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Full Length Research Paper

Sustainable Agriculture by Vermiculture: Earthworms and Vermicompost Can Ameliorate Soils Damaged by Agrochemicals, Restore Soil Fertility, Boost Farm Productivity and Sequester Soil Organic Carbon to Mitigate Global Warming

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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 which help in renewing natural fertility. It 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 with a serious 'withdrawal symptoms'. Application of 'composts' in farming are thought to be the answer to the 'restoration of damaged soils', 'promotion of high food productivity' while also improving 'soil fertility'. The scientifically produced 'composts' from food and farm wastes, with recent knowledge in biotechnologies are highly productive 'organic fertilizer' than those produced earlier by farmers in conventional ways. Among them the vermicompost made by biodegradation of waste organics by waste eater earthworms are scientifically proving to be a great 'soil conditioner and ameliorator' increasing the total physical, chemical and biological properties of soil, removing chemical contaminants from farm soil, restoring essential nutrients and improving soil fertility and promoting high crop productivity'. It is superior to all conventionally prepared composts giving productivity equivalent to, or even better than the chemical fertilizers. The earthworms germinated from the cocoons in vermicompost further help in conditioning the soils and improving its quality and fertility. Earthworms are great soil managers. More significantly, compost use in farms has potential to 'sequester' huge amounts of atmospheric carbon (CO_2) and bury them back into the soil improving soil fertility and also mitigating global warming. Application of all 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 and the environment in every way. The Intergovernmental Panel on Climate Change (2000) recognised that carbon (C) sequestration in soils as one of the possible measures through which the greenhouse gas (GHG) emissions and global warming can be mitigated.

Keywords: Earthworms as Soil Managers; Vermicomposts Can Ameliorate Chemically Contaminated and Damaged Soils; Vermicompost – Enrich Soils With Essential Nutrients and beneficial Soil Microbes; Composts – Sequester Atmospheric Carbon in Soil and Mitigate Global Warming**.**

INTRODUCTION

Chemical fertilizers which ushered the ‘green revolution’ in the 1950-60’s came as a ‘mixed blessing’ for mankind. It boosted food productivity, but at the cost of environment 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 soil with a serious ‘withdrawal symptoms’. There has been serious ‘contamination of the human food’ also due to the ‘residual pesticides’ remaining on fruits, vegetable and cereals after they are transported out from the farms for the consumers. (UNEP/GEMS,1992).

Application of ‘composts’ in farming are thought to be the answer for the ‘high food productivity while also maintaining soil fertility and productivity. Among them the vermicompost made by biodegradation of waste organics by waste eater earthworms are scientifically proving to be a ‘great soil amender and plant growth promoter’ superior to all conventionally prepared composts increasing the physical, chemical and biological properties of soil, restoring and improving its natural fertility. Vermicompost is rich in NKP (nitrogen 2-3%, potassium 1.85-2.25% and phosphorus 1.55-2.25%), micronutrients and also contain ‘plant growth hormones and enzymes’. All composts, but more so in vermicompost contain plenty of ‘beneficial soil microbes’ which help in ‘soil regeneration’ and ‘fertility improvement’ and also ‘protect crops from soil born diseases’.

The earthworms germinated from the cocoons in vermicompost further help in conditioning the soils and improving its quality and fertility. Earthworms are bio-indicators of healthy and fertile soils. Their populations indicate soil carbon levels and conditions that encourage biological activity, root growth and nutrient cycling. They are great ‘soil managers’ as envisaged by Sir Charles Darwin. They can even regenerate the ‘degenerated soils’ and restore its fertility and productivity.

‘Humus’ in vermicompost excreted by worms is of great agronomic value for the soils. It takes several years for soil organic matter (SOM) or ordinary composts to decompose to form humus while earthworms secrete humus in its excreta (vermicasts). Without humus plants cannot grow and survive. The ‘humic acids’, ‘fulvic acids’ and ‘humins’ in humus are essential to soil and plants in several ways. They hold ‘clay and sand’ together to form what we call ‘soil’. Billions of tons of humic substances are disappearing from soil worldwide every year due to floods, fires, and poor agricultural practices. Vermicompost has very high ‘porosity’, ‘aeration’, ‘drainage’ and ‘water holding capacity’ thus making the soil more ‘soft and porous’. It appears to retain more nutrients for longer period of time and work as ‘slow release fertilizer’ in soil.

Much of the world’s carbon is held in the soils, as ‘soil organic carbon’ (SOC). Loss of SOC as CO_2 due to aggressive ‘ploughing and tillage’ has augmented the atmospheric carbon pool inducing global warming and climate change. 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 use of composts. Vermicompost contains more ‘stable forms of carbon’ as ‘humus’ which remains in the soil for long periods of time and are not degraded and emitted as CO_2.

