (1986) reports as high as 7.37% nitrogen (N) and 19.58% phosphorus as P_2O_5 in worm's vermicast. Most nutrients in plant-available forms such as ‘nitrates’ (N), ‘phosphates’ (P), ‘soluble’ potassium (K), and magnesium (Mg) and 'exchangeable' phosphorus (P) and calcium' (Ca). Vermicomposts have large particulate surface areas that provide many micro-sites for microbial activities and for the strong retention of nutrients (Arancon and Edwards, 2006).

Suhane (2007) 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. Annual application of adequate amount of vermicompost also lead to significant increase in soil enzyme activities such as 'urease', 'phosphomonoesterase', 'phosphodiesterase' and 'arylsulphatase' and the soil has significantly more electrical conductivity (EC) and near neutral pH (Tiwari *et al.*, 1989). Vermicompost have a vast surface area, providing strong absorbability and retention of nutrients. They appear to retain more nutrients for longer period of time.

5.2 High Level of Beneficial Soil Microorganisms Promoting Plant Growth

Vermicomposts are rich in 'microbial populations and diversity', particularly 'fungi', 'bacteria' and 'actinomycetes' (Chaoui *et al.,* 2003). It contains a diversity of 30,000 bacterial & fungal organisms. Guts of earthworms are 'factories & storehouse' of beneficial soil microbes. Apparently, it is both the earthworms and its microbes that plays combined role in growth promotion and improved agricultural production. Worms and microbes secrete growth promoting plant hormones 'gibberlins', 'auxins' and 'cytokinins' which help mineralise the nutrients and make them 'bio-available' to plant roots. Microbes also help in plant protection. In a glasshouse trial, Buckerfield *et al.*, (1999) found that the 'stimulatory effect' of vermicompost on plant growth was apparently destroyed when it was 'sterilized'.

Parle (1963) reported bacterial count of 32 million per gram in fresh vermicast compared to 6-9 million per gram in the surrounding soil. Scheu (1987) reported an increase of 90% in respiration rate in fresh vermicast indicating corresponding increase in the microbial population. Suhane (2007) found that the total bacterial count was more than 10^{10} per gram of vermicompost. It included *Actinomycetes, Azotobacter, Rhizobium, Nitrobacter* and 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. Although phosphates are available in soils in rock forms but are not available to plant roots unless solubilized.

5.3 Rich in Growth Hormones Stimulating Total Plant Growth

Vermicompost consistently improves seed germination, enhance seedling growth and development and increase plant productivity. Neilson (1965) and Tomati *et al.*, (1987) have also reported that vermicompost contained growth promoting hormone 'auxins', 'cytokinins' and flowering hormone 'gibberellins' secreted by earthworms. Grappelli *et al.*, (1985) demonstrated 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.

5.4 Rich in Humic Acids Promoting Root Growth & Nutrient Uptake

Atiyeh *et al*.,(2002) 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. Humic 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 (Li *et al*., 2010).

This was also indicated by Canella *et al*., (2000) who found that humic acids isolated from vermicompost enhanced root elongation and formation of lateral roots in maize roots. Pramanik (2007) 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'.

6. Earthworms Vermicompost Protects Plants against Pest & 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 (Anonymous, 2001). Plants grown with vermicompost which contain balanced nutrients and greater microbial and faunal diversity compared to chemical fertilizers are less susceptible to a number of arthropod pests and sustain significantly lower pest populations. The other earthworm products - VERMIWASH (liquid filtered through body of worms) and VERMICOMPOST TEA (vermicompost brewed in water) can be made 100 % effective bio-pesticides to replace the toxic chemical pesticides. Vermicompost works to protect crops in three ways-

6.1 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 (Sinha and Valani, 2011). Vermicomposts are consistently capable of conferring or inducing plant resistance in economically important plants. It has been shown to increase 'resistance' in host plants against pests, pathogens, plant parasitic nematodes and a large number of arthropods including jassids (*Empoasca kerri*), aphids (*Myzus persicae* and *Aphis craccivora*), spider mites (*Tetranychus urticae*), mealy bugs (*Planococcus citri*) and caterpillars (*Pieris rapae*) (Chaoui *et al.,* 2002; Arancon *et al*., 2002, 2005 and 2007; Edwards *et al*., 2010).

