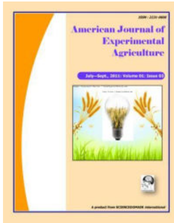

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Organic Farming by Vermiculture: Producing Safe, Nutritive and Protective Foods by Earthworms (Charles Darwin's Friends of Farmers)

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Review Article

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ABSTRACT

Agrochemicals which ushered in the 'green revolution' in the 1950-60's, boosted food productivity, but at the cost of environment and society. It increased food production but also destroyed the 'physical, chemical and the biological properties' of soil over the years of use. It killed the beneficial soil organisms and also impaired the power of 'biological resistance' in crops making them more susceptible to pests and diseases. No farmland of world is free of toxic pesticides today. Over the years it has worked like a 'slow poison' for the soil and society. According to UNEP and WHO 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.
Organic farming by earthworms (Sir Charles Darwin's 'friends of farmers') can provide a sustainable and also highly economical solution to the various problems created by the destructive agrochemicals in farm production. Earthworms vermicompost are 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

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holding capacity' and makes the soil soft. More significantly it also 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 by their beneficial microbes (chitin and cellulose degraders). 'Vermiwash' (liquid filtered through the body of worms) and the 'vermicompost tea' (solution of vermicompost) also works as very 'powerful bio-pesticides' eliminating the use of toxic chemical pesticides.

Agriculture has also been responsible for huge emissions of greenhouse gases and induction of global warming. Of the increase of atmospheric carbon over the last 150 years, about a third (33.3 %) is thought to have come from agriculture. Chemical agriculture has further augmented GHG emissions. From their production in factories to their transport and use in farms agrochemicals generate huge toxic wastes and pollution and greenhouse gases. Aggressive tillage of compacted soils (due to use of agrochemicals) depletes the 'soil organic carbon' (SOC) and emits large volumes of CO_2. Chemical nitrogen from the soil is oxidised as N_2O which is 312 times more powerful GHG than CO_2. Organic farming by vermicompost 'sequesters' large amount of 'atmospheric carbon' and bury them back into the soil as SOC improving soil fertility and also 'mitigating global warming'. Soil amended with vermicompost have significantly greater 'soil bulk density' and hence porous and lighter and never get compacted needing no or low tillage. Production of vermicompost divert huge amount of wastes from 'landfills' which emit large amount of powerful greenhouse gases like CH_4 and N_2O along with CO_2. Every 1 kg of waste diverted from landfills prevents 1 kg of greenhouse gas emission equivalent to CO_2. It is like a 'win-win situation' for the nation, farmers, environment and the society.

The objectives of this review paper is to scientifically prove that vermiculture technology with the aid of earthworms and its metabolic products (vermicast) can boost farm production without agrochemicals (completely organic) and justify the beliefs of Sir Charles Darwin who called the earthworms as 'friends of farmers' centuries ago. Besides, it will provide several social, economic and environmental benefits to the society by way of producing 'chemical-free' safe, 'nutritive and protective' foods (even against some forms of cancers) for the people, salvaging human wastes and reducing the needs for costly landfills, mitigating global warming by sequestering carbon into soil.

Keywords: Vermiculture and organic farming; high food production without agrochemicals; chemical-free, safe, nutritive and protective foods; soil carbon sequestration and fertility improvement; mitigation of global warming;

1. INTRODUCTION

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 and society. It dramatically increased the 'quantity' of the food produced but decreased its 'nutritional quality' and also destroyed the 'physical, chemical and 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 (UNEP Report, 2001).

There have been significant decline in the nutritive values of food produced by agrochemicals in the wake of 'green revolution'. Davis et al. (2004) compared the nutritive contents of 43 garden crops between 1950 (beginning of chemical farming) and 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).

More serious matter is that the global cropland, which provides about 99.7% of human food is shrinking by more than 10 million hectares (almost 37,000 square miles) a year due to soil erosion. Since 1950 some 30 % of the world's arable land has become unproductive. Soil is being washed away 10 to 40 times faster than it is being replenished, destroying croplands all over the world. To add to the problem, human population is increasing by some 81 million people every year placing more demand for food (Scholder, 2011).

The global movement for 'Organic Farming' is directed towards the production of biological based fertilizers (bio-fertilizers) and bio-control of pests and diseases (bio-pesticides) with restoration of biologically active 'disease-suppressive' fertile soils (with beneficial microbes and nematodes) that can also 'protect plant health' while promoting growth. The disease-suppressive soils were first described in the late 1800s (Huber and Schneider, 1982). The 'scientifically produced bio-fertilizers (composts) with recent knowledge in biotechnologies are much more nutritive and productive than those produced traditionally by farmers in earlier days. Organic farming systems with the aid of nutritive bio-fertilizer like 'earthworms vermicompost' can give very 'high food productivity' with significantly 'higher nutritional quality' while also improving the physical, chemical and biological properties of soil. Organic foods have also been found to be 'protective' to human health even against 'colon cancer' and 'breast cancer' (Olsson, 2006).

Earthworms vermicompost is highly nutritive and a powerful 'plant growth promoter and protector' and is scientifically proving to be a 'miracle plant growth promoter'. It is rich in NKP, micronutrients, beneficial soil microbes and also contain plant growth hormones and enzymes secreted by earthworms. Vermicompost retains nutrients for long time and also 'protect crops from pests and diseases'. It has high 'moisture holding capacity' and hence also reduce the use of water for farm irrigation by 40-50 %. Vermicompost rich in 'humus' (secreted by earthworms) provide the ability to glue clay, silt, and sand particles together enhancing the texture and structure of soil and preventing soil erosion. Billions of tons of humic substances are disappearing from soil worldwide every year due to floods, fires, and poor agricultural practices. The 'vermiwash' (liquid produced during vermicomposting) and 'vermicompost tea' (solution of vermicompost produced in water) are highly effective 'bio-pesticides' with 100 % control of crop pests and diseases.

Another vital issue today is the emission of 'greenhouse gases' (GHGs) inducing global warming and climate change from agriculture which contributes some 33% of the GHG**.** The loss of 'soil organic carbon' (SOC) as CO_2 due to aggressive 'ploughing and tillage' in the wake of chemical agriculture (as the soil became more compacted) has augmented the atmospheric carbon pool. Also significant amount of chemical nitrogen (urea) is lost from soil as 'nitrous oxides' (N_2O) into the air oxidized by sunlight. N_2O is a powerful 'greenhouse gas' nearly 312 times as compared to CO_2. Use of vermicompost (or any other compost) in farms would also 'sequester' huge amounts of atmospheric carbon (CO_2) and bury them back into the soil improving the soil fertility and also reducing GHG and mitigating global warming.

2. ORGANIC FARMING BY VERMICULTURE VERSUS CHEMICAL FARMING BY AGROCHEMICALS

Chemical agriculture is proving destructive in every way – agronomically, socially, economically and environmentally. Organic farming by vermiculture will be supportive in every way. Vermicompost works as a 'slow-release fertilizer' whereas chemical fertilizers release their nutrients rather quickly in soil and soon get depleted. Significant amount of chemical nitrogen is lost from soil due to oxidation in sunlight. Suhane (2007) calculated that upon application of 100 kg urea (N) in farm soil, 40-50 kg gets oxidised and escapes as 'ammonia' (NH_3) and 'nitrous oxides' (N_2O) into the air, about 20-25 kg leaches underground polluting the groundwater, while only 20-25 kg is available to plants. N_2O is a powerful 'greenhouse gas' nearly 312 times as compared to CO_2.

2.1 Properties of Farm Soil under Organic Farming and Chemical Farming

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). The study was made in Bihar, India where the farm soil is partly sandy being located in the Indo-Gangetic Plain. Natural fertility of the soil is eroded due to heavy use of agrochemicals over the last 50 years.

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

Chemical and biological properties of soil	Organic farming (Use of vermicompost)	Chemical farming (Use of chemical fertilizers)
Availability of nitrogen (kg/ha)	256.0	185.0
Availability of phosphorus (kg/ha)	50.5	28.5
Availability of potash (kg/ha)	489.5	426.5
Azatobacter (1000/gm of soil)	11.7	0.8
Phosphobacteria (100,000/kg of soil)	8.8	3.2
Carbonic biomass (mg/kg of soil)	273.0	217.0

Source: Vermicompost; Suhane (2007)

With continued application of vermicompost the organic nitrogen tends to be released at constant rate from the accumulated 'humus' and the net overall efficiency of nitrogen over a period of years is considerably greater than 50% of that of chemical fertilizers. Availability of phosphorus is sometimes much greater than that from inorganic fertilizers.

2.2 Agrochemicals: The 'Slow Poison' for Civilization

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. Farmers and agricultural laborers complain of headaches, dizziness, vomiting, nausea, difficulty in breathing, sensitivity to light, nails turning black and dropping off and chronic itching. WHO classified the common Class I pesticides 'methyl parathion', 'monocrotophos' and 'methamidophos' as 'extremely hazardous'. Millions of people suffer from 'acute pesticide poisoning' and thousands die every year from it in the developing countries. 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 Report, 1992).

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. 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. A study made by the Society for Research and Initiative for Sustainable Technologies and Institutions (SRISTI), Ahmedabad, India, to analyse the residual pesticide in soils of croplands of Gujarat found that 41 out of 70 samples 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.

A report by the Pesticide Action Network Of North America and Commonwealth 'Nowhere to Hide: Persistent Toxic Chemicals in the US Food Supply' tells that Americans can experience up to 70 daily exposures to residues of POPs (Persistent Organic Pollutants) including DDT and Dioxins through their foods. Two most pervasive POPs found in food are 'dieldrin' and DDE (breakdown product of DDT). Every day in the U.S. nearly 82 people die as a result of 'unintentional poisoning' and another 1,941 are treated for poisoning (CDCP, 2011). Unintentional poisoning is defined as due to persons taking a 'substance not meant to cause harm' and that is some food products especially raw fruits and vegetables from market. The US Agriculture Department showed that 73 % of the food grown conventionally by agrochemicals had residues from at least 'one pesticide' and were 6 times as likely as 'organically grown foods' to contain multiple pesticide residues. 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. 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).