Earthworms: The great soil managers and protectors

Earthworms derive their name from ‘earth’ meaning ‘soil’. Sir Charles Darwin believed that soil could not be present on earth until earthworms evolved and flourished. They are great ‘soil managers and protectors of earth’ as envisaged by Sir Charles Darwin who called them as ‘unheralded soldiers of mankind’ working day and night under the soil. They are adapted to live in different soil types from high organic carbon content to mineral soils (very low carbon content) and also sodic soils. Earthworms act as an aerator, grinder, crusher, chemical degrader and a biological stimulator in soil. In soil they inevitably work as ‘soil conditioner’ to improve its total physical, chemical and biological properties and also its nutritive value and productivity. This they do by soil fragmentation and aeration, breakdown of organic matter in soil and release of nutrients, secretion of plant growth hormones and, proliferation of nitrogen-fixing bacteria. Worms swallow large amount of soil with .organics everyday and digest them by enzymes. This is excreted out in the form of fine mucus coated granular aggregates called ‘vermicastings’ which are rich in NKP, micronutrients and beneficial soil microbes.

One square meter of healthy soil contains 1,000 earthworms. One acre of land can contain up to 3 million earthworms, the activities of which can bring 8 - 10 tonnes of topsoil to the surface (in the form of nutrient rich vermicasts) every year. Earthworms population of 0.2 to 1.0 million per hectare of land can be established within 3 months. Earthworms loosen the soil as they move through it. Their activity creates channels in the soil for movement of air and water. Presence of worms improves water penetration in compacted soils and can increase cumulative rainfall intake by up to 50%. Soils with a large healthy worm population drain 4 - 5 times faster than soils with very few worms. Worm activity can increase air-soil volume from 8 - 30% and increases the bioavailability of nutrients and trace elements which are present in the soil.

Barley and Jennings (1959) reported that worms significantly contribute nitrogen (N) contents to soil by over 85%. Earthworms can contribute between 20 to 40 kg nitrogen/ha/year in soil, in addition to other mineral nutrients and plant growth regulators and increase soil fertility and plant growth by 30-200%. (Darwin, 1881).

Earthworms recycle nitrogen in the soil in very short time and the quantity recycled is significant ranging from 20 to 200 kg N/ha/year. After 28 weeks soil with living

Table 1: Properties and Nutrient Value of Compost for Soil Amendments

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

Source: '*Vermiculture and Sustainable Agriculture*'; Sinha et al.,(2009

worms contained 75 ppm of nitrate nitrogen compared to the control soil without worms which contained 45 ppm. Worms increase nitrogen levels in soil by adding their metabolic and excretory products (vermicast), mucus, body fluid, enzymes and decaying tissues of dead worms. They also contribute nitrogen indirectly through fragmentation of organic materials and grazing on soil microorganisms. Earthworm tissues contains about 7.9 % N on a dry weight basis. Living worms release nitrogen from their bodies and after death it is rapidly decomposed in about 4 days releasing all nitrogen into the soil. In a study with potted ryegrass, over 70 % of the N15 added was incorporated into plant shoots after 16 days. Study found that 50% of the N in dead worm tissues was mineralized in 7 days while 70% in 10-20 days and the N was converted to NO3-N which is bio-available form on nitrogen to crop roots. The release of mineral N after death of earthworms could be significant since worm biomass can turn over up to 3 times a year in farm soil. Study estimated direct flux of nitrogen through earthworm biomass in farm soils ranging from 10-74 kg N/ha/year. In corn field mortality and decomposition of dead earthworms could contribute 23.5 kg N /ha/year. In case of inorganic fertilizer-treated farm soil it is only 15 .9 kg/ha/year.

Composts: The great soil builder and protector

Composts are decomposed products of organic wastes such as the cattle dung and animal droppings, farm and forest wastes and the municipal solid wastes (MSW). Bombatkar (1996) called them as 'miracle' plant growth promoter. They supply balanced nutrients to soil and stimulate growth; increase organic matter content of the soil including the 'humic substances' that affect nutrient accumulation and promote root growth. They in fact improve the total physical and chemical properties of the soil. They also add useful micro-organisms to the soil and provide food for the existing soil micro-organisms and thus increase their biological properties and capacity of self-renewal of soil fertility(table 1 above).

There are several agronomic benefits of composts application to soil. Composts contribute to healthy soils and plants in several ways. They improve 'soil structure' and 'moisture retention capacity' making water available for plants when they need it. They increase the amount of nutrients that are 'bio-available' to plants with steady release of nutrients over time. It also protects soil against 'extremes of temperature' and moisture.

