

The wonders of earthworms & its vermicompost in farm production: Charles Darwin's 'friends of farmers', with potential to replace destructive chemical fertilizers from agriculture

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ABSTRACT

Earthworms and its excreta (vermicast) promises to usher in the 'Second Green Revolution' by completely replacing the destructive agrochemicals which did more harm than good to both the farmers and their farmland. Earthworms restore & improve soil fertility and significantly boost crop productivity. Earthworms excreta (vermicast) is a nutritive 'organic fertilizer' rich in humus, NPK, micronutrients, beneficial soil microbes—'nitrogen-fixing & phosphate solubilizing bacteria' & 'actinomycets' and growth hormones 'auxins', 'gibberellins' & 'cytokinins'. Both earthworms and its vermicast & body liquid (vermiwash) are scientifically proving as both 'growth promoters & protectors' for crop plants. In our experiments with corn & wheat crops, tomato and egg-plants it displayed excellent growth performances in terms of height of plants, color & texture of leaves, appearance of flowers & fruits, seed ears etc. as compared to chemical fertilizers and the conventional compost. There is also less incidences of 'pest & disease attack' and 'reduced demand of water' for irrigation in plants grown on vermicompost. Presence of live earthworms in soil also makes significant difference in flower and fruit formation in vegetable crops. Composts work 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. However, with application of vermicompost the 'organic nitro-

gen' tends to be released much faster from the excreted 'humus' by worms and those mineralised by them and the net overall efficiency of nitrogen (N) is considerably greater than that of chemical fertilizers. Availability of phosphorus (P) is sometimes much greater. Our study shows that earthworms and vermicompost can promote growth from 50 to 100% over conventional compost & 30 to 40% over chemical fertilizers besides protecting the soil and the agro-ecosystem while producing 'nutritive and tasty food' at a much economical cost (at least 50-75% less) as compared to the costly chemical fertilizers.

Keywords: A Slow Release Fertilizer; Vermicompost – Miracle Growth Promoter; Rich in Nutrients; Humus & Hormones; Vermicompost Induce Biological Resistance in Plant; Suppress & Repel Pest Attack

1. INTRODUCTION

A revolution is unfolding in vermiculture studies for vermicomposting of diverse organic wastes by waste eater earthworms into a nutritive 'organic fertilizer' and using them for production of 'chemical-free safe food', both in quantity & quality without recourse to agrochemicals. Heavy use of agro-chemicals since the 'green-revolution' of the 1960's boosted food productivity, but at the cost of environment & society. It killed the beneficial soil organisms & destroyed their natural fertility, impaired the power of 'biological resistance' in crops making them more susceptible to pests & diseases. Che-

mically grown foods have adversely affected human health. The scientific community all over the world is desperately looking for an 'economically viable, socially safe & environmentally sustainable' alternative to the agro-chemicals.

Vermicomposts work as a 'slow-release organic fertilizer'. With their continued application the 'organic nitrogen' & other nutrients in compost tends to be released at constant rate from the accumulated 'humus' and the net overall efficiency of NPK over a period of years is considerably greater than 50% of that of chemical fertilizers. Our study shows that it can promote growth from 50 to 100% over conventional compost & 30 to 40% over chemical fertilizers besides protecting the soil and the agro-ecosystem while producing 'nutritive and tasty food' at a much economical cost (at least 50-75% less) as compared to the costly chemical fertilizers. Study found that maximum benefit from vermicompost is obtained when it constitutes between 10 to 40% of the growing medium [1].

The best part is that the use of earthworms and vermicompost in farm production provides dual-benefit to crops. While promoting excellent growth it also protects the crops from pests and diseases and thus significantly reduce the use of chemical pesticides.

Several farms in world especially in North America, Australia and Europe are going organic as the demand for 'organic foods' are growing in society. In 1980, the U.S. Board of Agriculture published a '*Report and Recommendations on Organic Farming*' based on case studies of 69 organic farmers in U.S. and reported that over 90,000 to 1,00,000 farmers in U.S. had already switched over to organic farming [2]. This must have gone in millions now. Earthworms will provide the answer [3]. They have over 600 million years of experience in land management, soil improvement & farm production. No wonder, Sir Charles Darwin called them as the 'unheralded soldiers of mankind and farmer's friend working day and night under the soil' [4,5]. Im-

portance of earthworms in growth of crop plants was indicated by the ancient Indian scientist Surpala as early as in the 10th Century A.D. in his epic 'Vrikshayurveda' (Science of Tree Growing) who suggested to add earthworms in pomegranate plants to get good quality of fruits [6].