2.3 The Agronomic, Social, Economic and Environmental Significance of Organic Farming

Organic farming by use of composts has several virtues and values. Use of vermicompost still has greater significance as it is 5-7 times more powerful than all the conventionally produced composts. Moreover, its use in farm soil eventually leads to generation of huge population of 'earthworms' from their cocoons in the vermicompost. Earthworms are great soil and environmental managers and add further to the agronomic, social, economic and environmental values of organic farming (Sinha et al., 2011b).

2.4 The Agronomic Significance

2.4.1 Increase the 'soil organic matter' (soil carbon) and soil structure which is vital for crop growth

Application of all composts increase the soil organic matter (SOM) i.e. soil carbon to more sustainable levels, above 3-5 % and improve fertility. In loamy soil, compost applied @16 tonnes /acre (35 t/ha) SOM increased from 1.1 % to 2.5 %. 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 and nutrient holding capacity. Soil 'erosion and compaction' are exacerbated when soils are depleted in organic matter. 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'. Soil carbon in farms is not being replaced in natural way. 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'. Humus enhances mineral breakdown and in turn nutrient availability to plants. Highly mature and stable composts (e.g. vermicompost) contain long-lasting form of carbon called 'humates' or 'humic and fulvic acids' which are very important for soil health and fertility (Compost Australia, 2011).

2.4.2 Increase beneficial soil microbes, microbial activity and essential nutrients

All composts are rich in beneficial soil microbes. Vermicompost is especially rich in microbial diversity. Earthworms further proliferates useful microbes in billions and trillions in soil. Earthworms can modify soil microbial community structure depending on the type of organic matter present in soil (Jack, 2010). 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'.

2.4.3 Improve cation exchange capacity

Compost application also increases the cation exchange capacity (CEC) of soil. An increase in soil CEC leads to higher 'soil adsorption' of positively charged cations such as 'calcium

(Ca), magnesium (Mg), potassium (K) and sodium (Na)'. The increase in cations translates into nutrients being held in the soil and made progressively available for plants uptake. This also leads to 'reduced acidity' and 'higher soil pH' (Compost Australia, 2011).

2.4.4 Reduces bulk density of soil, prevents soil compaction and erosion

All composts including vermicompost reduce the bulk density of the soil, preventing compaction and improving potential root growth, drainage and infiltration. This also reduces 'surface crusting and sealing' and allows better infiltration of rainfall and irrigation. Even a thin seal or crust, often just formed by raindrops on bare soil can reduce infiltration rates and increase 'run-off' and 'erosion'. Earthworms from vermicompost keep the soil more soft by their 'burrowing and aerating actions'. They have been called as 'nature's ploughman'.

2.4.5 Remove soil sodicity and salinity

A soil is regarded as sodic where exchangeable sodium (Na) is higher than 6 % and the pH is greater than 8.5. Compost plays an important role in managing 'sodic' and 'saline' soils. Sodicity is generally fought with application of 'gypsum' which increases the amount of 'exchangeable calcium' in the soil. But it is a slow process. Compost can help in spread of gypsum much faster in the soil by stimulating microbes and soil fauna (earthworms) that creates 'channels and pores' in the soil and gypsum moves through them much faster with rainfall and irrigation. Earthworms help more through their burrowing actions and excretion of vermicast which proliferate useful microbes in billions and trillions. Worms ingest soil and gypsum, mixing them together, resulting in fast and thorough spread of gypsum deep into the soil profile.

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 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).

As all composts (much so vermicompost) 'conserve soil moisture' it reduces the need for irrigation which is generally the source of most salts in soil. Vermicompost also increase the rate of 'water infiltration' and 'reduces evaporation', which means that less salt accumulates at the surface and the top soil is less saline. High soil salinity can also increase susceptibility to disease and nullify the natural disease suppressive effects of composts (Compost Australia, 2011).

2.4.6 Maintain optimal pH value of soil

Most compost have a neutralizing value of 5% calcium carbonate equivalent in the dry matter (3 % in fresh compost) compared with 50 % for ground limestone. The neutralising value of 30 tonnes of fresh compost is roughly equivalent to 2 tonnes of limestone. With repeated application at this rate, soil would either maintain or slightly increase in pH over time. In loamy soil, compost applied @16 tonnes /acre (35 t/ha) pH raised from 6.8 to 7.1 (Compost Australia, 2011).

2.4.7 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. The water stable aggregates of 'polysaccharide gums' produced by the bacteria inhabiting the intestine of earthworms increases the general entry of water into the soil and infiltration due to construction of cemented 'macro-pores' (Bhandari et al., 1967; Munnoli et al., 2002; Munnoli and Bhonsle, 2011). Increasing water holding capacity of soils prevents 'soil erosion' and improves productivity. Stockdrill and Lossens (1966) reported that the earthworms increased the water holding capacity of New Zealand soils by 17 %.

2.4.8 Suppress plant diseases

All composts have been found to suppress high levels of soil-borne disease. Vermicompost is much more efficient. 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* and *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 and 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 the composts suppress crop diseases. These are by competition, secretion of antibodies and hormones, predation and parasitism, induction of systemic defences in plants against diseases and by boosting immune systems (Magdoff, 2004; Hoitink, 2008).

2.5 The Social Significance

2.5.1 Nutritive chemical-free protective food for society

The biggest value of organic farming is that it produces almost 'chemical free and protective food' for the society. Organically grown fruits and vegetables have been found to be highly nutritious and have more beneficial nutrients, such as antioxidants, than their chemically grown counterparts (Anonymous, 2000; Bourne and Prescott, 2006). Antioxidant vitamins in vegetables are some of the nutrients besides vitamins, minerals, flavonoids and phytochemicals, which contribute greatly to human health protection. In a ten-year comparative study Mitchell (2007) reported levels of flavonoids 'quercetin' and 'kaempferol' in organic tomatoes (115.5 and 63.3 mg per gram of dry matter) were 79 % and 97 % higher than those in chemically grown tomatoes (64.6 and 32.06 mg per gram of dry matter) respectively. The levels of flavonoids increased over time in samples of tomatoes treated organically. 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).

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. Significantly higher vitamin C was reported in organically grown spinach, tomato, turnip, apple, cabbage, carrots, beetroots, celery, lentil, lettuce, pepper, potato and pears (Shankar and Sumathi, 2008). Smith (1993) reported high mineral contents in organic foods. 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 and 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.

Table 2. Nutrients levels in food products grown organically

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

Source: Winter and Davis (2006)

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. A serious negative impact of use of chemical fertilizers is the increase of 'water contents' of plant tissues. It other term 'decrease in dry matter'. On the contrary, all organic fertilizers significantly increase the 'dry matter' contents in plants even up to 96 %.

2.5.2 Organic foods reduces the risk of some cancers

More significantly, *in vitro* studies indicate that organic foods can reduce the risks of 'cancer' in humans. 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). 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.

2.5.3 The secondary metabolites in plants: Protector of human health

There are some secondary metabolites which are produced by plants under stress, such as drought or attacks by pests and pathogens as a part of the 'natural plant defence mechanisms'. Some of them may be harmful in high doses. Some beneficial secondary metabolites include 'glucosinolates', 'glycoalkaloids', 'flavonoids', 'carotenoids' and 'sulphur compounds'. They can quench 'free radicals', act as 'anti-proliferative agents', promote 'detoxifying enzymes', induce differentiation of 'cancer cells', 'inhibit metastasis', inhibit 'tumour blood vessel' formation and stimulate the human 'immune system' (Heaton, 2001).

Application of chemical pesticides protects plants from pests and diseases and reduces the needs for plants to produce these beneficial secondary metabolites for their defenses. Organic farming systems using variety of ways (especially by the earthworm vermicompost) to promote plant growth also induce 'biological resistance' in plants against insect pests and disease causing organisms. They naturally contain high levels of such beneficial secondary metabolites (Brandt and Molgaard, 2001). Heaton (2001) found five relevant studies that showed higher levels of 'secondary metabolites' in organic fruits and vegetables.

2.5.4 Impact of Earthworms and Vermicompost on Nutritional 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 and Barrett, 1994). Shankar and Sumathi (2008) studied tomato grown on vermicompost and reported that it had significantly higher total antioxidants, total carotene, iron (Fe), zinc (Zn), crude fibre and lycopene content than the other organically grown tomatoes. Also tomato, spinach and amaranthus grown on vermicompost had significantly higher vitamin C. Vermicompost applied tomato also registered significantly higher 'shelf-life' when stored at room temperature.

2.6 The Economic Significance

2.6.1 Conversion of product of negative economic value to positive economic value

Any composting system converts 'waste' (product of negative economic value) into a 'valuable resource' (nutritive biofertilizer – product of positive economic value) and diverts them from ending up in costly landfills. It is like 'killing two birds in one shot'. Construction of engineered landfills incurs -25 - 30 million US dollars upfront before the first load of waste is dumped. In 2002-03 Australians generated 32.3 million tonnes of MSW of which 17.4 mt i.e. about 54 % ended up in landfills. It costed $ 2458.2 million (Australian Bureau of Statistics, 2004).

2.6.2 Higher production of safe organic foods at low cost

A matter of considerable economic significance is that in organic farming by use of vermicompost 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 and 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 and 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 and 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 too which is also becoming a costly commodity.

2.7 The Environmental Significance of Organic Farming by Earthworms: Safe Waste Management and Mitigation of Global Warming

Organic farming by use of vermicompost and other vermiproducts (vermiwash and vermicompost tea) have been beneficial for environment in several ways –

2.7.1 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.