Vermicompost amendments as low as 20 % have been shown to decrease leaf consumption by caterpillars and population growth of aphids on cabbage (Arancon *et al.* 2005). Yasmin (2011) found that vermicompost was very effective in causing *Arabidopsis* plants to become resistant to the generalist herbivore *Helicoverpa zea*. Vermicompost causes plants to have non-preference and toxic effects on insects. This resistance adversely affects insect development and survival on plants grown in vermicompost-amended soil. This resistance is possibly due to the interactions between the diverse microbial communities in vermicompost with plant roots, as is evident from the sterilization assays of vermicompost.

6.2 Repel Crop Pests

There seems to be strong evidence that worms varmicastings sometimes repel hard-bodied pests. Edwards & 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.

Hahn (2011 a), doing commercial vermicomposting in U.S., claims that his product repels many different insect pests and suppress pathogenic bacteria, fungi and soil nematodes causing crop diseases. His scientific explanation is that this is due to production of enzymes 'chitinase' by worms which breaks down the chitin in the insect's exoskeleton. Chitin degraders can also digest bacteria and all other chitin based fungi. There are also 'cellulose degraders' enzymes in vermicompost that are able to digest bacteria and cellulosic fungi e.g. *Pythium* and *Phytopthora* which causes wide range of crop diseases. He asserts direct relationship between efficacy of repellency and the number of chitin degraders and the concentration of chitinase enzymes. At 25 million cfu/dwg of chitin degrader's aphids were driven from roses in 90 days; at 56 million cfu/dwg in 4 weeks and at 200 million cfu/dwg aphids were chased off in less than 1 week. Parasitic nematodes were also suppressed. A 20 acre cauliflower infested with 'centipedes' saw elimination in 3 months. Some 30,000 pine trees in the forest of San Bernardino, U.S. were being decimated by the 'bark beetles'. Upon treatment with chitin degraders & chitinase rich vermicompost the mortality was reduced to less than 1%. The neighbouring untreated pines are being lost at 80 + % every year. In a Pecan research project in U.S., application of chitinase rich vermicompost produced a 400 % increase in yield while also eliminating the 'pecan scab' and 'pecan weevil'.

The level of 'chitin degraders' in vermicompost prepared from feeding normal cattle dung & food wastes to the earthworms is generally 2-3 millions cfu/dwg which is below the 10 million cfu/dwg threshold for effective action. If about 30 % chitin is added to the feed material the level of chitin degraders can be significantly increased to 200 million cfu/dwg in the vermicompost. This can be achieved by adding shrimp or crab shells, melted cow horns or even dead bugs to the worm beds. Number of cellulose degraders in the vermicompost can be increased by adding paper or saw dust in the feed materials (geohahn@gmail.com; Personal Communication, 2011).

6.3 Suppress Plant Insects and Diseases

All composts (but more efficiently vermicompost) have been found to suppress high levels of soil-borne disease. Ayres (2007) 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. Naturally-occurring microbes (bacteria and fungi) can suppress organisms that cause diseases. Important plant diseases suppressed by composts are 'wilt' caused by *Fusarium* spp.; 'damping off' caused by *Fusarium, Pythium, Rhizoctonia* & *Sclerotium* spp.; 'stem and root rot' caused by *Fusarium, Rhizoctonia, Pythium, Phytopthora, Sclerotium* and *Aphanomyces* spp. Woody materials in composts that degrade slowly can provide long lasting disease suppression for more than 3 years as they release nitrogen, potassium & phosphorus slowly into the soil. Nitrogen (N) is a key nutrient in disease suppression and nitrogen deficiencies in soil can make plants more susceptible to diseases. There are several ways how all composts suppress crop diseases. These are by competition, secretion of antibodies & hormones, predation & parasitism, induction of systemic defences in plants against diseases and by boosting immune systems (Magdoff, 2004; Hoitink, 2008).