The beneficial impacts of compost / vermicompost on soil

All composts have several beneficial effects on soil properties (Magdoff, 2004; Hoitink, 2008). But vermicompost especially has miraculous effects. This is because they eventually generate huge population of earthworms in the soil from their cocoons.

i). Increase the 'Soil Organic Matter' (SOM), soil structure and prevent soil erosion

Australian soils are generally low in organic matter. Application of compost 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 at16 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. It can save 10-20 % of irrigation inputs. 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 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).

ii). Increase beneficial soil microbes, microbial activity and essential nutrients

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. Many nutrients are constantly removed from the farm soil every year through cropping. For example, nitrogen (N) is removed from 17 kg/t of yield with oats to 40 kg/t of yield with canola. Phosphorus (P) is removed from 2kg/t of yield with cereals to 6.5 kg/t of yield with canola. Potassium (K) is removed from 3.7 kg/t of yield with wheat to 20 kg/t of yield with hay. (GRDC, 2010). Nitrogen is also lost by oxidation as 'nitrous oxides' which is a powerful greenhouse gas (312 times than carbon dioxide). However as composts add 'biological nitrogen' it is oxidised very little as compared to the 'chemical nitrogen' added by the use of chemical fertilizers. 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'.

iii). Improve cation exchange capacity

Compost application also increases the cation exchange capacity (CEC) of soil. In loamy soil, compost applied at16 tonnes /acre (35 t/ha) CEC increased from 14.4 to 20.1 meq/100 gm. 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 more 'clay and organic matter' available, the greater the availability of the soil to absorb cations. 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).

iv). Reduces bulk density of soil, prevents soil compaction and erosion

Soil is made of large and small particles, organic matter and pockets of air (pores) and 'spaces' which determines its 'porosity'. Small pores (micro-pores) are important for water storage, while the large (macro-pores) for water infiltration and drainage, air movement and root growth. When this soil structure is disturbed soil can become 'compacted' and porosity is lost.

Bulk density gives a measure of 'soil porosity'. Soils with low bulk density have higher pore space, are less tightly packed and have a greater potential to store water and allow for roots to grow readily. Composts reduces the bulk density of the soil, improving potential root growth, drainage and infiltration. This also reduces 'surface crusting and sealing'and allow 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'.

v). Suppression of soil-born plant diseases

Composts have been found to suppress high levels of soil-borne disease. The global movement for 'Organic Farming' is directed towards restoration of biologically active 'disease-suppressive' fertile soils that can also 'protect plant health' while promoting plant growth. Earthworms may also act as 'vector' for dispersal of 'disease-suppressive' useful microbes in soils. (Compant et al., 2005). The disease-suppressive soils were first described in the late 1800s (Huber and Schneider, 1982). Vermicompost is much more efficient. Chaoui et al, (2002) and Jack (2010). 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 and it is done by a wide range of compost microbes. 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. Disease suppression depends upon maturity of composts. Nearly 90 % of ‘mature composts’ provides general suppression against ‘root rots’ caused by the fungus *Phytopthora* and *Pythium*. But ‘immature composts’ can increase the severity of plant diseases because as the organic matter breaks down it releases sugars which provides food for plant pathogens. Different compost ingredients (feedstock) gives different results. Carbon-rich composts are good at suppressing ‘plant parasitic nematodes’ because they support fungi which are antagonistic to these nematodes. 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. High soil salinity can also increase susceptibility to disease and nullify the natural disease suppressive effects of composts. Then composts with high salt content can encourage *Phytopthora* and *Pythium* causing root rots.

vi). 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 %.

This is of great agronomic significance as the ground water table is rapidly falling throughout the world including in Australia. Within 25 years, half of the world’s population could face hardship in finding enough freshwater for drinking and food production. About 3 million litre of water is needed to produce 1 hectare of corn; about 12-20 million litre to produce 1 ha of rice and about 250 litre to produce 1 kg of wheat. With the use of chemical fertilizers the demand for irrigation of chemically grown crops have further increased substantially.

vii). Remove soil salinity and sodicity

Almost a third of all agricultural land in Australia is affected by salinity or sodicity and this is increasing.

Sodium bonds with chlorine in the soil to form a salt. This reduces the availability of water to plants and can even cause plant death when present in high levels in soil. When chlorine is washed away leaving behind the ‘sodium’ it is sodic soil. Without its accomplice chlorine, sodium attaches to tiny clay particles in the soil. This makes the clay particles to lose their ability to stick together when wet and leads to soil instability. Sodic soils are prone to erosion and waterlogging. A soil is regarded as sodic where exchangeable sodium (Na) is higher than 6 % and the pH is greater than 8.5. High soil salinity can also increase susceptibility to disease and nullify the natural disease suppressive effects of composts.

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 earthworms that creates ‘channels and pores’ in the soil for movement of air and water and gypsum moves through them much faster with rainfall and irrigation.

Earthworms help more through their burrowing actions and excretion of vermicast which proliferates 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. Worms can alone combat salinity. 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%. There are several reports about earthworms combating soil salinity from Australian vineyards. (Sinha et al., 2009; Sinha et al, 2011 b).

As compost ‘conserve soil moisture’ it reduces the need for irrigation which is generally the source of most salts in soil. Compost 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. (Compost Australia, 2011).

viii). 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 at16 tonnes /acre (35 t/ha) pH raised from 6.8 to 7.1. (Compost Australia, 2011).