2.7.2 Diverting wastes from landfills and reducing emission of powerful greenhouse gases

All compost (including vermicompost), are produced from some 'waste materials' of society. Composting of wastes organics by waste eater earthworms (vermicomposting) is proving to be economically and environmentally preferred technology over the conventional microbial composting technology as it 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. It has potential to divert huge amount of wastes ending up in landfills which are proving as an 'environmental burden' for society as they emit large amount of powerful greenhouse gases like methane (22 times powerful than CO_2) and nitrous oxides (312 times powerful than CO_2) along with CO_2. Every 1 kg of waste diverted from landfills prevents 1 kg of greenhouse gas emission equivalent to CO_2. In 2005, landfill disposal of MSW contributed 17 million tons CO_2-e (equivalent) of GHG in Australia, equivalent to the emissions from 4 million cars or 2.6 % of the national GHG emissions (Australian Greenhouse Office, 2007).

2.7.3 Sequestering Carbon in Soil and Mitigating Greenhouse Gases and Global Warming

Much of the world's carbon is held in the soils, including the agricultural (farmlands) soils as 'soil organic carbon' (SOC). The global pool of SOC is about 1,550 Pg C (1 Pg= 1,000 million metric tons or MMT) i.e., 41 %. Taken together with the 'soil inorganic carbon' which is about 750 – 950 Pg C i.e. 23 %, this is about three times of the atmospheric carbon pool as CO_2 which is 20 %. The rest 16 % carbon is with the terrestrial vegetation. (Follett,2001). Ever since agriculture started (7000-10,000 yrs ago) the balance between these two carbon pools SOC and the atmosphere have been changing. The loss of 'soil organic carbon' (SOC) as CO_2 due to aggressive 'ploughing and tillage' in the wake of modern mechanized farming practices has augmented the atmospheric carbon pool as greenhouse gas inducing the global warming and climate change. Soil erosion is also a major cause of the loss of SOC. Use of fossil fuels since 1750 has further accelerated the process. 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). Australia has 473 million hectares of agricultural land and emitted 537 million tonnes of CO_2 in 2009 (Leu, 2011).

All over the world agricultural and environmental scientists are trying to reverse the trend by putting more carbon back into the soil – a process called 'carbon sequestration' through sustainable agricultural practices mainly organic farming by the use of composts. Compost use in farms would 'sequester' huge amounts of atmospheric carbon (CO_2) and bury them back into the soil, mitigate greenhouse gases and global warming. Composts are in fact disintegrated products of 'plant biomass' which are formed from atmospheric CO_2 fixed during photosynthesis by green plants. Plants absorb atmospheric CO_2 and converts them into 'plant material' (biomass) in sunlight. Some of this remains in the ground as soil organic matter (SOM). This is about 58 % of the soil organic carbon (SOC) (Robbins, 2004).

The Intergovernmental Panel on Climate Change (2000) recognized 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. Applying organic wastes or their composted products to agricultural lands could increase the amount of carbon (C) stored in these soils and contribute significantly to the reduction of GHG. Application of composts to the soil can lead either to a build-up of soil organic carbon (SOC) over time, or a reduction in the rate at which soil organic matter (SOM) is being depleted from soils – thus benefiting the soil in every way (Bolan, 2011).

Lal and Bruce (1999) estimated that the carbon sequestration potential of the global croplands (agriculture farms) is about 0.75 – 1.0 Pg C per year. Total potential for soil carbon sequestration by agriculture especially 'organic farming' by the use of composts may be as high as 1.4 Pg C a year which would offset no less than 40 % of the estimated annual increase in atmospheric CO_2 concentration. Soil carbon sequestration in agricultural farmlands by organic farming alone might offset the CO_2 emissions from fossil fuels for one or two decade or even longer. A study by FiBL, the world's largest Organic Scientific Research Organization found that 'Organic Farming' practices remove about 2,000 kg of CO_2 from the atmosphere every year and sequester it in a hectare of farmland. Study by the UK Soil Association found that the organic farming practices by composts remove about 2,200 kg of CO_2 per hectare per year and sequester it in farmland. The peer reviewed Rodale Studies reported that over 7,400 kg of CO_2 can be sequestered per hectare per year. With Australia having 473 mha of farmlands, it has to practise organic farming with higher use of composts and sequester 1,100 kg CO_2 per hectare per year to make Australia CO_2 neutral (Leu, 2011).

But one of the problems faced with the use of all composts as a means of 'soil carbon sequestration' is their subsequent degradation in the soil and release of CO_2 back into the atmosphere. However, as they are 'slow release fertilizers' their carbon get oxidised much slowly and if continued application of composts are made over the years they would capture back the released CO_2 much faster (as the rate of CO_2 fixation by green plants during photosynthesis are very rapid) and bury them back into the soil. A medium term (7-12 years) research from Europe demonstrated that 30 % – 50 % of compost carbon is retained over that period (Biala and Kavanagh, 2011). And as the soil organic matter (SOM) decomposes over time it results in the development of more 'stable carbon compound' called 'humus'. Highly mature and stable composts contain 'long-lasting form of carbon' called 'humates' or 'humic and fulvic acids'.

Earthworms secrete 'humus' and hence the vermicompost contains more stable forms of carbon which remains in the soil for long periods of time and are not emitted as CO_2. Vermicomposts are 'highly degraded and mature composts' prepared in the gut of earthworms and excreted out as 'vermicasts'. And as long as good population of earthworms are there in any farm soil they will continue to feed on the soils with 'fragile carbons' (liable to be oxidised as CO_2) and secrete more 'stable carbons' in the form of humates to be retained in soil.

3. EARTHWORMS and VERMICOMPOST: THE MIRACLE PLANT GROWTH PROMOTER and PROTECTOR

Earthworms are called 'living ploughs' by virtue of their excellent ability to loosen soil, improve soil aggregates stability, improve porosity, increase water infiltration, gather nutrients and enhance nutrients availability and increase fertility by their feeding and burrowing actions. In general the land ploughed by earthworms for 3 years will become high yielding farmland. Healthy soil is rich in minerals, soil microorganisms, earthworms and humus. Air and water can penetrate soil through earthworm tunnels. Earthworms climb up to the surface of soil to grab remnants of plants and feed in tunnels and thus fertilize all strata of soil. 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). Earthworms also encourage root growth and reduce incidence of root diseases, increase pasture and crop yields and increase grain quality in terms of 'protein content'.

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 the conventional composts discussed above. Kale and Bano (1986) reports as high as 7.37% nitrogen (N) and 19.58% phosphorus as P_2O_5 in worms vermicast. 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 has very 'high porosity', 'aeration', 'drainage' and 'water holding capacity'. They have a vast surface area, providing strong absorbability and retention of nutrients. They appear to retain more nutrients for longer period of time. Study showed that soil amended with vermicompost had significantly greater 'soil bulk density' and hence porous and lighter and never compacted. Significantly, vermicompost works as a 'soil conditioner' and its continued application over the years lead to total improvement in the quality of soil and farmland, even the degraded and sodic soils (Nelson and Rangarajan, 2011).

There have been several reports that worm worked waste 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.

Sinha and Valani (2011) has reported extraordinarily good growth of potted cereal and vegetable crops on vermicompost as compared to conventional composts and chemical fertilizers. He also reported good yields in farmed wheat crops grown on vermicompost (comparable with chemical fertilizers) which progressively increased upon successive applications of same amount of vermicompost over the years. Interestingly, lesser amount of vermicompost was needed to maintain the same productivity of the previous years as the 'natural fertility' of the soil was build up over successive application of vermicompost over the years. He also found that there is an 'optimal value' of vermicompost for good crop productivity, below which the productivity is reduced and above which there is no significant increase in productivity. This optimal value may vary from crop to crop.

Application of vermicompost significantly reduces the demand for irrigation by nearly 30-40%. Most remarkable observation was significantly less incidence of pests and disease attacks in vermicompost applied crops.

3.1 Some Significant Properties of Vermicompost of Great Agricultural Values

3.1.1 High levels of bio-available nutrients for plants

Vermicompost contains most nutrients in plant-available forms such as 'nitrates' (N), 'phosphates' (P), 'soluble' potassium (K), and magnesium (Mg) and 'exchangeable' phosphorus (P) and calcium' (Ca). Vermicomposts have large particulate surface areas that provides many micro-sites for microbial activities and for the strong retention of nutrients (Arancon and Edwards, 2006).

3.1.2 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).

Guts of earthworms are 'factories and 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 from diseases (Compant et al., 2005). In a glasshouse trial, Buckerfield et al., (1999) found that the 'stimulatory effects' of vermicompost on plant growth and protection 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.

Pramanik et al. (2007) studied the microbial population in vermicompost prepared from cow dung and municipal solid wastes (MSW) as substrates (raw materials) and found that it was in highest abundance in cow dung vermicompost. The total bacterial count was 73×10^8, the cellulolytic fungi was 59×10^6 and the nitrogen-fixing bacteria was 18×10^3. It was least in vermicompost obtained from MSW. The total bacterial count was 16×10^8, the cellulolytic fungi were 21 x 10^6 and the nitrogen-fixing bacteria were 5 x 10^3. Application of lime in the substrate enhanced the population of all above mentioned microbes irrespective of the substrates used for vermicomposting.

Plant growth promoting bacteria (PGPB) directly stimulates growth by nitrogen (N) fixation, solubilization of nutrients, production of growth hormones such as 1-aminocyclopropane-1-carboxylate (ACC) deaminase and indirectly by antagonising pathogenic fungi by production of siderophores, chitinase, β-1,3-glucanase, antibiotics, fluorescent pigments and cyanide. There is also substantial body of evidence to demonstrate that microbes, including bacteria, fungi, actinomycetes, yeasts and algae, also produce 'plant growth regulators' (PGRs) such as 'auxins', 'gibberellins', 'cytokinins', 'ethylene' and 'ascorbic acids' in appreciable quantities and as their population is significantly boosted by earthworms large quantities of PGRs are available in vermicompost (Sinha et al., 2009 a and b; Sinha and Valani, 2011).