Edwards & Arancon (2004), Arancon et al. (2005 & 2007 b) have found that use of vermicompost in crops inhibited the soil-born fungal diseases and suppressed the insect pest populations such as the two-spotted spider mite (*Tetranychus urticae*), mealy bug (*Pseudococcus* sp.) and aphid (*Myzus persicae*). They also found statistically significant suppression of plant-parasitic nematodes in field trials with pepper, tomatoes, strawberries and grapes. Yardim *et al*. (2006) found that vermicompost suppressed tomato hornworm (*Manduca quinquemaculata*) and cucumber beetles (*Acalymma vittatum* and *Diabrotica undecimpunctata*). 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 access 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 (2004) also studied the agronomic effects of small 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.

Several authors have also reported 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 (Sinha & Valani, 2011).

7. Vermiwash: Liquid from Body of Earthworms an Effective Biopesticide

The brownish-red liquid which collects from all vermicomposting beds is also useful in farming. 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). It has the capacity to revive even a dying plant (Mr.Avnish Bhardwaj; avnish.bhardwaz@live.com).

More importantly this liquid also contains good numbers of beneficial microbes - the chitin and cellulose degraders. Farmers from Bihar in North India reported high 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.

Hahn (2011 a) indicated that the vermiwash liquid can be made more effective as pest repellent and diseases suppressant if the numbers of the beneficial microbes (chitin & cellulose degraders) are increased in them. Under normal worm feed materials usually 2-3 millions chitin degraders and 4-5 million cellulose degraders are formed in a given volume of vermiwash liquid but the threshold number required for effective action is about 10 millions. If sugars are added to the vermiwash and fermented for some hours the number of chitin and cellulose degrader microbes can also multiply in several millions in short time.

8. Vermicompost Tea: Fermented Solution of Vermicompost an Effective Growth Promoter & Plant Protector

Arancon *et al.* (2007 a) reported that if the solid vermicompost is brewed in water it results into ‘vermicompost tea’ which is very effective plant growth promoter and easy to be used as foliar spray. Hahn (2011 a & b) also reported that ‘vermicompost tea’ can be used as spray for promoting growth, repelling pests and suppressing plant diseases. A farmer in U.S. with 500 acres of lemons was losing 3 % of his trees every year from the damages done by fungus *Phytopthora cinnamomi*. He began spraying vermicompost tea @ 5 gallons per acre twice a year. It stopped the tree losses and also increased production (Hahn, 2011 b).

Vermicompost prepared by adding chitins and cellulosic materials in the feed can have high number of chitin and cellulose degraders in vermicompost tea. This solution can also be fermented with sugars to multiply the numbers of pest and disease killer microbes in millions and billions in short time. About 9 billion chitin and cellulose degraders were produced in a given volume of solution in 24 hours. Hence with smaller amount of vermicompost farmers can make large volumes of bio-pesticides with very high number of pest and disease killer microbes (Hahn, 2011 b).

9. Studies on Growth Impacts of Vermicompost on Horticultural Crops

There have been several reports that earthworms and its vermicompost can promote excellent plant growth and yield in horticultural crops in terms of height of plants, colour & texture of leaves, appearance of fruiting structures etc. as compared to chemical fertilizers and the conventional composts with less incidences of pest and disease attacks & reduced demand of water for irrigation (Edwards & Burrows, 1988).