2. EARTHWORMS: THE SOIL MANAGER

Earthworms restore & improve soil fertility and boost crop productivity by the use of their excretory products - 'vermicast'. They excrete beneficial soil microbes, and secrete polysaccharides, proteins and other nitrogenous compounds into the soil. They promote soil fragmentation and aeration, and bring about 'soil turning' and dispersion in farmlands. Worm activity can increase air-soil volume from 8-30%. One acre of land can contain up to 3 million earthworms the activities of which can bring up to 8-10 tons of 'top soil' to the surface (in the form of vermicast) every year. Presence of worms regenerate compacted soils and improves water penetration in such soils by over 50%. [7-9]. U.S. study indicate that 10,000 worms in a farm plot provides the same benefit as three farmers working 8 hours in shift all year round with 10 tons of manure applied in the plot [10].

Indian study showed that an earthworm population of 0.2-1.0 million per hectare of farmlands can be established within a short period of three months. On an average 12 tons/hectare/year of soil or organic matter is ingested by earthworms, leading to upturning of 18 tons of soil/year, and the world over at this rate it may mean a 2 inches of fertile humus layer over the globe [11]. Studies at CSIRO, Australia found that introductions of earthworms in disturbed lands can yield substantial benefits to agricultural productivity and amelioration of soil degradation.

3. CHEMICAL FERTILIZERS-A BANE, COMPOST THE BOON: REDISCOVERING THE VALUE OF 'COMPOST' FOR SAFE FOOD PRODUCTION

Chemical fertilizers which ushered the 'green revolution' in the 1950-60's came as a 'mixed blessing' for mankind. It dramatically increased the 'quantity' of the food produced but decreased its 'nutritional quality' and also the 'soil fertility' over the years. The soil has become addict and increasingly greater amount of chemical fertilizers are needed every year to maintain the soil fertility and food productivity at the same levels. There is evidence that a plateau has been reached in global efforts to in-

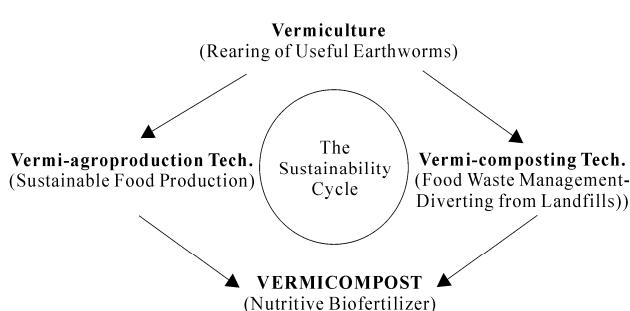


Figure 1. The sustainability cycle of vermiculture technology: from food waste to food again.

crease the yield per hectare through agro-chemicals. The early response to chemical fertilizers is 'levelling off' after a 3% annual increase 1950-1984. Over the years it has worked like a 'slow poison' for the soil with a serious 'withdrawal symptoms'. The farmers today are caught in a 'vicious circle' of higher use of agrochemicals to boost food productivity at the cost of declining soil fertility. 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.

Organic farming systems with the aid of various nutrients of biological origin such as compost (conventional microbial compost or vermicompost made by earthworms) are thought to be the answer for the 'food safety and security' in future. Among them 'composts' made from biodegradation of organics of MSW (municipal solid waste) which is being generated in huge amount every day all over the world are most important. The organic fraction of the MSW (about 70-80%) containing plenty of nitrogen (N), potash (K) and phosphorus (P) is a good source of macro and micronutrients for the soil. Also, there is always greater economic as well as ecological wisdom in converting as much 'waste into compost'.

4. AGRONOMIC VALUES OF COMPOST (CONVENTIONAL OR VERMICOMPOST)

Composts (conventional or vermicompost) are aerobically decomposed products of organic wastes such as the cattle dung and animal droppings, farm and forest wastes and the municipal solid wastes (MSW). Some believe it is a 'miracle' plant growth promoter [12]. They supply balanced nutrients to plant roots and stimulate growth; increase organic matter content of the soil and thus improve their physical and chemical properties; 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 fertility renewal. One ton of conventional compost may contain 10 lbs of nitrogen (N), 5 lbs of phosphorus (P_2O_5) and 10 lbs of potash (K_2O). Compost made from poultry droppings contain highest nutrient level among all compost [13].

There are other agronomic benefits of composts application, such as high levels of soil-borne disease suppression and removal of soil salinity. One study 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 [14]. Other reported that with application of compost in vineyards, levels of exchangeable sodium (Na) under vine were at least reduced to 50% [15]. Biological properties of soil were also improved with up to ten-fold increase in total microbial counts. Most significant was three-fold increase in the population of earthworms under the vine with long-term benefits to the soil.