3.1.3 Rich in growth hormones: biochemical stimulating total plant growth

Researches show that vermicompost further stimulates plant growth even when plants are already receiving 'optimal nutrition'. Vermicompost has consistently improved seed germination, enhanced seedling growth and development and increased plant productivity much more than would be possible from the mere conversion of mineral nutrients into plant-available forms. 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. It was demonstrated by Grappelli et al., (1985) 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.

3.1.4 Rich in humic acids: biochemical promoting root growth and 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 acid is secreted by earthworms in its excreta. Without humus plants cannot grow and survive. The 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 (Kangmin 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 et al. (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'.

3.1.5 Vermicompost is free of pathogens

Study indicates that vermicomposting leads to greater reduction of pathogens after 3 months upon storage. Whereas, the samples which are subjected to only thermofilic composting, retains higher levels of pathogens even after 3 months. Earthworms selectively kills all the 'harmful microbes' including *Salmonella* and *Escherichia coli* either by devouring upon them or by secretion of 'anti-pathogenic ceolomic fluids' in the medium in which they inhabit (Sinha and Valani, 2011).

3.1.6 Vermicompost is free of toxic chemicals

Several studies have found that earthworms effectively bio-accumulate or biodegrade several organic and inorganic chemicals including 'heavy metals', 'organochlorine pesticide' and 'polycyclic aromatic hydrocarbons' (PAHs) residues in the medium in which it inhabits (Sinha and Valani, 2011).

4. VERMICOMPOST and ITS PRODUCTS: A POWERFUL BIO-PESTICIDES and SAFE ALTERNATIVE TO THE TOXIC CHEMICAL PESTICIDES

There has been considerable reports and evidences in recent years regarding the ability of earthworms and 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; Arancon et al., 2002; Chaoui et al., 2002; Arancon et al., 2005; Compant et al., 2005; Wang et al., 2007; Elmer, 2009 and Jack, 2010). 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 mechanisms leading to vermicompost-mediated plant defenses against insect pests has not been deciphered but it may be due to the 'antagonistic microbes' found in vermicompost. (Hu et al., 2003). Another possibility is the presence of 'fungivorous' and 'bacterivorous' nematodes or 'insect-parasitic organism' such as the 'entomopathogenic nematodes' (EPN) in vermicompost. EPN are lethal parasites of insects that are widely found in soils throughout the world. Their ability actively to locate their insect hosts, specific association with highly virulent bacteria, high reproductive potential and mass production and harmless impacts on vertebrates and plants make these nematodes highly suitable for the development of environmentally friendly alternatives for the biological control of insect pests instead of chemical control. A *Bacillus* like bacterium appears to be associated with this nematode which does the job. This nematode kills *Galleria* larvae within 5 days, infects and kills two other insects *Pieris rapae and Tenebrio molitor* quickly (Weimin et al., 2010). Study indicates that vermicompost application significantly increase the 'insectivorous' and 'fungivorous' nematodes while depress the population of 'plant-parasitic nematodes' in soils. The other vermiproducts - 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-

4.1 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* & *Aphis* *craccivora*), spider mites (*Tetranychus urticae*), mealy bugs (*Planococcus citri*) and caterpillars (*Pieris rapae*) (Chaoui et al., 2002; Arancon et al., 2002, 2005 & 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.

4.2 Repel Crop Pests

It has been observed that abundant use of nitrogen as in chemical fertilizers attracts aphids more due to more free amino acids. Crops fertilized organically are less or even not at all affected by aphids. Organically grown plants have a more solid 'collenchymatous thickening' systems increasing the mechanical strengths of cell walls and a decreased water contents in plant tissues both favoring a 'protective effect' against aphids. There seems to be strong evidence that earthworm vermicasts repel hard-bodied pests like aphids. 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 (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 degraders aphids were driven from roses in 90 days; at 56 m cfu/dwg in 4 weeks and at 200 m + 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 and 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 and 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 (Personal Communication, 2011).

4.3 Suppress Plant Pests and Disease

Edwards and Arancon (2004), Arancon et al. (2002, 2004, 2005 & 2007a) and Yardim et al. (2006) have found that use of vermicompost resulted in major suppression of all three types of insect pest attacks whether sucking or chewing. In all crops it inhibited the soil-born fungal diseases and suppressed the insect pests such as cabbage white caterpillars, tomato hornworm (*Manduca quinquemaculata*), cucumber beetles (*Acalymma vittatum* and *Diabrotica undecimpunctata*), 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. There was significant decrease in populations of jassids, aphids, coccinellid beetles and spider mites on groundnuts in soils amended with vermicompost (Ramesh, 2000). 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). Chaoui et al., (2002), Edwards and Arancon (2004) & Arancon et al., (Undated) also studied the effects of vermicompost, on suppression of *Phytopthora, Fusarium* and *Plasmodiphora* in tomatoes and cabbage; *Pythium* and *Rhizoctonia* in cucumber and radishes and *Verticillium* on strawberries in greenhouses and suppression of *Phomposis* and *Sphaerotheca fulginae* in 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 and Valani, 2011).

Earthworms have also been found to be directly involved in suppression of soil-borne plant diseases (Elmer, 2009). 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.

Earthworms may also act as 'vector' for dispersal of 'disease-suppressive' useful microbes in soils. (Compant et al., 2005) For example *A. trapezoids* mentioned above 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). The presence of earthworms in soil was also correlated with increase in colonization of wheat roots by *P. corrugata*. In addition to stimulating the activities of and / or dispersing disease-suppressive microbes, earthworms may also directly decrease the viability of plant pathogens. The tobacco mosaic virus (TMV) and cowpea mosaic virus (CPMV) passed through the gut of earthworms *Eisenia fetida* was significantly reduced in its infectivity. Their proteins were completely damaged. The polysaccharide in earthworms are also thought to perform 'anti-bacterial' function on plant – pathogen microbes (Wang et al., 2007).

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. This may become the future safe and non-chemical 'biological based strategies' for crop disease control and protection, completely eliminating the destructive chemical based control. (Jack, 2010).

4.4 Vermiwash: Liquid Filtered Through 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 and 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.

4.5 Vermicompost Tea (Vermicompost Brewed in Water): An Effective Biopesticide: Some Experiences from US

Arancon et al. (2007 b) studied 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. Foliar application of 'vermicompost tea' achieved a yield of 400 % in 'pecan nuts' in the U.S. also increasing 'trees resistance' to insects & pests and eliminating the 'pecan weevil' and 'pecan scab' problems. 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. Hahn got 9 billion chitin and cellulose degraders in a given volume of solution in 24 hours. Hence with smaller amount of vermicompost farmers can make large volumes of vermi-biopesticides with very high number of pest and disease killer microbes (Hahn, 2011 b). (geohahn@gmail.com).

5. FACTORS DETERMINING THE NUTRITIONAL QUALITY OF VERMICOMPOST AS A HIGH GROWTH PROMOTING ORGANIC FERTILIZER

The nutritional quality of vermicompost is determined primarily by the type of the substrate (raw materials) and species of earthworms used for composting, along with microbial inoculants, liming, aeration, humidity, pH and temperature. Cattle dung has been found to yield most nutritive vermicompost when composted by *Eisinea fetida*. Pramanik (2007) found that application of lime @ 5 gm/kg of substrate and 'microbial inoculation' by suitable 'cellulolytic', 'lignolytic' and 'N-fixing' strains of microbes not only enhance the rate of vermicomposting but also results into nutritionally better vermicompost with greater enzymatic (phosphatase and urease) activities. Studies indicate that inoculation with N-fixing bacteria significantly increased the 'nitrogen' (N) content of the vermicompost. Liming generally enhance earthworm activities as well as microbial population. Earthworms after ingesting microbes into its gut proliferate the population of microbes to several times in its excreta (vermicast). It is therefore advantageous to use beneficial microbial inoculants whose population is rapidly increased for rapid composting and also better compost quality.
Pramanik (2007) studied the vermicomposting of four (4) substrates viz. cow dung, grass, aquatic weeds and municipal solid wastes (MSW) to know the 'nutritional status and enzymatic activities' of the resulting vermicomposts in terms of increase in total nitrogen (N), total phosphorus (P) and potassium (K), humic acid contents and phosphatase activity.

5.1 Total Nitrogen (N)

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

5.2 Total Phosphorus (P) and Potassium (K)

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

5.3 Humic Acid

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

5.4 Phosphatase Activity

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

6. SOME EXPERIMENTAL STUDIES ON HIGH GROWTH IMPACTS OF VERMICOMPOST OVER CHEMICAL FERTILIZERS

There have been several reports that earthworms and its vermicompost can induce excellent plant growth and enhance crop production. Edwards and Burrows (1988) found that vermicompost consistently improved seed germination, enhanced seedling growth and development, and increased plant productivity significantly. Thakur and Sharma (2005) reported that the yield, total production, income and profits from crops like maize, wheat and peas increased significantly by 2 to 3 times under organic farming systems by vermicompost as compared to the chemical farming systems by agrochemicals done for years.

6.1 Cereal Crops

Several workers have reported amazing growth impacts of vermicompost on cereal crops especially wheat and rice crops which are either comparable to or better than the chemical fertilizers.

1. Nighawan and Kanwar (1952) studied that earthworms vermicast when applied in wheat crops significantly increased 'plant height', 'number of tillers and leaves', promoted 'early ear heading', increased 'ear head length' and 'dry matter' per plant in *Triticum aestivum* over control. Roberts et al. (2007) also reported significantly high yield of wheat crops under vermicompost.