Compost use sequester atmospheric carbon into soil and mitigate 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 - in soils as SOC and the atmosphere as CO_2 have been changing. The loss of 'soil organic carbon' (SOC) as CO_2 due to aggressive 'ploughing and tillage' in the wake of modern mechanised farming practices has augmented the atmospheric carbon pool as greenhouse gas inducing the global warming and climate change. Of the increase of atmospheric carbon over the last 150 years, about a third (33.3 %) is thought to have come from agriculture (Robbins, 2004). 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 disintegrated products of 'plant biomass' 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) recognised that carbon (C) sequestration in soils as one of the possible measures through which the greenhouse gas (GHG) emissions and global warming can be mitigated. 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 world agricultural crops and more by 'organic farming' with 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 emitted 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'.

As earthworms secrete 'humus' in its excreta vermicompost contains more stable forms of carbon which remains in the soil for long periods of time and are not emitted as CO_2. Also 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 (germinated from cocoons in vermicompost) 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 the soil for long time. Also there is significantly 'reduced' need of 'soil tillage and ploughing' in farms with continued application of vermicompost over the year, further reducing CO_2 emissions from SOC.

Vermicompost: The miracle soil conditioner and regenerator of degraded Soils

Vermicompost is a highly 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

Table 2: Farm Soil Properties Under Vermicompost Vis-a-vis Chemical Fertilizers

Chemical and Biological Properties of Soil	Organic Farming (Use of Vermicompost)	Chemical Farming (Use of Chemical Fertilizers)
1) Availability of nitrogen (kg/ha)	256.0	185.0
2) Availability of phosphorus (kg/ha)	50.5	28.5
3) Availability of potash (kg/ha)	489.5	426.5
4) *Azatobacter* (1000/gm of soil)	11.7	0.8
5) Phospho bacteria (100,000/kg of soil)	8.8	3.2
6) Carbonic biomass (mg/kg of soil)	273.0	217.0

Source: *Vermicompost*; Suhane (2007)

fungi' and are scientifically proving as a 'miracle for even degenerated soils' with significantly high agronomic impacts (5-7 times) on crops over the conventional composts (Subler et al, 1998). 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) for soils. 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. Farmer in Sangli district of Maharashtra, India, grew grapes on 'eroded wastelands' with degraded soils and applied vermicasting at 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; Sinha and Valani, 2010; Sinha et al, 2011 a and b). 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 at 6 tons/ha as compared to control. There was significant improvement in soil quality of plots amended with vermicompost at 6 tons / ha. The sodicity (ESP) of the soil was 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.

There have been several reports that soils amended with vermicompost can induce excellent plant growth. (Agarwal, 1999; Sharma, 2001; Roberts et al, 2007; Agarwal et al, 2010; Guerrero, 2010; Sinha et al, 2009 and 2010, a, b and c). 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. Sinha and Valani (2011) has reported extraordinarily good growth of potted soil 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 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.

Application of vermicompost has other soil benefits. It significantly reduces the demand for irrigation by nearly 30-40% as soil moisture improves. Test results indicated better availability of essential micronutrients and useful microbes in vermicompost applied soils.

Properties of farm soil using vermicompost vis-a-vis chemical fertilizers

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) (Table 2 above).

Earthworms and Vermicompost Can Clean-Up Contaminated / Polluted Soils and Restore Fertility

No farmland of world are free of toxic pesticides, mainly aldrin, chlordane, dieldrin, endrin, heptachlor, mirex and toxaphene. Use of vermicompost in any farmland results into development of huge population of earthworms in the farm soil germinated from the worm 'cocoons'. Earthworms have been found to bio-accumulate heavy metals, pesticides and lipophilic organic micro-pollutants like the polycyclic aromatic hydrocarbons (PAHs) from the soil. Several studies have found definite relationship between 'organochlorine pesticide' residues in the soil and their amount in earthworms, with an average concentration factor (in earthworm tissues) of about 9 for all compounds and doses tested. Studies indicated that the earthworms bio-accumulate or biodegrade 'organochlorine pesticide' and PAHs residues in the medium in which it lives. (Davis,1971; Haimi et al., 1992).

Earthworm uptake chemicals from the soil through passive 'absorption' of the dissolved fraction through the moist 'body wall' in the interstitial water and also by mouth and 'intestinal uptake' while the soil passes through the gut. They swallow large amount of soil every day, grind them in their gizzard and digest them in their intestine with aid of enzymes. Only 5-10 percent of the digested and ingested material is absorbed into the body and the rest is excreted out in soil in the form of fine mucus coated granular aggregates called 'vermicastings' which are rich in NKP, micronutrients and beneficial soil microbes. The worm vermicasts also provides wonderful sites for 'adsorption' of heavy metals and pollutants in soil. This is due the presence of 'hydrophilic' groups in the 'lignin contents' and 'humus' of the vermicompost. Hence the polluted soil is not only 'cleaned-up' but also 'improved in quality and fertility'. (Sinha et al, 2008).