5. VERMICOMPOST VS CONVENTIONAL COMPOST

Our studies at Griffith University, Australia has conclusively proved that the indigenously prepared earthworms vermicompost is 'exceptionally superior' over all brands of conventionally prepared & marketed composts certified by Compost Australia. Studies confirm that vermicompost is at least 4 times more nutritive than conventional cattle dung compost [16]. In Argentina, farmers who use vermicompost consider it to be seven (7) times richer than conventional composts in nutrients and growth promoting values [17,18]. This is mainly due to 'humus' content in vermicompost excreted by earthworms which otherwise takes very long time to form humus in conventional composting system through slow decay of organic matter. The 'humic acid' in vermicompost stimulate plant growth even in small amount [19]. Vermicompost retains nutrients for long time than the conventional compost & while the latter fails to deliver the required amount of macro and micronutrients including the vital NPK (nitrogen, potassium & phosphorus) to plants in shorter time, the vermicompost does. Vermicompost also has very 'high porosity', 'aeration', 'drainage' and 'water holding capacity' than the conventional compost and this again due to humus contents. [16].

Earthworm participation enhances natural biodegradation and decomposition of organic materials from 60 to 80% by promoting the growth of 'beneficial decomposer aerobic bacteria' in the waste biomass. The quality of compost is significantly better, rich in key minerals & beneficial soil microbes. It is also disinfected and free of any pathogens as the worms release anti-pathogenic coelomic fluid in the waste biomass [20]. In fact in the conventional aerobic composting process which is thermophilic (temperature rising up to 55°C) many beneficial microbes are killed and nutrient especially nitrogen is lost (due to gassing off of nitrogen). Some studies found that while the conventional compost was higher in 'ammonium', the vermicompost tended to be higher in 'nitrates', which is the more bio-available form of nitro-

gen for plants [21]. They also found that vermicompost has higher N availability than the conventional compost on a weight basis and the supply of several other plant nutrients e.g. phosphorus (P), potassium (K), sulfur (S) and magnesium (Mg), were significantly increased by adding vermicompost as compared to conventional compost to soil. Study found the NPK value of vermicompost processed by worms from the same feedstock (cattle dung) significantly increases by 3 to 4 times. It also enhances several micronutrients [22].

Studies have found that if 100 kg of soil organics (with say containing 2 kg of plant nutrients) are processed through the earthworms, there is a production of about 300 kg of 'fresh living soil' with 6% of NPK and several trace elements that are equally essential for healthy plant growth. This magnification of plant nutrients is possible because earthworms produce extra nutrients from grinding rock particles with organics and by enhancing atmospheric nitrogen fixation. Earthworms activate this ground mix in a short time of just one hour. When 100 kg of the same organic wastes are composted conventionally unaided by earthworms, about 30 kg compost is derived with 3% NPK [11].

Although the conventional composting process is completed in about 8 weeks, but additional 4 weeks is required for 'curing'. Curing involves the further aerobic decomposition of some compounds, organic acids and large particles that remain after composting. Less oxygen and water is required during curing. Compost that has had insufficient curing may damage crops. Vermicompost do not require any curing and can be used straightway after production. It retains nutrients for long time and while the conventional compost fails to deliver the required amount of macro and micronutrients including the vital NPK (nitrogen, potassium & phosphorus) to plants in shorter time, the vermicompost does. [12,23]. This was also verified by us [24].

6. SOIL PROTECTIVE COMPOST VS SOIL DESTRUCTIVE CHEMICAL FERTILIZERS

Upon successive application, all composts condition the soil with rich population of 'beneficial soil microbes' & and 'essential nutrients' thus reinforcing its natural fertility, whereas, the chemical fertilizers destroy the beneficial microbes and impair the natural fertility of soil while also affecting soil pH and porosity. Composts work as a 'slow-release fertilizer' whereas chemical fertilizers release their nutrients rather quickly in soil and soon get depleted. Nitrogen and phosphorus particularly are not all available to plant roots from the conventional composts in

Table 1. NPK value of vermicompost compared with conventional cattle dung compost made from cattle dung.

| Nutrients | Cattle Dung Compost | Vermicompost |
|-----------|---------------------|--------------|
| 1. N | 0.4-1.0% | 2.5-3.0% |
| 2. P | 0.4-0.8% | 1.8-2.9% |
| 3. K | 0.8-1.2% | 1.4-2.0% |

Source: Agarwal [22]

Table 2. Comparison between nutritive values of the end products of conventional composting and vermicomposting systems (CNP in %; Others in mg/100 gm of compost).

| Parameter | Conventional Composting | Vermicomposting |
|--------------------------|-------------------------|-----------------|
| Total Carbon (C) | 9.34% | 13.5% |
| Total Nitrogen (N) | 1.05% | 1.33% |
| Available Phosphorus (P) | 0.32% | 0.47% |
| Iron (Fe) | 587.87 | 746.2 |
| Zinc (Zn) | 12.7 | 16.19 |
| Manganese (Mn) | 35.25 | 53.86 |
| Copper (Cu) | 4.42 | 5.16 |
| Magnesium (Mg) | 689.32 | 832.48 |