2. Kale and Bano (1986) studied the grain yield of rice crops (*Oryza sativa*) on vermicompost and chemical fertilizers and found that rice crops receiving vermicompost @ 10,000 kg / ha were statistically at par with those receiving chemicals @ 200 kg / ha. Kale et al. (1992) reported greater population of nitrogen fixers, actinomycetes and mycorrhizal fungi in paddy fields inducing better nutrient uptake by crops and better growth in all vermicompost applied soils.
3. Baker and Barrett (1994) 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.
4. Palaniswamy (1996) studied that earthworms and its vermicast improve the growth and yield of wheat by more than 40 %.
5. Bhattacharjee et al.,(2001) conducted field trial on upland rice using 10 tons of vermicompost (VC) / ha and 5 tons of VC plus NPK (recommended doses) / ha.VC treated plots revealed significant increase in both grain and straw yield coupled with improvement in soil aggregation, water use efficiency and nutrient uptake compared to the control and NPK treated plots.
6. Guerrero (2010) reported about the growth impacts of vermicompost on corn crops (*Zea mays*). There was 14 % increase in ear yield of corn crops applied with vermicompost @ 5 ton / ha as compared to inorganic fertilizers applied at normal recommended dose. The yield of grain in rice crops (*Oryza sativa*) was 40 % higher.
7. Krishnamoorthy and Vajranabhaiah (1986) studied the impact of vermicompost and garden soil in different proportion on wheat crops. They found that when the garden soil and vermicompost were mixed in 1:2 proportions, the growth was about 72-76 % while in pure vermicompost, the growth increased by 82-89 %.
8. Reddy and Ohkura (2004) studied the agronomic impacts of vermicompost on sorghum (*Sorghum bicolour*) and compared with normal compost and chemical fertilizers (N + P_2O_5). Sorghum on vermicompost showed significantly higher growth performances in all growth parameters – root length, number of leaves, plant height and shoot biomass over the normal compost and also over the chemical fertilizers.

6.2 Fruit Crops

Several studies have indicated high growth performance of vermicompost on horticultural crops (Atiyeh et al., 2000). But the presence of live worms in soil makes a significant difference in the numbers of flowers and fruit formation per plant, size and weight of the fruits.

1. Buckerfield and 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.

2. Farmer in Sangli district of Maharashtra, India, grew grapes on '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).
3. 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. 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.
4. 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.
5. 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 %
6. Sarjolta (2009) reported about use of vermicompost in 'apple orchards' in India. It is used once a year between 5-15 kg per plant. About 12 – 30 cm growth per year is 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 fruits' have 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; vineet787@gmail.com).

6.3 Vegetable Crops

Studies on the production of important vegetable crops like tomato (*Lycopersicum esculentus*), eggplant (*Solanum melangona*) and okra (*Abelmoschus esculentus*) on vermicompost have yielded very good results (Agarwal et al., 2010).

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 VC) received an optimal nutrient supply.

2. 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.
3. Karmegam and Daniel (2008) studied the effect of vermicompost and chemical fertilizer on hyacinth beans (*Lablab purpureas*) and found that all growth and 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.
4. Suthar (2009) studied the impact of vermicompost (VC), chemical fertilizers (NPK) and farmyard manure (FYM) on root and 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.

6.4 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 with 38,000 acres of orchards in the New Mexico, 181,000 acres in Texas, 129,000 acres in Georgia and 86,000 acres in Oklahoma. 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. Treatments used included ‘vermicompost’, ‘poultry litter’ and ‘mycorrhizal fungi’. The organically treated test sites out-yielded the conventionally managed and chemically fertilized orchards by 18 pounds per tree in 2005 and by 12 pounds per tree in 2007. More significantly, foliar application of ‘vermicompost tea’ – brew made of vermicompost achieved a yield of 400 % also increasing ‘trees resistance’ to insects and 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).

7. EXPERIMENTAL STUDIES ON POTTED and FARMED CEREAL AND VEGETABLE CROPS

Application of vermicompost in potted and field crops displayed excellent growth performances in terms of height of plants, colour and texture of leaves, appearance of fruiting structures etc. as compared to chemical fertilizers and the marketed conventional composts certified by Compost Australia. There was also less incidences of pest and disease attack and reduced demand of water for irrigation (Agarwal, 1999; Bhatia, 2000; Bhatia et al., 2000; Sharma, 2001; Sinha et al, 2009 a,b; Sinha et al., 2010 a,b,c; Sinha et al, 2011a; Sinha and Valani, 2011).

7.1 Potted Egg-Plants

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.

7.2 Potted Lady's Finger Plants

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.

7.3 Potted Tomato Plants

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 (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'.

7.4 Potted Corn Crops

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 those on vermicompost grew by 15 cm within the same period. Once the worms build up the soil fertility, it enhances growth rapidly. Corn plants with vermicompost in soil also attained maturity (appearance of male and female reproductive organs) very fast.

Most significant finding was that when the dose of vermicompost is doubled from 200 grams to 400 grams, it simply enhanced total plant growth to almost two-fold (from average 58 cm on 200 gm VC to average 104 cm on 400 gm VC). Corn plants with double dose of vermicompost achieved maturity in much shorter time. Male reproductive organs (spike) appeared after 81 days in plants grown on 200 gm of vermicompost, while in those grown on 400 grams, it appeared just after 39 days (in nearly half of the time). The female reproductive organs and eventually the 'new corn' appeared after 96 days and 111 days respectively in plants grown on 200 grams of vermicompost, while it appeared only after 69 days and 75 days respectively, in plants grown on 400 grams of vermicompost.

However, there is an 'optimal limit' about the use of vermicompost for any crop after which there is no significant improvement in crop growth and yield even if the amount of vermicompost is increased substantially. 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.

7.5 Potted Wheat Crops

Wheat crops on vermicompost maintained very good growth from the very beginning and achieved maturity in just 12 weeks. The striking rates of seed germination were very high, nearly 48 hours (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. Seeds were healthy and nearly 35-40% more as compared to plants on chemical fertilizers. The total growth performance of wheat crops (in terms of health, color and texture of shoots and leaves) on vermicompost and earthworms was significantly better over the chemical fertilizers. What they achieved in 8-9 weeks, was achieved by those on chemicals in 12 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.

7.6 Farmed Wheat Crops (India)

We studied the agronomic impacts of vermicompost and compared it with cattle dung compost and chemical fertilizers in exclusive application and also in combinations on farmed wheat crops. Cattle dung compost was applied four (4) times more than that of vermicompost as it has much less NPK values as compared to vermicompost. Exclusive application of vermicompost promoted yield of wheat crops in farms significantly higher (40.1 Q/ha) over the chemical fertilizers (34.2 Q/ha) applied in full dose. This was nearly 18% higher over chemical fertilizers. And when same amount of agrochemicals were supplemented with vermicompost @ 25 quintal/ha the yield increased to about 44 Q/ha which is only about 10% higher over the wheat crops grown on exclusive application of vermicompost. This 10% increase in production do not make much economic sense as it will be neutralized by the high cost of agrochemicals and hence the high cost of crop production. On cattle dung compost applied @ 100 Q/ha (4 times of vermicompost) the yield was just over 33 Q/ha which is about 18% less than that on vermicompost and that too after using 400% more conventional composts.

Application of vermicompost had other agronomic, economic and environmental benefits. It significantly 'reduced the demand of water for irrigation' by nearly 30-40%. Test results indicated 'better availability of essential micronutrients and useful microbes' in vermicompost applied soils. Most remarkable observation was significantly 'less incidences of pests and disease' attacks in vermicompost applied crops.

8. IMPORTANT FEEDBACKS FROM FARMERS IN INDIA and AUSTRALIA USING VERMIPRODUCTS

We interviewed some farmers in India using vermicompost and 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 and maturity and reduced harvest cycle.

Table 3. Farmers' opinion on the use of vermicompost on various crops

Crops	Doses of Vermicompost Applied	Growth Impacts
1. Cereals	**2 Tons /Acre**	
Oats		Very Good
Rice		Excellent
Maize		Very Good
2. Pulses	**2 Tons /Acre**	
Garden Pea		Very Good
Black Gram		Very Good
3. Oil Seeds	**3 – 5 Tons / Acre**	
Sunflower		Very Good
Ground Nut		Very Good
Soyabean		Very Good
Mustard		Very Good
4. Vegetables	**4 – 6 Tons / Acre**	
Cabbage		Excellent
Potato		Excellent
Tomato		Excellent
Carrot		Excellent
Pumpkin		Excellent
Cucumber		Very Good
5. Fruits	**2 – 3 Kg / Plant**	
Grapes		Excellent
Banana		Excellent
Water-melon		Excellent
Custard apple		Excellent
Pomegranate		Excellent
Mango		Very Good
6. Ornamentals	**4 Tons / Acre**	
Roses		Excellent
Chrysanthemum		Excellent
Marigold		Excellent
7. Other Crops		
Sugarcane		Excellent
Cotton		Very Good
Tea		Good
Coffee		Very Good

Source: (Kale, 1998; 2006)

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 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.
- 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; (Sinha et al. 2009a).

Kale (2006) also interviewed some farmers in India who has been applying vermicompost on various crops for over 5-6 years. Opinions of farmers about growth impacts and amount of vermicompost used are given in table 3 above. Growth impacts included total health of the crops with flowering and fruiting.