Some significant properties of vermicompost for improving soil fertility and productivity

a). Proliferate the population of earthworms (the 'natural ploughman') in farm soil

Vermicompost contain large number of worm 'cocoons' which germinate into worms eventually proliferating the population of earthworms in farm soil. Up to 3 cocoons per worm per week are produced. From each cocoon about 10-12 tiny worms emerge. Given the optimal conditions of moisture, temperature and feeding materials earthworms can multiply by 2^8 i.e. 256 worms every 6 months from a single individual. Each of the 256 worms multiplies in the same proportion to produce a huge biomass of worms in a short time. The total life-cycle of the worms is about 220 days. They produce 300-400 young ones within this life period.

In general a land inhabited and ploughed by earthworms for 3 years will become high yielding farmland. According to the estimate of an American researcher, 1,000,000 (one million) earthworms in a garden / farm plot provide the same benefit as three gardeners/farmers 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; Sinha and Valani, 2011). Another study in Canada concluded that a 200 sq. ft. garden with low worm population of only five (5) worms / cubic foot in it can produce 35 pounds (about 1/3 lb. per worm) of top-grade fertilizer each garden year. (Gardenline, 1996).

b) High levels of bio-available soil 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).

c) 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. Microbes also help in plant protection. In a glasshouse trial, Buckerfield et al., (1999) found that the 'stimulatory effect' of vermicompost on plant growth was apparently destroyed when it was 'sterilized'.

Parle (1963) reported bacterial count of 32 million per gram in fresh vermicast compared to 6-9 million per gram in the surrounding soil. Scheu (1987) reported an increase of 90% in respiration rate in fresh vermicast indicating corresponding increase in the microbial population. Suhane (2007) found that the total bacterial count was more than 10^{10} per gram of vermicompost. It included *Actinomycetes, Azotobacter, Rhizobium, Nitrobacter* and phosphate solubilizing bacteria which ranged from 10^2-10^6 per gm of vermicompost. The PSB has very significant role in making the essential nutrient phosphorus (P) 'bio-available' for plant growth promotion. Although phosphates are available in soils in rock forms but are not available to plant roots unless solubilised. Pramanik (2007) studied the microbial population in vermicompost prepared from cow dung. The total bacterial count was 73 x 10^8, the cellulolytic fungi was 59 x 10^6 and the nitrogen-fixing bacteria was 18 x 10^3.

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.

d). Contains plant growth hormones

There is also substantial evidence that vermicompost contains growth promoting plant hormones 'gibberlins', 'auxins', 'cytokinins' 'ethylene' and 'ascorbic acids' (secreted by the earthworms and the microbes - bacteria, fungi, actinomycetes, yeasts and algae) which help mineralise the nutrients and make them 'bio-available' to plant roots. As the population of beneficial soil microbes is significantly boosted by earthworms large quantities of growth hormones are available in vermicompost (Tomati et al, 1987).

e) Rich in humic acids for soils

Humic acids are slowly produced in soils after long degradation of organic matters over the years. But the earthworms excrete in its excreta and hence vermicompost is rich in humic acids. Without humus plants cannot grow and survive. (Atiyeh et al, 2007). 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 (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'.

f). Suppress soil-born plant disease and repel insect pests

Edwards and Arancon (2004) and Ayres (2007) have found that use of vermicompost in crops inhibited the soil-born fungal diseases and repelled insect pests. 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). (Anonymous, 2001).
Hahn (2011) also reported that vermicompost 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.

Some studies of crop growth in soils amended with vermicompost, conventional compost and chemical fertilizers

There have been several studies on vermicompost amended soils inducing excellent plant growth as compared to conventional composts and chemical fertilizers. Some important ones are listed here.

Cereal Crops

1). 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 %.
2). Kale et al. (1992) reported greater population of nitrogen fixers, actinomycetes and mycorrhizal fungi inducing better nutrient uptake by crops and better growth in all vermicompost applied soils. The grain yield of rice crops (*Oryza sativa*) receiving vermicompost at 10,000 kg / ha were statistically at par with those receiving agrochemicals at 200 kg / ha. Gradually over the years the amount of vermicompost applied is significantly reduced while maintaining same yield.
3). 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.