Source: Jadia & Fulekar [25]

the first year because N & P in organic matter are resistant to decay. Nitrogen is about one half effective as compared to chemical fertilizer, but phosphorus & potassium are as effective as chemical fertilizers. However, with continued application of compost over the years the 'organic nitrogen' (N) from the accumulated 'humus' (through a long decay process) tends to be released and the net overall efficiency of nitrogen (N) over a period of years is considerably greater than 50% of that of chemical fertilizers. Availability of phosphorus is sometimes much greater [12,26]. But vermicompost releases nitrogen (N) much faster and even after single application as 'humus' is directly excreted by worms and they also mineralise nitrogen from the waste organics to make it bio-available to plants. The net overall efficiency of nitrogen (N) is considerably greater than that of chemical fertilizers [27]. All compost (including vermicompost), are produced from some 'waste materials' of society which is converted into a 'valuable resource'. It is like 'killing two birds in one shot'. More significant is that it is of biological origin i.e. a 'renewable resource' and will be readily available to mankind in future. Whereas, chemical fertilizers are made from petroleum products which are

'non-renewable' and a 'depleting' resource. While in the use of compost the environment is 'benefited' at all stages - from production (salvaging waste & diverting them from landfills and reducing greenhouse gases) to application in farms (adding beneficial microbes to soil & improving biochemical properties), in the use of chemical fertilizers the environment is 'harmed' at all stages - from procurement of raw materials from petroleum industries to production in factories (generating huge amount of chemical wastes and pollutants) and application in farms (adversely affecting beneficial soil micro-organisms and soil chemistry). And with chemical fertilizers, there is yet another problem. A significant amount of 'nitrogen' (N) is lost from the soil due to oxidation in sunlight. Studies indicate that upon application of 100 kg urea (N) in farm soil, 40-50 kg gets oxidised and escapes as 'ammonia' (NH_3) into the air, about 20-25 kg leaches underground polluting the groundwater, while only 20-25 kg is available to plants [16]

Properties of Farm Soil Using Compost Vis-a-vis Chemical Fertilizers

Suhane [16], studied the chemical and biological properties of soil under organic farming (using various types of composts) and chemical farming (using chemical fertilizers - urea (N), phosphates (P) and potash (K)). Results are given in **Table 1**.

7. ADVANTAGES OF USE OF VERMICOMPOST OVER CHEMICAL FERTILIZERS

The biggest advantage of great socio-economic significance is that the food produced is completely organic, 'safe & chemical-free'. Use of vermicompost enhances

Table 3. Farm soil properties under organic farming and chemical farming.

| Chemical & Biological Properties of Soil | Organic Farming (Use of Composts) | Chemical Farming (Use of Chemical Fertilizers) |
|--|-----------------------------------|--|
| 1) Availability of Nitrogen (kg/ha) | 256.0 | 185.0 |
| 2) Availability of Phosphorus (kg/ha) | 50.5 | 28.5 |
| 3) Availability of Potash (kg/ha) | 489.5 | 426.5 |
| 4) Azatobacter (1000/gm of soil) | 11.7 | 0.8 |
| 5) Phospho Bacteria (100,000/kg of soil) | 8.8 | 3.2 |
| 6) Carbonic Biomass (mg/kg of soil) | 273 | 217 |

Source: Suhane [16]

size, color, smell, taste, flavour and keeping quality (storage value) of flowers, fruits, vegetables and food grains. Studies indicate that vermicompost gives 30-40% higher yield of crops over chemical fertilizers. Of greater agronomic significance is that the minerals in the vermicompost are 'readily & immediately bio-available' to the plants. Chemical fertilizers (and also manures) have to be broken down in the soil before the plants can absorb. Vermicompost also has greater 'water holding capacity' due to humus contents and hence reduces the requirement of water for irrigation by 30-40%. Use of chemical fertilizers require high amount of water for irrigation.

Another big advantage of great economic & environmental significance is that over successive years of application, vermicompost 'build-up the soils natural fertility' and also regenerates a rich population of earthworms in the farm soil from the cocoons which further help improve soil fertility and subsequently lesser amount of vermicompost is required to maintain a good yield and productivity. On the contrary, with the continued application of chemical fertilizers over the years the 'natural fertility of soil is destroyed' and it becomes 'addict to chemicals'. Subsequently greater amount of chemicals are required to maintain the same yield & productivity of previous years. More uses of agro-chemicals to boost food productivity are in fact a 'self-defeating' proposition.