9.1 Some Studies on Fruits & Nuts

9.1.1 Grapes (Vitis vinifera)

Buckerfield & Webster (1998) found that 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. The yield in grapes was worth additional value of AU $ 3,400 / ha. Significantly, the yield was greater by 55 % when vermicompost applied soil was covered under mulch of straw and paper. Still more significant was that 'single application' of vermicompost had positive effects on yields of grapes for long 5 years. There were other agronomic benefits. Biological properties of soil were improved with up to ten-fold increase in total microbial counts. Levels of exchangeable sodium (Na) under vine were at least reduced to 50% and there were three-fold increase in the population of earthworms under the vine with long-term benefits to the soil.

Farmer in Sangli district of Maharashtra, India, grew grapes on soil of 'eroded wastelands' and applied vermicasting @ 5 tons/ha. The grape harvest was normal with improvement in quality, taste and shelf life. Soil analysis showed that within one year pH came down from 8.3 to 6.9 and the value of potash increased from 62.5 kg/ha to 800 kg/ha. There was also marked improvement in the nutritional quality of the grape fruits (Sinha et al., 2009).

9.1.2 Strawberries (Fragaria ananasa)

Arancon *et al*. (2004) 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. 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. 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. 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 use increased the yield and quality of marketable strawberry fruits up to 58.6 %

9.1.3 Cherries

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. At the first harvest, trees with vermicompost yielded an additional $ 63.92 and $ 70.42 per tree respectively. After three harvests profits per tree were $ 110.73 and $ 142.21 respectively.

9.1.4 Apples

Study was done on the use of vermicompost in 'apple orchards' in Himachal Pradesh, India. It is used once a year between 5-15 kg per plant. About 12 – 30 cm growth per year was observed in apple trees. More significant observations were that ever since vermicompost were being used (2002-03) the quantity and quality of the apple fruits have increased, both in terms of 'size and taste'. The 'storage value of fruit' has also increased. The soil quality of the apple orchard has also improved. Apple farmers in India have practically given up the use of chemical fertilizers. (Personal Communication; Vineet Sarjolta (2012): vineet787@gmail.com)

9.1.5 Pecan Nuts

Study made by USDA (United States Department of Agriculture) on 'Pecan Nuts' gave very encouraging results. US provide about 90 % of the pecan nuts to the world. Pecan is a good source of 'protein' and contains 'antioxidants' and 'plant sterols' which may improve consumers 'cholesterol' status by reducing the 'bad' LDL cholesterol levels. Significantly, foliar application of 'vermicompost tea' achieved a yield of 400 % also increasing 'trees resistance' to insects & pests and eliminating the 'pecan weevil' and 'pecan scab' problems. The USDA report (2008) by Alfredo Flores asserts that the organic production techniques by vermicompost tea that they have tested on pecans can also apply to walnuts, peaches, apricots, apples and all tree crops (www.nps.ars.usda.gov) (Hahn, 2011 b).

9.2 Some Studies on Vegetable Crops

1) Munroe (2007) reported that lettuce grown on vermicompost showed significantly higher yield by 20 % in wet weight as compared to control and conventional compost. Average weight of lettuce head was 313 gm on vermicompost, while on ordinary compost it was 257.5 gm and 259.1 on control. He also studied the agronomic impacts of vermicompost on tomato plants (*Lycopersicum esculentus*) and reported that the VC applied plants were bigger and healthier and the yield was substantially higher even though the other tomato plants (without vermicompost) received an optimal nutrient supply.

2) Karmegam and Daniel (2008) studied the effect of vermicompost & chemical fertilizer on hyacinth beans (*Lablab purpureas*) and found that all growth & yield parameters e.g. total chlorophyll contents in leaves, dry matter production, flower appearance, length of fruits and fruits per plant, dry weight of 100 seeds, yield per plot and yield per hectare were significantly higher in those plots which received vermicompost either alone or in combination with chemical fertilizers (NPK). The highest fruit yield of 109 ton / ha was recorded in plots which received vermicompost @ 2.5 tons / ha plus half dose (50 %) of recommended NPK.