9. CONCLUSIONS AND REMARKS

Various kinds of 'Organic Fertilizers' e.g. Farm Yard Manure, Cattle Dung Compost, Poultry Droppings, MSW Compost, Sewage Sludge, Microbial Inoculants and Plant Bio-fertilizers and Earthworm Vermicastings are being produced and used for farming all over the world some due to economic reasons where farmers cannot afford for the costly chemical fertilizers and others due to social and environmental reasons in developed nations who are getting aware of the potential impending dangers of use of agrochemicals in food production. There are reports of use of 'human urine' in Nepal. Urine contains a balanced mix of nutrients like nitrogen (N), phosphorus (P), potassium (K) and sulphur (S). Up to 90 % of the P can be precipitated in powder form called 'struvite' ($MgNH_4PO_4.6H_2O$) by adding magnesium (Mg) (Etter, 2011). However, microbiological contamination and safety of food is an important concern related with the use of all 'organic fertilizers' made from either human wastes or animal manures if they have not been properly treated or composted. Regulations require that they must be applied more than 90 days before harvest. Use of earthworm vermicompost has the biggest advantage as they are completely 'disinfected' and also 'detoxified' by the earthworms and also highly nutritive & rich in humus. A quiet 2nd 'Non-Chemical Ever Green Revolution' is now taking place in Asia and all over the world in various names like 'The Ecological Agriculture', 'Organic Agriculture' etc. (Lampkin, 1990). Today over 60,000 farmers in Bangladesh and 20,000 in India are practising Ecological Agriculture called 'Nayakrishi Andolan' (New Agricultural Movement) with the help of earthworms and its vermicompost (Kesavan & Swaminathan, 2006).

Vermicompost performed significantly well over conventional composts 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 (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. Soil amended with vermicompost have significantly greater 'soil bulk density' and hence porous and lighter and never get compacted needing no or low tillage. Moreover, the worms keep the soil porous and soft by their burrowing actions. About 10,00000 (1 million) earthworms in a farm plot would provide the same benefit as three farmers working 8 hours in shifts all year round while also adding 10 tons of organic manure to the plot. Another great significance of vermicompost application is 'less incidence of pest and disease attacks' on crops and better taste and nutritive value of fruits and vegetables grown on it.

A matter of great significance 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).

Earthworms 'biomass' produced during vermicomposting comes as a additional valuable resource for the farmers. It is finding new uses in feed, pharmaceutical and detergent industries and for promoting 'poultry and fishery' as they are rich in 'proteins'. Some 'bioactive compounds' found in earthworms promises to produce modern medicines for curing some deadly diseases of mankind.

Future researches about vermicompost use in agriculture should be directed towards following studies –

1. Growth promotion activities in major crops (cereals, pulses, fruits and vegetables), time taken for maturation and yield and with view to replace 'chemical fertilizers';
2. Incidence of pest and disease attacks on crops, 'pest repellent and disease suppressive' activities of vermicompost, supported by the use of 'vermiwash' and 'vermicompost tea' and with view to eliminate the use of 'chemical pesticides';

3. Nutritional quality and storage values of fruits and vegetables, protein values of cereals and pulses produced by vermicompost;
4. Reduction in water for irrigation due to increased 'water holding capacity' of soils by vermicompost; and
5. Mitigation of 'global warming' by reduction of GHG emissions during vermicomposting of organic wastes, reduced 'tillage' of farm soil and sequestration of atmospheric 'carbon' into soil by vermicompost.

REFERENCES

Anonymous. (2000). Organic food is far more nutritious: Newsletter of the National Assoc. Of Sustainable Agriculture Australia (NASAA); Feb. 10, 2000.

Anonymous. (2001). Vermicompost as insect repellent; Biocycle., Jan. 01, 19.

Ayres, Mathew. (2007). Suppression of soil-borne plant diseases using compost; Paper Presented at 3rd National Compost Research and Development Forum; Organized by COMPOST Australia, Murdoch University, Perth.

Agarwal, Sunita. (1999). Study of vermicomposting of domestic waste and the effects of vermicompost on growth of some vegetable crops; Ph. D Thesis Awarded by University of Rajasthan, Jaipur, India. (Supervisor: Dr. Rajiv K. Sinha)

Agarwal, Sunita, Sinha, Rajiv K., Sharma, Jaya. (2010). Vermiculture for sustainable horticulture: agronomic impact studies of earthworms, cow dung compost and vermicompost vis-à-vis chemical fertilizers on growth and yield of lady's finger (*Abelmoschus esculentus*). Int.J. of Global Environmental Issues ; In Rajiv K. Sinha et. al. (Eds.) Special Issue on 'Vermiculture Technology'), 10, 366-377.

Ansari, Abdullah, A. (2008). Effect of vermicompost on the productivity of potato (*Solanum tuberosum),* spinach (*Spinacia oleracea*) and turnip (*Brassica campestris*); World Journal of Agricultural Sciences, 4(3), 333-336.

Arancon, N.Q., Edwards, C. A., Lee, S. (2002). Management of plant parasitic nematode population by use of vermicomposts; Proceedings of Brighton Crop Protection Conference on Pests and Diseases, 8B-2, 705–716. (arancon.1@edu.osu).

Arancon, N.Q., Edwards, C.A., Bierman, P., Metzger, J.D., Lee, S. and Welch, C. (2003).Effects ofvermicomposts on growth of field-grown tomatoes, peppers and strawberries; Pedobiologia., 47, 731-735.

Arancon, N.Q., Edwards, C.A., Bierman, P., Welch, C., Metzger, J.D. (2004). Influences of vermicomposts on field strawberries: effects on growth and yields. Bioresource Technology., 93(2), 145-153.

Arancon, N.Q., Edwards, C.A. (2004). Vermicompost can suppress plant pest and disease attacks; Biocycle., 51 – 53.

Arancon, N.Q., Galvis, P.A., Edwards, C.A. (2005). Suppression of insect pest populations and damage to plants by vermicomposts. Bioresource Technology, 96(10), 1137-1142.

Arancon, N.Q., Edwards, C.A. (2006). Effects of vermicompost on plant growth; In: Guerrero, R.D. and Guerrero-del Castillo, M.R. (Eds): Vermitechnologies for Developing Countries*;* Philippine Fisheries Association, Laguna, Philippines., pp. 32 - 65.

Arancon, N.Q., Edwards, C.A., Yardim, E.N., Oliver, T.J., Byrne, R.J. and Keeney, G. (2007a). Suppression of two-spotted spider mite, mealy bugs and aphids populations and damage by vermicomposts; Crop Protection., 26, 29 – 39.

Arancon, N.Q., Edwards, C.A., Dick, R., Dick, L. (2007b). Vermicompost tea production and plant growth impacts; Biocycle (November), pp. 51-52.

Atiyeh, R.M., Subler, S., Edwards, C.A., Bachman, G., Metzger, J.D., Shuster, W. (2000). Effects of vermicomposts and composts on plant growth in horticultural container media and soil; Pedobiologia., 44, 579-590.
Atiyeh, R.M., Lee, S., Edward, C.A., Arancon, N.Q., Metzger, J.D. (2002). The influence of humic acids derived from earthworm-processed organic wastes on plant growth; J. of Bioresource Technology, 84, 7-14.
Baker, Geoff, Barrett, Vicki. (1994). Earthworm identifier; Publication of Council of Scientific and Industrial Research Organization (CSIRO), Division of Soil and Land Management, Australia.
Biala, J., Kavanagh, A. (2011). Use compost for mitigating climate change; Paper presented at Int. Symposium on 'Organic Matter Management and Compost Use in Horticulture'., Adelaide, Australia, April 4-7, 2011; (biala@optusnet.com.au)
Binet, F., Fayolle, L., Pussard, M. (1998). Significance of earthworms in stimulating soil microbial activity. Biol. Fertil. Soils, 27(1), 79-84.
Bolan, N.S. (2011). Enhancing soil carbon sequestration utilizing compost; Paper presented at Int. Symposium on 'Organic Matter Management and Compost Use in Horticulture'; Adelaide, Australia, April 4-7, 2011, University of South Australia (Nanthi.bolan@unisa.edu.au).
Bhatia, Sonu. (2000). Earthworm and sustainable agriculture: study of the role of earthworm in production of wheat crop*;* Ph.D Thesis Awarded by University of Rajasthan, Jaipur, India. (Supervisor: Rajiv K. Sinha).
Bhatia, Sonu, Sinha, Rajiv K., Reena Sharma. (2000). Seeking alternatives to chemical fertilisers for sustainable agriculture: a study on the impact of vermiculture on the growth and yield of potted wheat crops (*Triticum aestivum* Linn). International J. of Environmental Education and Information; University of Salford, UK, 19(4), 295-304.
Bhatanagar, P., Mamta Sharma. (1993). Monitoring of organochlorine pesticide residues in wheat and drinking water samples from Jaipur (India); Academy of Environmental Biology Symposium on 'Toxicity Evaluation in Biosystems'., Indore, India, Nov. 7-9, 1993.
Bhattacharjee, G., Chaudhari, P.S., Datta, M. (2001). Response of paddy crop on amendment of the field with different levels of vermicompost. Asian J. Of Microbiol. Biotech. and Env. Sc., 3, 191-196.
Bhandari, G.S., Randhwa, M.S.and Naskina, M.S. (1967). Polysaccharide contents of earthworms casts; Current Science., 36, 519 – 520.
Bombatkar, Vasanthrao. (1996).The miracle called compost; The Other India Press, Pune, India.
Bourn, D., Prescott, J. (2002). A comparison of the nutritional value, sensory qualities and food safety of organically and conventionally produced foods. Critical Review of Food Science & Nutrition, 42, 1 – 34.
Brandt, K., Molgaard, J.P. (2001). Organic agriculture; does it enhance or reduce the nutritional value of plant foods? J. of Science of Food & Agriculture., 31, 924 – 931.
Buckerfield, J.C., Webster, K.A. (1998). Worm-worked waste boost grape yield: prospects for vermicompost use in vineyards; The Australian and New Zealand Wine Industry Journal., 13, 73-76.
Buckerfield, J.C., Flavel, T.C., Lee, K.E., Webster, K.A. (1999). Vermicompost in solid and liquid forms as a plant-growth promoter; Pedobiologia., 43, 753-759.
Canellas, L.P., Olivares, F.L., Okorokova, A.L., Facanha, R.A. (2000). Humic acids isolated from earthworm compost enhance root elongation, lateral root emergence and plasma membrane H^+-ATPase activity in maize roots; J. of Plant Physiology., 130, 1951-1957.
CDCP (2011). Poisoning in the U.S. Fact Sheet; Centres for Disease Control and Prevention; (www.cdc.gov/injury/wisqars)

Chaoui, H.I., Zibilske, L.M., Ohno, T. (2003). Effects of earthworms casts and compost on soil microbial activity and plant nutrient availability. J. of Soil Biology and Biochemistry., 35 (2), 295-302.