8. EARTHWORMS IMPROVES TOTAL PHYSICAL, CHEMICAL & BIOLOGICAL QUALITY OF SOIL

Earthworms are regarded as 'biological indicator' of soil fertility and a 'soil conditioner'. They lead to total improvement in the physical (soil porosity & softness), chemical (good pH and essential plant nutrients) and biological (beneficial soil microbes & organisms) quality of soil and land where they inhabit. They swallow large amount of soil with organics (microbes, plant & animal debris) everyday, grind them in their gizzard and digest them in their intestine with aid of enzymes. Only 5-10 percent of the chemically digested and ingested material is absorbed into the body and the rest is excreted out in the form of fine mucus coated granular aggregates called 'vermicastings' which are rich in NPK (nitrates, phosphates and potash), micronutrients and beneficial soil microbes [28].

9. EARTHWORMS & VERMICOMPOST: MIRACLE PLANT GROWTH PROMOTER & PROTECTOR

Earthworms vermicast is a highly nutritive 'organic fer-

tilizer' rich in humus, 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'. [29-31]. One study reports as high as 7.37% nitrogen (N) and 19.58% phosphorus as P_2O_5 in worms vermicast [32]. Another study showed that exchangeable potassium (K) was over 95% higher in vermicompost [16]. There are also good amount of calcium (Ca) and magnesium (Mg). Vermicompost has very 'high porosity', 'aeration', 'drainage' and 'water holding capacity'. More important is that it contains 'plant-available nutrients' and appears to increase & retain more of them for longer period of time. A matter of still greater agronomic significance is that worms & vermicompost also increases 'biological resistance' in plants (due to Actinomycetes) and protect them against pest and diseases either by repelling or by suppressing them [1,34,35].

9.1. High Levels of Bio-Available Nutrients for Plants

Earthworms mineralize the nitrogen (N) and phosphorus (P) and all essential organic & inorganic elements in the compost to make it bio-available to plants as nutrients [36]. They recycle nitrogen in soil in very short time ranging from 20 to 200 kg N/ha/year & increase nitrogen contents by over 85% [37]. After 28 weeks the soil with living worms contained 75 ppm of nitrate nitrogen (N), compared with the controlled soil which had only 45 ppm [38]. Worms increase nitrogen levels in soil by adding their metabolic & excretory products (vermicast), mucus, body fluid, enzymes and decaying tissues of dead worms [39,40]. Lee [41] suggests that the passage of organic matter through the gut of worm results in phosphorus (P) converted to forms which are more bio-available to plants. This is done partly by worm's gut enzyme 'phosphatases' and partly by the release of phosphate solubilizing microorganisms in the worm cast [42].

9.2. High Level of Beneficial and Biologically Active Soil Microorganisms

Among beneficial soil microbes stimulated by earthworms are 'nitrogen-fixing & phosphate solubilizing bacteria', the 'actinomycetes' & 'mycorrhizal fungi'. Studies found that the total bacterial count was more than 10^{10} /gm of vermicompost. It included *Actinomycetes*, *Azotobacter*, *Rhizobium*, *Nitrobacter* & Phosphate Solubilizing Bacteria ranges from 10^2 - 10^6 per gm of vermi-

compost [16].

9.3. Rich in Humus: Key to Growth and Survival of Plants

Vermicompost contains 'humus' excreted by worms which makes it markedly different from other organic fertilizers. It takes several years for soil or any organic matter to decompose to form humus while earthworms secrete humus in its excreta. Without humus plants cannot grow and survive. The humic and fulvic acids in humus are essential to plants in four basic ways – 1) Enables plant to extract nutrients from soil; 2) Help dissolve unresolved minerals to make organic matter ready for plants to use; 3) Stimulates root growth; and, 4) Helps plants overcome stress. Presence of humus in soil even help chemical fertilizers to work better [43]. This was also confirmed by other study [44]. One study found that humic acids isolated from vermicompost enhanced root elongation and formation of lateral roots in maize roots. Humus in vermicast also extracts 'toxins', 'harmful fungi & bacteria' from soil & protects plants [19].

9.4. Rich in Plant Growth Hormones

Some studies speculated that the growth responses of plants from vermicompost appeared more like 'hormone-induced activity' associated with the high levels of nutrients, humic acids and humates in vermicompost [21, 45]. Researches show that vermicompost use further stimulates plant growth even when plants are already receiving 'optimal nutrition'. It consistently improved seed germination, enhanced seedling growth and development, and increased plant productivity significantly much more than would be possible from the mere conversion of mineral nutrients into plant-available forms. Some studies have also reported that vermicompost contained growth promoting hormone 'auxins', 'cytokinins' and flowering hormone 'gibberellins' secreted by earthworms [16,47,48].

9.5. Enzymes for Improving Soil Nutrients & Fertility

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. [30,31]. They also increases the levels of some important soil enzymes like dehydrogenase, acid and alkaline phosphatases and urease. Urease play a key role in N-cycle as it hydrolyses urea and phosphatase bioconvert soil phosphorus into bio-available form for plants.