3) Suthar (2009) studied the impact of vermicompost (VC), chemical fertilizers (NPK) and farmyard manure (FYM) on root & shoot length, weight and number of cloves in garlic (*Allium sativum*) and found that the best growth performance was achieved on VC (15 ton/ha) + 50 % NPK as compared to FYM (15 ton/ha) + 100 % NPK. The average fruit weight on vermicompost was also approximately 26.4 % greater than the other combinations.

4) Ansari [2008] studied the production of potato (*Solanum tuberosum*), spinach (*Spinach oleracea*) and turnip (*Brassica campestris*) by application of vermicompost in a reclaimed sodic soil in India. The overall productivity of vegetable crops during the two years of trial was

significantly greater in plots treated with vermicompost applied @ 6 tons/ha as compared to control. There was significant improvement in soil quality of plots amended with vermicompost @ 6 tons / ha - reduction from initial 96.74 to 73.68 in sodicity (ESP) and increase from initial 336.00 kg/ha to 829.33 kg / ha in available nitrogen (N) contents. The study also indicated that the requirement of vermicompost for leafy vegetable crops like spinach was lower (4 tons/ha) whereas that of tuber crops like potato and turnip was higher (6 tons/ha).

9.3 Our Studies on Some Potted Vegetable Crops

9.3.1 Egg-Plants (Solanum melangona)

Potted egg-plants grown on vermicompost with live earthworms in soil bored on average 20 fruits/plant with average weight being 675 gm. Whereas, those grown on chemical fertilizers (NPK) bored only 14 fruits/plant with average weight being only 500 gm. Total numbers of fruits obtained from vermicompost (with worms) applied plants were 100 with maximum weight being 900 gm while those on chemicals were 70 fruits and 625 gm as maximum weight of a fruit. Interestingly, egg-plants grown on exclusive vermicompost (without worms) did not perform as with those with worms, but were significantly better over those on chemical fertilizers. Presence of earthworms in soil made a significant difference in development of fruits in egg-plants (See table 3).

Table 3. Agronomic impacts of vermicompost, earthworms & vermicompost vis-a-vis chemical fertilizer on growth and development of egg plants

Treatments	Av. Vegetative Growth (Inches)	Av. No. of Fruits / Plant	Av. Wt. of Fruits / Plant	Total No. of Fruits	Max. Wt. of One Fruit
1. Earthworms (50 Nos.) + VC * (250 gm)	28	20	675 gm	100	900 gm
2. Vermicompost (250 gm)	23	15	525 gm	75	700 gm
3. Chemical Fertilizer (NPK) (Full dose)	18	14	500 gm	70	625 gm
4. CONTROL	16	10	425 gm	50	550 gm

Source: Agarwal (1999); VC = Vermicompost.

9.3.2 Lady's Finger Plants (Abelmoschus esculentus)

Potted lady's finger plants grown on vermicompost (with live worms in soil) bored on average 45 fruits/plant with average weight being 48 gm. Whereas, those grown on chemical fertilizers (NPK) bored only 24 fruits/plant with average weight being only 40 gm. Total numbers of fruits obtained from vermicompost (with worms) applied plants were 225 with maximum weight being 70 gm while those on chemicals were 125 fruits and 48 gm as maximum weight of a fruit. Again, okra plants grown on exclusive vermicompost (without worms) did not perform as with those with worms, but were significantly better over those on chemical fertilizers. Presence of earthworms in soil added with vermicompost made a significant difference on the development of fruits of okra plants (See table 4).