Chaoui, H.I, Edwards, C.A., Brickner, A., Lee, S.S., Arancon, N.Q. (2002). Suppression of the plant parasitic diseases: *Pythium* (damping off), *Rhizoctonia* (root rot) and *Verticillium* (wilt) by vermicompost. Proceedings of Brighton Crop Protection Conference on Pest and Diseases;

Compost Australia (2011). Compost for Soils; Publication of Compost Australia; (www.compostforsoils.com.au).

Compant, S., Duffy, B., Nowak, J., Clement, C., Barka E.A. (2005). Use of plant growth-promoting bacteria (from soil) for bio-control of plant diseases; Principles, mechanisms of action and future prospects. Appl. Environ. Microbiol., 71 (9), 4951 – 4959.

Davis, D.R., M.D. Epp, H.D. Riordan. (2004). Changes in USDA food composition data for 43 garden crops, 1950 to 1999. J. Of American College of Nutrition, 23, 669 – 682.

Edwards, C.A., Burrows, I. (1988). The potential of earthworms composts as plant growth media; In Edward, C.A. and E.F. Neuhauser (Eds.), Earthworms in Waste and Environmental Management. SPB Academic Publishing, The Hague, The Netherlands; ISBN 90-5103-017-7, pp: 21-32.

Edwards, C.A. and Arancon, N.Q. (2004). Vermicompost supress plant pests and diseases attacks. In *REDNOVA NEWS*: http://www.rednova.com/display/?id =55938

Edwards, C.A., Arancon, N.Q., Vasko-Bennett M., Askar, A., Keeny, G., Little, B. (2010). Suppression of green peach aphid *(Myzus periscae*), citrus mealybug (*Planococcus citri*) and two spotted spider mite (*Tetranychus urticae*) attacks on tomato and cucumbers by aqueous extracts from vermicompost; J. Of Crop Protection, 29, 80- 93.

Elmer, W.H. (2009). Influence of earthworm activity on soil microbes and soil-borne diseases of vegetables. Plant Dis., 93(2), 175-179.

Etter, B., Elizabeth, T. and Kai, M.U. (2011). Urine as a resource in Nepal: Sandec News: Dept. of Water and Sanitation in Developing Countries; July 2011, No. 12. (www.eawag.ch/stun). (bastian.etter@eawag.ch).

Follet, R. (2001). Soil management concepts and carbon sequestration in croplands soils'; Soil and Tillage Research., 61, 77-92.

Grappelli, A., Tomati, V., Galli, E. and Vergari, B. (1985). Earthworm casting in plant propagation. Horticultural Science, 20, 874-876.

Gunathilagraj, K. (1996). 'Earthworm: An Introduction'; Indian Council of Agricultural Research Training Program. Tamil Nadu Agriculture University, Coimbatore.

Guerrero, R.D. (2010). Vermicompost production and its use in crop production in the philippines; Int. J. of Global Environmental Issues ; In Rajiv K. Sinha et. al., (Eds.) Special Issue on 'Vermiculture Technology', 10, 378-383. Inderscience Pub.

GRDC (2010). Recycled organic fertilizer fact sheet; Grains Research and Development Corporation (Australia); (www.grdc.com.au).

Hahn, George. (2011). 'Chitin rich vermicompost repels pests and suppress plant diseases; (Personal Communication; Email: geohahn@gmail.com).

Hahn, George. (2011b). Effect of vermicompost tea on pecan nuts; Personal Communication; Email: (goehahn@gmail.com).

Heaton, S. (2001). Organic farming: food quality and human health; A Review of the Evidence; Soil Assoc. Of the United Kingdom, Bristol.

Hoitink, Harry. (2008). Compost use for disease suppression; In 'On farm Composting Handbook' (www.plantpath.osu.edu).

Huber, D.M., Schneider, R.W. (1982).The description and occurrence of disease suppressive soils; In R.W. Schnieder and St. Paul (Ed.) 'Suppressive Soils and Plant Disease'; American Phytopathological Society, 1-7.

Hu, Y., Sun, Z., Cheng, W. (2003). Advances in vermiculture and inhibition of vermicompost to soil-borne disease. Chinese J. of Applied Ecology, 14, 296 – 300.

Ismail, A., Cheah, S.F. (2003). Determination of vitamin C, β-carotene and riboflavin contents in five green vegetables organically and conventionally grown. Malaysian J. of Nutrition, 9(1), 31 – 39.

Jack, Allison. (2010). Suppression of plant pathogens with vermicomposts; In CA Edwards, NQ Arancon, and RL Sherman (Eds.) 'Vermiculture Technology: Earthworms, Organic Wastes and Environmental Management'., Boca Raton, FL, CRC Press (US)., p.623

Kale, R.D., Bano, K. (1986). Field trials with vermicompost. an organic fertilizer; In Proc. of National Seminar on 'Organic Waste Utilization by Vermicomposting'. GKVK Agricultural University, Bangalore, India.

Kale, R.D., Mallesh, B.C., Kubra, B., Bagyaraj, D.J. (1992). Influence of vermicompost application on the available macronutrients and selected microbial populations in a paddy field. Soil Biology and Biochemistry., 24, (12), 1317-1320.

Kale, R.D. (1998). Earthworm: Cinderella of organic farming; Prism Books Pvt. Ltd., Bangalore, India (dr.rdkale@gmail.com).

Kale, R.D. (2006). Vermicompost – crown jewel of organic farming (A Memoir); N.D. Kale, Malleswaram, Banglore, India; (dr.rdkale@gmail.com)

Kangmin, Li., Peizhen, Li, Hongtao, Li.(2010). Earthworms helping economy, improving ecology and protecting health. Int. J. of Global Environmental Issues; In Rajiv K. Sinha et. al. (Eds.), Special Issue on 'Vermiculture Technology', 10, 354-365. Inderscience Pub.

Karmegam, N., Daniel, T. (2008). Effect of vermicompost and chemical fertilizer on growth and yield of hyacinth bean (*Lablab purpureas*); Dynamic Soil, Dynamic Plant; Global Science Books, 2(2), 77-81.

Krishnamoorthy, R.V., Vajranabhaiah, S.N. (1986). Biological activity of earthworm casts: an assessment of plant growth promoter levels in the casts; Proc. of Indian Academy of Sciences (Animal Science), 95, 341-351.

Kesavan, P.C., Swaminathan, M.S. (2006). Farm green revolution to ever green revolution: pathways and technologies; Current Science, 91,145 – 46.

Lampkin, N. (1990). Organic Agriculture., Farming Press; Ipswitch, U.K.

Lal, R. and Bruce, J. (1999). The potential of world's croplands soils to sequester carbon (c) and mitigate the greenhouse effect; Environmental Science and Policy., 2, 177-185.

Leu, A. (2011). Mitigating climate change with soil organic matter; Paper presented at Int. Symposium on 'Organic Matter Management and Compost Use in Horticulture'; Adelaide, Australia, April 4-7, 2011; Organic Federation of Australia (leu@austarnet.com.au)

Leclerc, J., Miller, M.L., Joliet, E., Rocquelin, G. (1991). Vitamin & mineral contents of carrot & celeriac grown under mineral & organic fertilization. J. of Biological Agriculture & Horticulture., 7, 339 – 348.

Lloyd, Janice. (2011). Disturbing new information: pesticides in food; (www.offthegridnews.net); In 'USA TODAY'. (Personal Communication by George Hahn; geohahn@gmail.com)

Lumpkin, H.M. (2005). A comparison of lycopene and other phytochemicals in tomatoes grown under conventional and organic management systems; The World Vegetable Centre, Taiwan; Technical Bull.; AURDC., 34(4),48.

Magdoff, F.R. (2004). Soil organic matter in sustainable agriculture' (www.compostforsoils.com.au)

McKnight, G.M., Duncan, C.W., Leifert, C. And Golden, M.H. (1999). Dietary nitrate in man: friend or foe? British Journal of Nutrition, 81, 349 – 358.

Mitchell, A.E. (2007).Ten-year comparison of the influence of organic and conventional crop management practices on the flavonoids in tomatoes. J. of Agricultural and Food Chemistry, (June 2007)

Munroe, Glenn. (2007). Manual of on-farm vermicomposting and vermiculture; Pub. of Organic Agriculture Centre of Canada., pp: 39.

Munnoli, P.M., Arora, J.K., Sharma, S.K. (2002). Impact of vermi-processing (by earthworms) on soil characteristics; J. Of Ind. Pollution Control, 18(1), 87 – 92.

Munnoli, P.M., Saroj, B. (2011). Water holding capacity of vermicompost of press-mud in mono and polyculture vermireactors; The Environmentalist (UK); (Accepted for Publication); (prakashsunanda@rediffmail.com).

Neilson, R.L. (1965). Presence of plant growth substances in earthworms, demonstrated by the paper chromatography and went pea test. Nature, (London), 208, 1113-1114.

Nelson, Eric. and Rangarajan, Anu. (2010). Vermicompost: a living soil amendment; Publication of Cornell University, Ithaca, U.S. (http://cwmi.css.cornell.edu/vermicompost.htm).

Nighawan, S.D., Kanwar, J.S. (1952). Physico-chemical properties of earthworm castings. Indian J. of Agricultural Sciences, 22, 357-375.

Olsson, M.E., Anderson, C.S., Oredsson, S. Berglund, R.H. and Gustavsson,K-E. (2006). Antioxidants levels and inhibition of cancer cells proliferation in-vitro by extracts from organically and conventionally cultivated strawberries. J. of Agricultural Food and Chemistry, 54, 1248 – 1255.