10. EARTHWORMS REDUCE SOIL SALINITY & IMPROVE FERTILITY OF SODIC SOILS

Studies indicate that *Esinea fetida* can tolerate soils nearly half as salty as seawater i.e. 15 gm/kg of soil and also improve its biology and chemistry. (Average seawater salinity is around 35 g/L). 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 tones/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% [27].

Ansari [49] studied the production of potato (*Solanum tuberosum*) by application of vermicompost in a reclaimed sodic soil in India. With good potato growth the sodicity (ESP) of the soil was also reduced from initial 96.74 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.

11. EARTHWORMS PROTECTS PLANTS AGAINST PESTS AND DISEASES & SIGNIFICANTLY REDUCE USE OF CHEMICAL PESTICIDES

Earthworms are both 'plant growth promoter and protector'. There has been considerable evidence in recent years regarding the ability of earthworms and its vermicompost to protect plants against various pests and diseases either by suppressing or repelling them or by inducing biological resistance in plants to fight them or by killing them through pesticidal action. The actinomycetes fungus excreted by the earthworms in their vermicast produce chemicals that kill parasitic fungi such as *Pythium* and *Fusarium* [34]. Another study confirmed that application of vermicompost reduced the damage by striped cucumber beetle (*Acalymma vittatum*), spotted cucumber beetle (*Diabotrica undecimpunctata*) on cucumber and larval hornworms (*Manduca quinquemaculata*) on tomatoes in both greenhouse and field experiments [50].

11.1. Ability to Induce Biological Resistance in Plants

Vermicompost contains some antibiotics and actinomycetes which help in increasing the 'power of biological resistance' among the crop plants against pest and diseases. Spray of chemical pesticides was significantly reduced

by over 75% where earthworms and vermicompost were used in agriculture [13,16].

11.2. Ability to Repel Crop Pests

There seems to be strong evidence that worms varmicastings sometimes repel hard-bodied pests [1,33]. Studies reported 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 [34]. George Hahn, doing commercial vermicomposting in California, U.S., claims that his product repels many different insects pests. His explanation is that this is due to production of enzymes 'chitinase' by worms which breaks down the chitin in the insect's exoskeleton [17].

11.3. Ability to Suppress Plant Disease

Studies reported that vermicompost application suppressed 20-40% infection of insect pests i.e. aphids (*Myzus persicae*), mearly bugs (*Pseudococcus spp.*) and cabbage white caterpillars (*Peiris brassicae*) on pepper (*Capiscum annuum*), cabbage (*Brassica oleracea*) and tomato (*Lycopersicum esculentum*) [51].

Studies have also found that use of vermicompost in crops inhibited the soil-born fungal diseases. They also found significant suppression of plant-parasitic nematodes in field trials with pepper, tomatoes, strawberries and grapes [34]. The scientific explanation behind this concept is that high levels of agronomically beneficial microbial population in vermicompost protects plants by out-competing plant pathogens for available food resources i.e. by starving them and also by blocking their excess to plant roots by occupying all the available sites. This concept is based on 'soil-foodweb' studies pioneered by Dr. Elaine Ingham of Corvallis, Oregon, U.S. (<http://www.soilfoodweb.com>).

Edwards and Arancon [27] also reported the disease suppressing effects of applications of vermicompost, on attacks by fungus *Pythium* on cucumber, *Rhizoctonia* on radishes in the greenhouse, by *Verticillium* on strawberries and by *Phomopsis* and *Sphaerotheca fulginae* on grapes in the field. In all these experiments vermicompost applications suppressed the incidence of the disease significantly. They also found that the ability of pathogen suppression disappeared when the vermicompost was sterilized, convincingly indicating that the biological mechanism of disease suppression involved was 'microbial antagonism'.

Studies also reported considerable suppression of root knot nematode (*Meloidogyne incognita*) and drastic suppression of spotted spider mites (*Tetranychus spp.*) and aphid (*Myzus persicae*) in tomato plants after appli-

cation of vermicompost teas (vermiwash liquid) [52]. They are serious pests of several crops.

12. SOME KEY STUDIES SUPPORTING SOIL FERTILITY IMPROVEMENT AND GOOD CROP PRODUCTION BY EARTHWORMS AND VERMICOMPOST OVER CHEMICAL FERTILIZERS

There have been several reports that earthworms and its vermicompost can induce excellent plant growth and enhance crop production.

12.1. Cereal Crops

Glasshouse studies made at CSIRO Australia 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% & also resisted crop diseases as compared to the control. The plants were grown in a 'red-brown earth' with poor nutritional status and 60% moisture. There was about 460 worms m⁻² [53]. They also reported that in Parana, Brazil invasion of earthworms significantly altered soil structure and water holding capacity. The grain yields of wheat and soybean increased by 47% and 51%, respectively [54].