Table 4. Agronomic impacts of vermicompost, worms with vermicompost vis-a-vis chemical fertilizer on growth and development of lady's finger plants

Treatment	Av.Vegetative Growth (Inches)	Av.No. of Fruits/ Plant	Av.Wt. of Fruits /Plant	Total No. of Fruits	Max. Wt. of One Fruit
1. Earthworms (50 Nos.) + VC*	39.4	45	48 gm	225	70 gm
2. Vermicompost (250 gm)	29.6	36	42 gm	180	62 gm
3. Chemical Fertilizer (NPK) (Full dose)	29.1	24	40 gm	125	48 gm
4. CONTROL	25.6	22	32 gm	110	43 gm

Source: Agarwal (1999); VC * = Vermicompost

9.3.3 Tomato Plants (Solanum lycopersicum)

Tomato plants on vermicompost (250 gm) & vermicompost (250 gm) with earthworms (50) 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 (cow manure). 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 and certified by Compost Australia. It could not compete with indigenously prepared vermicompost even when applied in 'double dose' (500 gm) (See table 5).

Table 5. Growth of tomato plants promoted by vermicompost, vermicompost with earthworms, composted cow manure and chemical fertilizers (Average growth in cm)

Parameters	Control	Chemical Fertilizers (5 gm x 3 times)	Composted Cow Manure (500 gm) (Marketed)	Vermi-compost (250 gm)	Vermi-compost (250 gm) + Earthworms (50)
Number of fruits after Wk. 9	4	16	6	22	27
Avg. Growth after Wk.10	50	130	53	207	206

Source: Sinha & Valani. *Vermiculture Revolution*, NOVA Science Publication, USA (2011).

9.4 Feedbacks from Farmers in India & Australia

We interviewed some farmers in Bihar State of India using vermicompost & vermiwash in farming. Most of them asserted to have switched over to 'organic farming' by vermicompost completely giving up the use of chemical fertilizers in the last 5-6 years. Some of them harvested three (3) different crops in a year (reaping 2-3 times more harvest) due to their rapid growth & maturity and reduced harvest cycle. We got some feed backs from Australian farmers through emails whom we educated about vermi-products.

Some of the important observations of the organic 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 & disease attack' (by at least 75%) in crops applied with vermicompost. Cauliflowers grown on vermicompost remain 95% 'disease free'. Late Blight (fungal disease) in banana was almost reduced by over 95%. Spray of vermiwash completely protected the crops (See photo 1);

A B

Photo 1. showing disease resistance in cauliflower induced by vermicompost
(Curtsey: Farmer Bhagat Ji, Hazipur, Bihar, 2010)

(A). Cauliflower grown on chemical fertilizers (Susceptible to diseases)

(B). Cauliflower grown on vermicompost (Resistant to diseases)

- 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 colourful and bigger in size.

Kale (2006) also interviewed some farmers in South India who has been applying vermicompost on various crops for over 5-6 years. Growth impacts included total health of the crops with flowering and fruiting (See table 6).

Table 6. Farmers opinion on the use of vermicompost on various horticultural crops

CROPS	Doses of Vermicompost Applied	Growth Impacts
1. Oil Seeds	**3 – 5 Tons / Acre**	
Sun Flower		Very Good
Ground Nut		Very Good
Soyabean		Very Good
Mustard		Very Good
2. Vegetables	**4 – 6 Tons / Acre**	
Cabbage		Excellent
Potato		Excellent
Tomato		Excellent
Carrot		Excellent
Pumpkin		Excellent
Cucumber		Very Good
3. Fruits	**2 – 3 Kg / Plant**	
Grapes		Excellent
Banana		Excellent
Water-melon		Excellent
Custard apple		Excellent
Pomegranate		Excellent
Mango		Very Good
4. Ornamentals	**4 Tons / Acre**	
Roses		Excellent
Chrysanthemum		Excellent
Marigold		Excellent

Source: (Kale, 1998; 2006)

10. Economic Significance of Vermiculture Horticulture: Higher Production of Safe Organic Foods at Lower Cost of Input

A matter of considerable economic significance is that in organic farming by use of vermicompost or any organic fertilizer, the 'cost of food production' will be significantly low by at least 50-60 % as compared to costly chemical fertilizers and the food produced will be a 'safe chemical-free organic food' for the society. It is a 'win-win' situation for both producers (farmers) and the consumers (feeders). The farmers today are caught in a 'vicious circle' of higher use of agrochemicals to boost crop productivity at the cost of declining soil fertility. The amount of chemicals used per hectare has been steadily increasing over the years to maintain the same yield as the soil became 'addict'. Nearly 3-4 times of agro-chemicals are now being used per hectare what was used in the 1960s. This is adversely affecting their economy as the cost of agrochemicals has been rising all over the world. Government in developing nations have to subsidize the cost of agro-chemicals to make it affordable to farmers and also to keep the cost of food production artificially low for society.