Palaniswamy, S. (1996). Earthworm and plant interactions; Paper presented in ICAR Training Program; Tamil Nadu Agricultural University, Coimbatore.

Parle, J.N. (1963). A microbiological study of earthworm casts. J of General Microbiology., 31, 13-23.

Pramanik, P., Ghosh, G.K.,Ghosal, P.K., Banik, P. (2007). Changes in organic-C, N, P and K and enzyme activities in vermicompost of biodegradable organic wastes under liming and microbial inoculants; J. of Bioresource Technology., 98, 2485-2494.

Ramesh, P. (2000). Effects of vermicompost & vermicomposting on damage by sucking pests to groundnut (*Arachis hypogea*); Indian J. Agric. Sci., 70(5), 334.

Rao, B. Narsimha. (1993). Pollution problems caused by pesticides; Symposium on Toxicity Evaluation in Biosystem; Academy of Environmental Biology., Indore, India. Nov. 7-9, 1993.

Reddy, Vikram, Katsumi, Ohkura. (2004). Vermicomposting of rice straw and its effect on sorghum growth. Tropical Ecology., 45 (2), 327-331.

Roberts, P., Jones, G.E., Jones, D.L. (2007). Yield responses of wheat (*Triticum aestivum)* to vermicompost. Compost Science and Utilization, 15, 6-15.

Robbins, Mike. (2004). Carbon trading, agriculture and poverty; Pub. of World Association of Soil and Water Conservation.,(Special Pub. No. 2); 48 pp.

Sadhale, Nailini. (1996). Recommendation to incorporate earthworms in soil of pomegranate to obtain high quality fruits. In Surpala's Vrikshayurveda, Verse 131. The Science of Plant Life by Surpala, 10th Century A.D. Asian Agri-History Bulletin; No. 1. Secunderabad, India.

Sarjolta, Vineet. (2009). Use of Vermicompost in Apple Orchards in Himachal Pradesh, India; Personal Communication (Email: vineet787@gmail.com).

Scheu, S. (1987). Microbial activity and nutrient dynamics in earthworms casts. J. of Biological Fertility Soils, 5, 230-234.

Scholder, Jerry. (2011). Introduction to vermistabilization: WORMS (Worms Operating to Reduce Municipal Sludges) to produce organic fertilizers; Personal Communication; (jerry@vermistabilization.com).

Schuphan, W. (1974). Nutritional value of crops as influenced by organic and inorganic fertilizer treatments. Plant Foods & Human Nutrition, 23, 333-358.

Shankar, K.S., Sumathi, S. (2008). Effect of organic farming on nutritional profile of tomato crops; Central Research Institute for Dryland Agriculture; Hyderabad, India.

Sharma, Reena. (2001). Vermiculture for sustainable agriculture: study of the agronomic impact of earthworms and their vermicompost on growth and production of wheat crops; Ph.D. Thesis; Awarded by University of Rajasthan, Jaipur, India (Supervisor: Dr. Rajiv K. Sinha).

Singh, R., Sharma, R.R., Kumar, S., Gupta, R.K., Patil, R.T. (2008). Vermicompost substitution influences growth, physiological disorders, fruit yield and quality of strawberry (Fragaria ananassa Duch.). Bioresoursce Technology, 99, 8507-8511.

Sinha, Rajiv K., Sunil, Herat, Dalsukh, Valani, Krunal, Chauhan. (2009a). Vermiculture and Sustainable Agriculture'; American-Eurasian J. of Agricultural and Environmental Sciences; ISSN 181, 5 (S), 01- 55. IDOSI Publication (Special Issue).

Sinha, Rajiv K., Pancham, Singh, Dalsukh, Valani, Sunita, Agarwal. (2009b). Earthworms vermicompost: an economically viable and environmentally sustainable alternative to destructive chemical fertilizers: some experimental studies on potted and farmed cereal and vegetable crops; In Justin A Daniels (Ed.) Advances in Environmental Research - 9 (Chapter 2); NOVA Science Publishers, N.Y., USA; ISBN: 978 – 1 – 61728 – 999 - 6.

Sinha, Rajiv K., Dalsukh, Valani. (2010). Earthworms : Charles Darwin's 'Unheralded soldiers of mankind and farmer's friend' working day and night under the soil: their role as soil managers; In Justin A Daniels (Ed.) Advances in Environmental Research - 9 (Chapter 8); NOVA Science Publishers, N.Y., USA; ISBN: 978 – 1 – 61728 – 999 - 6.

Sinha, Rajiv K., Agarwal, S., Chauhan, K., Valani, Dalsukh. (2010a). The wonders of earthworms and its vermicompost in farm production: Charles Darwin's 'friends of farmers', with potential to replace destructive chemical fertilizers from agriculture; J. of Agricultural Sciences., 1 (2), 76-94. Scientific Research Publication, USA.

Sinha, Rajiv K., Pancham, Singh, Dalsukh, Valani, Sunita, Agarwal. (2010b). Earthworms vermicompost : an economically viable and environmentally sustainable alternative to destructive chemical fertilizers: some experimental studies on potted and farmed cereal and vegetable crops; In Justin A Daniels (Ed.) Advances in Environmental Research - 9 (Chapter 2); NOVA Science Publishers, N.Y., USA; ISBN: 978 – 1 – 61728 – 999 - 6.

Sinha, Rajiv K., Dalsukh, Valani, Krunal Chauhan, Sunita Agarwal. (2010 c).Embarking on a second green revolution for sustainable agriculture by vermiculture biotechnology using earthworms: reviving the dreams of Sir Charles Darwin. J. of Agricultural Biotechnology and Sustainable Development., 2(7), 113-128. Academic Journals, USA;

Sinha, Rajiv K., Dalsukh, Valani. Brijal, K. Soni, Vinod, Chandran. (2011a). Earthworms vermicompost : a sustainable alternative to chemical fertilizers for organic farming; Agricultural Issues and Policies; NOVA Science Publishers, N.Y., USA; ISBN 978-1-61122-580-8.

Sinha, Rajiv K., Dalsukh, Valani, Vinod, Chandran, Brijal, K. Soni. (2011b). Earthworms - the soil managers: their role in restoration and improvement of soil fertility; Agricultural Issues and Policies; NOVA Science Publishers, N.Y., USA; ISBN 978-1-61122-514-3.

Sinha, Rajiv K., Dalsukh, Valani. (2011). Vermiculture Revolution: The Technological Revival of Charles Darwin's Unheralded Soldier's of Mankind; NOVA Science Publication, U.S.A. (Under Publication)

Smith, B.L. (1993). Organic foods versus supermarket foods: elemental levels. J. Of Appl. Nutrition, 45, 35 – 39.

Stockdill, S.J., Lossens, G.G. (1966). The role of earthworms in pasture production and moisture conservation; Proc. Of New Zealand Grassland Association, pp. 168 – 183.

Subler, Scott., Edwards Clive and Metzger James, (1998). Comparing vermicomposts and composts. Biocycle., 39, 63-66.

Suhane, R.K. (2007). Vermicompost (In Hindi); Pub. Of Rajendra Agriculture University, Pusa, Bihar., pp: 88 (www.kvksmp.org) (Email: info@kvksmp.org).

Suthar, S. (2009). Impact of vermicompost and composted farmyard manure on growth and yield of garlic (*Allium stivum* L.). Int. J. of Plant Production, 3(1), 1-12.

Thakur, D.S., Sharma, K.D. (2005). Organic farming for sustainable agriculture and meeting the challenge of food security in 21st century: An economic analysis. Ind. J. of Agric. Economics., 60 (2), 205-219

Tiwari, S.C., Tiwari, B.K., Mishra, R.R. (1989). Microbial populations, enzyme activities and nitrogen-phosphorus-potassium enrichment in earthworm casts and in surrounding soil of a pineapple plantation. J. of Biology and Fertility of Soils., 8, 178-182.

Tomati, V., Grappelli, A., Galli, E. (1987). The presence of growth regulators in earthworm-worked wastes; In Proc. of Int. Symp. on 'Earthworms'; Italy; 31 March-5 April, 1985., pp: 423-436.

UNEP/GEMS. (1992).The contamination of food; Publication of United Nation Environment Program., Environment Library No. 5, Nairobi, Kenya.

UNEP. (2001). Breaking the cycle of poison; Report by Sarojeni V. Rengam (www.ourplanet.com)

Wang, C., Sun, Z., Liu, Y., Zheng, D., Liu, X., Li, S. (2007). Earthworm polysaccharide and its anti-bacterial function on plant-pathogen microbes in vitro; European J. Of Soil Biol., 43, 135-142.

Webster, Katie, A. (2005). Vermicompost increases yield of cherries for three years after a single application; J. Of Eco-Research, South Australia,(www.ecoresearch.com.au).

Winter, C.K., Sarah, F. Davis. (2006). Organic Foods. J. of Food Science, 71, 117 – 124.

Weimin, Ye, Andrea, Torres-Barragan, Yasmin, J. Cardoza. (2010). *Oscheius carolinensis* n. sp. (Nematoda: Rhabditidae): A potential entomopathogenic nematode from vermicompost; Nematology, 12(1), 121 – 135.

Worthington, V. (2001). Nutritional quality of organic versus conventional fruits, vegetables and grains. J. Of Alternative and Complementary Medicine, 7, 161 – 173.

Yardim, E.N., Arancon, A.Q., Edwards, C.A., Oliver, T.J., Byrne, R.J. (2006). Suppression of tomato hornworm and cucumber beetles populations and damage by vermicomposts. Pedobiology, 50, 23 – 29.

Yasmin, J.C. (2011). *Arabidopsis thaliana* resistance to insects mediated by an earthworm-produced organic soil amendment. Pest Management Science, 67, 233 – 238.

Xu, Kuiwu, Xingting, Dai. (1998). 'Culture and utilization of earthworms". Nanjing Publisher, China.