Some studies were made on the impact of vermicompost and garden soil in different proportion on wheat crops in India. It was 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% [55]. Another study reported that earthworms & its vermicast improve the growth and yield of wheat by more than 40% [56]. Other studies also reported better yield and growth in wheat crops applied with vermicompost in soil. [57-59].

Studies made on the agronomic impacts of vermicompost on rice crops (*Oryza sativa*) reported greater population of nitrogen fixers, actinomycetes and mycorrhizal fungi inducing better nutrient uptake by crops and better growth [60]. Another study was made on the impact of vermicompost on rice-legume cropping system in India. Integrated application of vermicompost, chemical fertilizer and biofertilizers (*Azospirillum* & phosphobacteria) increased rice yield by 15.9% over chemical fertilizer used alone. The integrated application of 50% vermicompost, 50% chemical fertilizer and biofertilizers recorded a grain yield of 6.25 and 0.51 ton/ha in the rice and legume respectively. These yields were 12.2% and 19.9% higher over those obtained with 100% chemical fertilizer when used alone [61]. Studies made in the

Philippines also reported good response of upland rice crops grown on vermicompost [62].

12.2. Fruit Crops

Study found that worm-worked waste (vermicompost) boosted grape yield by two-fold as compared to chemical fertilizers. Treated vines with vermicompost produced 23% more grapes due to 18% increase in bunch numbers. The yield in grapes was worth additional value of AU \$ 3,400/ha [63]. 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 [27].

Study was made on the agronomic impacts of vermicompost and inorganic (chemical) fertilizers on strawberries (*Fragaria ananassa*) 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. Also, farm soils applied with vermicompost had significantly greater 'microbial biomass' than the one applied with inorganic fertilizers [7]. Studies 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% [64].

Studies made on the agronomic impact of vermicompost on cherries 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 [65].

12.3. Vegetable Crops

Studies on the production of important vegetable crops

like tomato (*Lycopersicum esculentus*), eggplant (*Solanum melongena*) and okra (*Abelmoschus esculentus*) have yielded very good results [27,66-68]. Another study was made on the growth impacts of earthworms (with feed materials), vermicompost, cow dung compost and chemical fertilizers on okra (*A. esculentus*). Worms and vermicompost promoted excellent growth in the vegetable crop with more flowers and fruits development. But the most significant observation was drastically less incidence of 'Yellow Vein Mosaic', 'Color Rot' and 'Powdery Mildew' diseases in worm and vermicompost applied plants [69]. Study was made on the production of potato (*Solanum tuberosum*) by application of vermicompost in a reclaimed sodic soil in India. The overall productivity of potato was significantly high (21.41 tons/ha) on vermicompost applied @ 6 tons/ha as compared to control which was 04.36 tons/ha. The sodicity of the soil was also reduced and nitrogen (N) contents increased significantly [49]. Study was made on the growth impacts of organic manure (containing earthworm vermicasts) on garden pea (*Pisum sativum*) and compared with chemical fertilizers. Vermicast produced higher green pod plants, higher green grain weight per plant, higher percentage of protein content and carbohydrates and higher green pod yield (24.8-91%) as compared to chemical fertilizer [70].

Studies made on the effects of vermicompost & chemical fertilizer on hyacinth beans (*Lablab purpureas*) found that all growth & yield parameters e.g. total chlorophyll contents in leaves, dry matter production, flower appearance, length of fruits and fruits per plant, dry weight of 100 seeds, yield per plot and yield per hectare were significantly higher in those plots which received vermicompost either alone or in combination with chemicals. The highest fruit yield of 109 ton/ha was recorded in plots which received vermicompost @ 2.5 tons/ha [71].

12.4. Herbage Production

A study was made on the impact of earthworms on soil properties and herbage production in a field micro-plot experiment in Ireland. Study site was reclaimed after industrial peat mining, and seeded with perennial ryegrass and clover. The presence of earthworms had little effect on herbage production in the first year. But total herbage yield was 25% greater in the second year and 49% greater in the third year in plots receiving annual topdressing of cattle slurry with earthworms compared to similarly-treated plots with cattle slurry but without earthworms. Ironically, no effect of earthworms on herbage yield was detected in plots receiving chemical fer-

tilizers only [54].

The conclusion drawn from such study is that it is the earthworms in soil which matters in plant productivity and not the organic manure (cattle slurry) alone. In the first year, it took the earthworm to restore and condition the disturbed mined soil. However, the cattle slurry (dung) provided the necessary feed materials for the worms to act with vigor and excrete nutritive 'vermicast' in soil which promoted higher herbage yield in the second year (25%). In the third year, the worm population in soil increased significantly leading to higher excretion of vermicast, higher soil fertility and higher plant production (49%).

In a bucket experiment they found that the cumulative herbage yields over a period of 20 months was 89% higher in buckets with earthworms added with cattle manure as compared to those without earthworms but only with cattle manure, and only 19% higher in buckets receiving exclusive chemical fertilizers. These results were as compared to control.