Fruit Crops

1). Buckerfield and Webster (1998) found that vermicompost in soil 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. 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 soils and 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

Table: 3: Growth of Wheat Crops (*Triticum aestivum*) on Potted Soil Amended With Vermicompost, Cattle Dung Compost and Chemical Fertilizers

Parameters		Control	Treatment 1 Earthworms and VERMICOMPOST	Treatment 2 CHEMICAL FERTILIZER	Treatment 3 Cattle Dung COMPOST
(1)	Number of seed germinated out of 100	50	90	60	56
(2)	Root length (Av. cm)	7.13	16.46	9.32	8.23
(3)	Shoot length (Av. Cm)	22.1	59.99	25.2	23.1
(4)	Ear length (Av. cm)	4.82	8.77	5.45	5.1
(5)	Total height of plant (Av. cm)	34.16	85.22	39.97	37.30
(6)	Leaf length (Av. cm)	12.73	26.37	14.19	13.45
(7)	Dry weight of ears (Av. cm)	0.135	0.466	0.171	0.16
(8)	Number of seed grains per ear (Average)	11.8	31.1	19.9	17.4
(9)	Chlorophyll content (mg/l)	0.783	3.486	1.947	1.824
(10)	Number of tillers per plant	1	2-3	1-2	1-2

Source: Sharma (2001) .
Key: Av. = Average; Chemical Fertilizer (N=1.40 gm Urea; P=2.50 gm Phosphate; K=1.04 Potash; Earthworms = 50 Nos.; Vermicompost = 250 gm; Compost 250 gm

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). 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 in soil. 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. Farm soils applied with vermicompost had significantly greater 'microbial biomass' than the one applied with inorganic fertilizers.
3). 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.
4). Farmer in Sangli district of Maharashtra, India, grew grapes on soil of 'eroded wastelands' and applied vermicasting at 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).

Our studies on some potted soil crops amended with vermicompost, conventional compost and chemical fertilizers

This was designed to assess the agronomic impacts of vermicompost on soils. About 8 kg of near neutral soil devoid of any organic matter was used in each pot. Chemical fertilizers were used as urea for nitrogen, single super phosphate and murate of potash. Vermicompost and cattle dung compost were prepared indigenously from same feed stock. Cattle dung were processed by mixed species of earthworms *Eisinea fetida, Perionyx excavatus and Eudrilus euginae* to produce vermicompost which was done in 3 months while it took nearly 5-6 months to produce normal cattle dung compost without using earthworms. While vermicompost and cattle dung compost were applied only once, chemicals were applied three times during the period of growth and maturation of crops.

Potted Wheat Crops

Three treatments with four (4) replicas of each were prepared and one kept as control. Results are given in Table 3.

Important Observations and Findings

The potted wheat crops with 'earthworms and vermicompost' in soil made excellent progress from the very beginning - from seed germination until maturation. They were most healthy and green, leaves were broader, shoots were thicker and the fruiting ears were much broader and longer with average greater number of seed grains per ear. Significantly, they were much better (nearly two-fold in growth and bored over 55% more seed grains) over those grown on chemical fertilizers. This conclusively proves that vermicompost significantly improve the nutritional status and other growth promoting factors of soils as compared to the conventional compost over a period of time.

Table :4: Growth of Egg-Plants (*Solanum melangona*) on Potted Soil Amended With Vermicompost, Cattle Dung Compost and Chemical Fertilizers

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

Source: Agarwal (1999); VC * = Vermicompost.

(**N.B.** Value of vegetative growth was taken that was achieved on the 90th day of the study, while the fruiting was estimated from the 45th day and ending with over 120 days).

Table 5: Growth of Okra Plants (*Hubiscus esculentus*) on Potted Soil Amended With Vermicompost, Cattle Dung Compost and Chemical Fertilizers

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

Source: Agarwal (1999); *VC = Vermicompost

Potted Egg-Plants

There were three (3) treatments with five (5) replicas of each and a control. Results are given in Table 4.

Important observations and findings

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, presence of earthworms in soil made a significant difference in development of fruits in egg-plants.

Potted Okra Plants

There were three (3) treatments with five (5) replicas of each and a control. Results are given in Table 5.

(N.B. Value of vegetative growth was taken that was achieved on the 90th day of the study, while the fruiting was estimated after 45th day and ending with over 120 days.).

Important observations and findings

Potted okra 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, presence of earthworms in soil added with vermicompost made a significant difference on the development of fruits of okra plants.

Potted Corn Crops

This study was designed to test the growth promoting

Table 6: Growth of Corn Crops in Potted Soil Amended With Vermicompost and Conventional Compost and Only Earthworms in Soil (Average Growth in cm**)**

Parameters Studied	Treatment – 1 Earthworms (25) With Feed in Soil (400 gm)	Treatment - 2 Conventional COMPOST in Soil (400 gm)	Treatment – 3 VERMICOMPOST in Soil (400 gm)
Seed Sowing	9th Sept. 2007	Do	Do
Seed Germination	5th Day	6th Day	5th Day
Avg. Growth In 3 wks	41	42	53
Avg. Growth In 4 wks	49	57	76
App. of Male Rep. Organ (In wk 6)	None	None	Male Rep. Organ
Avg. Growth In 6 wks	57	70	104
Avg. Growth In 9 wks	64	72.5	120
App. of Female Rep. Organ (In wk 10)	None	None	Female Rep. Organ
App. of New Corn (In wk 11)	None	None	New Corn
Avg. Growth In 14 wks	82	78	135
Color and Texture of Leaves	Green and thick	Light green and thin	Deep green, stout, thick and broad leaves