The cost of production of vermicompost is simply insignificant as compared to chemical fertilizers. Vermicompost can even be produced ‘on-farm’ at low-cost by simple devices, while the chemical fertilizers are high-tech & high-cost products made in factories. While the compost is produced from ‘human waste’ - a raw material which is in plenty all over the world, the chemical fertilizers are obtained from ‘petroleum products’ which is a vanishing resource on earth.

Slowly over the years, as the worms build up the soil’s physical, chemical & biological properties, the amount of vermicompost can be slowly reduced while maintaining the same yield and thus further reducing cost. The yield per hectare may also increase further as the soil’s natural fertility is restored & strengthened. With compost costs approximately 60-70 % less than the cost of chemical fertilizers, applying vermicomposts in farm production can pay significant dividends for farmer’s and nation’s economy. With high soil moisture holding capacity of vermicompost, (nearly 40-50 %) there can be significant savings on water for irrigation which is also becoming a costly commodity.

11. Environmental Significance of Vermiculture Horticulture: Converting Waste into Resource, Eliminating Agrochemicals & Mitigation of Global Warming & Climate Change

11.1 Replacing the Environmentally Destructive Agrochemicals in Farm Production

In the production of chemical fertilizers, from the procurement of raw materials (petroleum products) to their production in factories and transport to farms and their uses by farmers generate huge toxic wastes and pollution and also emission of greenhouse gases at all stages. Adverse effects of chemical pesticides on the agricultural ecosystem (soil, flora, fauna and water bodies in farms) have now started to become more evident all over the world.

11.2 Converting Waste into Resource

All compost (including vermicompost), are produced from some ‘waste materials’ of society. Vermicomposting by waste eater earthworms is rapid and nearly odorless process, reducing composting time by more than half and the end product is both ‘disinfected’, and ‘detoxified’. Given the optimum conditions of temperature (20-30 °C) and moisture (60-70 %), about 5 kg of worms (numbering approx.10, 000) can vermiprocess 1 ton of organic wastes into vermicompost in just 30 days and the process becomes faster with time.

11.3 Mitigation of Global Warming

Much of the world’s carbon is held in the soils, including the agricultural soils as ‘soil organic carbon’ (SOC). The loss of SOC as CO_2 due to aggressive ‘ploughing and tillage’ in the wake of modern mechanised chemical farming practices has augmented the atmospheric carbon pool as greenhouse gas inducing the global warming and climate change. Of the increase of atmospheric carbon over the last 150 years, about a third (33.3 %) is thought to have come from agriculture (Robbins, 2004). All over the world agricultural & environmental scientists are trying to reverse the trend by putting more carbon back into the soil – a process called ‘carbon sequestration’ through organic farming by the use of composts (Bolan, 2011). All composts are disintegrated plant products and their use in farms would ‘sequester’ huge amounts of atmospheric carbon (absorbed by plants as CO_2 during photosynthesis) and bury them back into the soil, mitigate greenhouse gases & global warming. Vermicompost contains more stable forms of carbon which remains in the soil for long periods of time. The Intergovernmental Panel on Climate Change (2000) recognised that carbon (C) sequestration in soils as one of the possible measures through which the greenhouse gas (GHG) emissions and global warming can be mitigated. (Biala & Kavanagh, 2011).

Vermicomposting has potential to divert huge amount of wastes ending up in landfills & every 1 kg of waste diverted from landfills prevents 1 kg of greenhouse gas emissions equivalent to CO_2.