Source: *Vermiculture Revolution* (Sinha, 2011; NOVA Science Publication, USA)

Table 7: Growth of Wheat Crops in Farm Soils Amended With Vermicompost, Cattle Dung Compost and Chemical Fertilizers

Treatment	Input / Hectare	Yield / Hectare
1) CONTROL	(No Input)	15.2 Q / ha
2) Vemicompost (VC)	25 Quintal VC / ha	40.1 Q / ha
3) Cattle Dung Compost (CDC) 100 Quintal CDC / ha	33.2 Q / ha	
4) Chemical Fertilizers (CF)	NPK (120:60:40) kg / ha	34.2 Q / ha
5) CF + VC	NPK (120:60:40) kg / ha + 25 Q VC / ha	43.8 Q / ha
6) CF + CDC	NPK (120:60:40) kg / ha + 100 Q CDC / ha	41.3 Q / ha

Source: Suhane (2007)

Keys: N = Urea; P = Single Super Phosphate; K = Murete of Potash (In Kg / ha).

capabilities of earthworms (added with feed materials) in soil and soil amended with 'vermicompost', and 'conventional compost'. Vermicompost was prepared indigenously while conventional compost was obtained from local market certified by Compost Australia. It had three (3) treatments with three (3) replicas of each. Results are given in Table 6.

Important observations and findings

Corn plants with vermicompost in soil achieved rapid and excellent growth and attained maturity (appearance of male and female reproductive organs) very fast. Plants on conventional compost could not achieve maturity until the period of study (week 14). Soils with earthworms provided with 'feed materials' performed better than those on conventional compost at the completion of study (Week 14). It infers that worms need sufficient 'organic residues' in soil to feed upon and convert into vermicast which works as 'storehouse' of nutrients and the growth promoting biochemical factors.

Studies on farmed wheat crops

We also studied the growth of wheat crops directly on farm soils amended with vermicompost, cattle dung compost and chemical fertilizers in exclusive application and also in combinations. Cattle dung compost was applied four (4) times more than that of vermicompost. Vermicompost was prepared primarily from 'cattle dung' mixed with 'food and farm wastes'. Results are given in Table 7.

FINDINGS AND DISCUSSION

Exclusive application of vermicompost in farm soils promoted yield of wheat crops 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. On cattle dung compost applied at 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 benefits. It significantly increased the moisture holding capacity of soils by nearly 30-40%. Test results indicated 'better availability of essential micronutrients and useful microbes' in vermicompost applied soils.

Earthworms and vermicompost produce nutritive and health protective organic foods

Organically grown fruits and vegetables (especially on vermicompost) have been found to be highly nutritious, rich in 'antioxidants' than their chemically grown counterparts and can be highly beneficial for human health (Sinha et al., 2011 a and c; Sinha and Herat, 2012). Organic foods have elevated antioxidants levels in about 85 % of the cases studied with average levels being 30 % higher compared to chemically grown foods. (Anonymous, 2000; Benbrook, 2005; Bourne and Prescott, 2006). Smith (1993) reported high mineral contents in organic foods. Antioxidant vitamins in vegetables are some of the nutrients besides vitamins, minerals, flavonoids and phytochemicals, which contribute greatly to human health protection. Studies indicate that organic foods are high in 'organic acids' and 'poly-phenolic compounds' many of which have potential health benefits like antioxidants. (Winter and Davis, 2006). A Japanese study indicated that organic vegetables had 30 % to 10 times higher levels of 'flavonoids' as compared to chemical grown counterparts and with very high 'anti-mutagenic activity'. This is of great significance in preventing some deadly diseases leading to tremendous health benefits (Ren et al., 2001). The greatest anti-mutagenic activity was found in organic spinach.

Studies made at CSIRO (Council of Scientific and Industrial Research Organization), 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.(Sinha et al., 2011 c; Sinha and Herat, 2012; Sinha et. al. 2013)

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. The 'anti-mutagenic' properties of organic foods carry great significance in this respect (Ren et al., 2001; Ferguson et al., 2004). A wide range of studies show that antioxidant plant phenolic compounds are 'anti-proliferative' and can prevent or slow tumour progression. Flavonoids can interfere with several steps in the development of cancers. They can protect DNA from oxidative damage that leads to abnormal cell proliferation. They can inhibit 'cancer promoters' and activate 'carcinogen-detoxification system' (Galati and O'Brien, 2004; Galati et al., 2000). Recent research has confirmed a specific mechanism leading to the anti-cancer activities of the flavonoids 'resveratrol'. It starves cancer cells by inhibiting the actions of a key protein that helps feed cancer cells (Benbrook, 2005).

Studies of flavonoids extracted from 'cranberries' have revealed significant impacts on a number of human cancer cell lines. It is suggested that flavonoids extracts from 'cranberries' might someday find application as a novel 'anti-cancer' drug (Ferguson et al., 2002). Extracts from organic strawberries showed higher 'anti-proliferative' activity against 'colon cancer' and 'breast cancer' cells than did the extracts from conventional strawberries (Olsson et al., 2006). European study found that the carrot antioxidant 'falcarinol' satisfied six criteria suggested for food intake of antioxidants to reduce the risk of cancers (Benbrook, 2005). Tomato is one of the most 'protective food' due to excellent source of balanced mixture of minerals and antioxidants, including vitamin C, total carotene and lycopene. Lycopene has been found to have preventive effects on 'prostate cancer' in human beings. Lumpkin (2005) reported significantly higher lycopene in tomato grown organically. A potent antioxidant in canola oil has recently been discovered which has 'anti-mutagenic', 'anti-proliferative' and 'anti-bacterial impacts' (Kuwahara et al., 2004).

Protection from cardiovascular diseases by organic foods rich in antioxidants

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

Important feedbacks about farm soils from farmers using vermicompost in India

We interviewed some farmers in India using vermicompost for agriculture. Most of them asserted to have switched over to organic farming by vermicompost completely giving up the use of chemical fertilizers in the last 4-5 years with very encouraging results, benefiting their economy (reduced cost of food production), the environment (no use of chemicals) and the society (chemical-free foods). Some of them asserted to have harvested three (3) different crops in a year (reaping 2-3 times more harvest) due to their rapid growth and maturity and reduced harvest cycle.

Some of the important revelation by farmers with respect to soil improvement with vermicompost application were:

1). Reduced use of 'water for irrigation' as application of vermicompost over successive years improved the 'moisture holding capacity' of the soil;

2). Reduced 'termite attack' in farm soil especially where earthworms were in good population;

3). Reduced need of 'tillage and plough' as the soil became more 'porous and soft';

4). Faster rate of 'seed germination' and rapid seedlings growth and development as soil became more porous; (Sinha et al., 2011 c; Sinha and Herat, 2012; Sinha et. al. 2013)

CCONCLUSIONS AND RECOMMENDATION

Use of all compost can benefit the farm soil, agriculture and the environment in every way. But vermicompost is a 'blessing' for soils. It helps the soil by its agronomic properties and also by generating the great soil managers – the earthworms. It can be a sustainable alternative to the costly chemical fertilizers for farmers in both developed and the developing countries while also producing 'safe organic foods' for the society. It adds beneficial soil microbes and the much needed soil organic carbons (SOC) for strengthening the soil structure, preventing erosion and maintaining fertility and high productivity. It can improve the total physical, chemical and biological properties of soil which has been destroyed by the long use of chemical fertilizers over the years. It also improves 'moisture holding capacity' of the soil by 30-40 % and thus reducing water for irrigation by the same amount.

Use of composts also make the soil more porous and soft and require much less tillage thus saving on cost of fossil fuels for farmers and reducing emissions of greenhouse gases. Reduced tillage would also reduce the loss of SOC as CO_2, mitigate global warming and reverse the 'soil degradation' caused since millennia by ploughing.

Among the various composts, both made indigenously from food wastes and cattle dung and those from the market duly certified by Compost Australia, the earthworms vermicompost performed significantly well in promoting growth of all crops – cereals, fruits and vegetables when amended in soils in both potted crops as well as in farmed crops experiments. There was also 'less incidences of pest and disease attack', better taste of fruits and vegetables grown on vermicompost. In case of vegetable crops presence of earthworms in soil made a significant difference in the growth and development of fruits. This testifies the beliefs of ancient Indian Scientist Sir Surpala (10^{th} Cent. A.D.) who recommended to add earthworms in the soil to get good fruits of pomegranate. (Sadhale, 1996). This definitely relates with secretion of flowering hormones 'gibberlins' by earthworms which aids in flower formation and fruit development. Nevertheless, all soils applied with vermicompost would eventually have good number of earthworm population after sometimes, germinated from their cocoons in vermicompost.

Compost use in farms would also 'sequester' huge amounts of atmospheric carbon (CO_2) and bury them back into the soil, mitigate greenhouse gases and global warming. Application of all 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 (releasing back some CO_2) – thus benefiting the soil and the environment in every way. Vermicompost is beneficial this way too as it contains more 'stable carbon' (as humates) that resists depletion/degradation and CO_2 emission.

Vermicompost will be a 'recipe' to restore the 'degenerated and chemically contaminated soils' of world agricultural ecosystems resulting from the heavy use of agrochemicals in the wake of green revolution.

All composts are of biological origin i.e. a 'renewable resource' and will be readily available to mankind in future. Chemical fertilizers are made from 'non-renewable' and 'depleting' resources apart from being highly destructive to farm soils.

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