12. Discussion

This is a revolutionary century for world horticulture & agriculture and 'Organic Farming' is the key word. It has to be 'economically viable' (at low-cost with high productivity); environmentally sustainable (without any adverse effects on soil, air, water and biodiversity and with potential to mitigate global warming); and 'socially acceptable' (nutritive & protective foods for the society to promote human health and without any adverse effects). Vermi - horticulture by earthworms promises to fulfil all the above conditions. A quiet 2nd 'Non-Chemical Ever Green Revolution' is now taking place in world in various names like 'The Ecological Agriculture', 'Organic Agriculture' etc. Today over 60,000 farmers in Bangladesh and 20,000 in India are practising organic farming with the help of earthworms and its vermicompost (Kesavan and Swaminathan, 2006).

Use of all earthworm products (vermicompost, vermiwash & vermicompost tea) would significantly reduce or even replace the use of costly and dangerous 'agrochemicals' in agriculture, reduce emission of 'greenhouse gases' from agriculture and also reduce 'water for irrigation' thus benefiting the farmers and the economy and ecology of the nation in every way. They seems to be justifying the beliefs of the great visionary scientists Sir Charles Darwin who called earthworms as '*friends of farmers and unheralded soldiers of mankind working day and night under the soil*' and the great Russian Scientist Antoly Igonin who called them as both '*productive and protective*' for ecosystem.

Earthworms products can truly be a 'sustainable alternative' to the agrochemicals which are proving destructive all on counts - socially (as slow poison for society), economically (increasing cost of food production due to high cost of chemical fertilizers), agronomically (degrading soil properties and its natural fertility and increasing susceptibility in crops to pest and diseases) and environmentally (soil and water pollution & greater emissions of greenhouse gases from the production and use of agrochemicals).

Vermicompost also performed significantly well over conventional composts (even certified by Compost Australia) and chemical fertilizers in all experiments on field and potted crops. Vegetable crops performed exceedingly well when 'live earthworms' were also present in soil along with its vermicast. They made excellent impact on 'fruit development' justifying the beliefs of ancient Indian vermiculture scientist Sir Surpala (10th Century A.D.) who recommended to add earthworms in soil of pomegranate plants to get good quality fruits. (Sadhale, 1996). This definitely relates with secretion of flowering hormones 'gibberlins' by earthworms which aids in flower formation and fruit development. Vermicompost contain large number of worm 'cocoons' which eventually germinate to produce huge population of earthworms in farm soil. Each worm produce 2-3 cocoons every week & 10-12 baby worms emerge from each cocoon. Another great significance of vermicomost application is 'less incidence of pest and disease attacks' on crops and better taste and nutritive value of fruits and vegetables grown on it.

What is most significant is that there is an 'optimal limit' of the use of vermicompost for any crop after which there is no need to increase the amount of vermicompost to maintain the same high yield of the previous years. After some years of continued application of vermicompost, the soil becomes fertile enough (rich in humus and beneficial soil microbes) to sustain same crop growth and yield in future even on lower doses of vermicompost. This is contrary to the chemical fertilizers where the doses have to be constantly increased to maintain the same yield of the previous years.

As vermicompost is made from 'renewable biological resources' it will be readily available to mankind in future. Agrochemicals are made from 'non-renewable geochemical resources' and hence 'depleting' in future. In the use of vermicompost the environment is 'benefited' at all stages-from production (salvaging waste and diverting them from landfills and reducing greenhouse gases) to use in farms (adding beneficial microbes and organic carbon to soil and improving physical and biochemical properties). In the use of agrochemicals the environment is 'harmed' at all stages- from procurement of raw materials from mines and industries to their production in factories (generating huge amount of chemical wastes and pollutants and emitting greenhouse gases) and their use in farms (adversely affecting soil's physical, chemical and biological properties and also emitting powerful greenhouse gas N_2O from the rapid oxidation of chemical nitrogen in soil).

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