13. OUR EXPERIMENTAL STUDIES SUPPORTING EARTHWORMS AND ITS VERMICOMPOST AS SUPERIOR CROP NUTRIENT OVER CONVENTIONAL COMPOST & CHEMICAL FERTILIZERS

13.1. Cereal Crops

13.1.1. Farm Wheat Crops (Agriculture Research Institute, Jaipur, India)

This facility was provided by ARI at Jaipur, India. Results are given in **Table 4**.

Key Observations, Findings and Discussion

In the farm experiment the highest growth and yield in wheat crop was achieved where reduced dose (3/4) of chemical fertilizer (NPK- 90:75:60) were supplemented with full dose of vermicompost (@ 2.5 tons/ha. Although vermicompost alone can work as 'driving force' but when chemical fertilizers are added as 'helping hand' it can do even better. However, the total yield of the grain (grain/ear) as well as the ear length of crops grown on vermicompost were as good as those grown on full doses of chemical fertilizers (NPK- 120:100:80).

13.1.2. Farm Wheat Crops (Rajendra Agriculture University, Bihar, India)

This facility was provided by RAU, Pusa, India under a collaborative research program. Cattle dung compost was applied four (4) times more than that of vermicompost. Results are given in **Table 5**.

Table 4. Agronomic impacts of earthworms, vermicompost vis-a-vis chemical fertilizers on farm wheat crops.

| | Treatments | Shoot Length (cm) | Ear Length (cm) | Root Length (cm) | Wt. of 1000 grains (In grams) | Grains/Ear |
|----|---|-------------------|-----------------|------------------|-------------------------------|------------|
| 1. | Vermicompost (@ 2.5 t/ha) | 83.71 | 13.14 | 23.51 | 39.28 | 32.5 |
| 2. | Earthworms (1000 Nos.) In 25 × 25 m farm land | 67.83 | 9.85 | 18.42 | 36.42 | 30.0 |
| 3 | NPK (90:75:60) (Reduced Dose) + VC (Full Dose) (2.5 t/ha) | 88.05 | 13.82 | 29.71 | 48.02 | 34.4 |
| 4 | NPK (120:100:80) (Full Dose) | 84.42 | 14.31 | 24.12 | 40.42 | 31.2 |
| 5. | CONTROL | 59.79 | 8.91 | 12.11 | 34.16 | 27.7 |

Source: Ph. D Thesis (Reena Sharma [72]); University of Rajasthan, Jaipur, INDIA; Key: VC = Vermicompost; N = Urea; P = Phosphate; K = Potash (In Kg/hectare).

Table 5. Agronomic impacts of vermicompost, cattle dung compost & chemical fertilizers in exclusive applications & in combinations on farmed wheat crops.

| 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: Sinha et al. [27]; Key: N = Urea; P = Phosphate; K = Potash (In Kg/ha)

Key Observations, Findings & Discussion

Exclusive application of vermicompost supported yield comparable to rather better than 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 over 28% and nearly 3 times over control. On cattle dung compost applied @ 100 Q/ha (4 times of vermicompost) the yield was just over 33 Q/ha. Application of vermicompost had other agronomic benefits. It significantly reduced the demand for irrigation by nearly 30-40%. Test results indicated better availability of essential micronutrients and useful microbes in vermicompost applied soils. Most remarkable observation was significantly less incidence of pests and disease attacks in vermicompost applied crops.

13.1.3. Potted Corn Crops (Griffith University, Australia)

Study 1: This was designed to compare the agronomic impacts of earthworms, vermicompost & worms with

chemical fertilizers on corn plants. Results are given in **Table 6**.

Key Observations, Findings and Discussion

Corn plants with earthworms and vermicompost in soil achieved very good growth and were better over chemical fertilizers studied until week 19. While the plants on chemicals grew only 5 cm (87 cm to 92 cm) in 7 weeks those on vermicompost grew by 15 cm (90 cm to 105 cm) within the same period. But plants with earthworms only (without feed) failed to perform. Most significant finding was that plants on vermicompost demanded less water for irrigation.

Study 2: This was designed to test the growth promoting capabilities of earthworms added with feed materials and ‘vermicompost’, as compared to ‘conventional compost’. The doses of vermicompost & conventional compost were ‘doubled’ (400 gm). Crushed dry leaves were used as feed materials (400 gm). Results are given in **Table 7**.

Key Observations, Findings and Discussion

Corn plants with vermicompost in soil achieved rapid and excellent growth and attained maturity very fast. Plants in soil with conventional compost could not achieve maturity until the period of study (week 14). Plants with worms (provided with feed) performed better than those of conventional compost. A significant finding was that when the dose of vermicompost was doubled from 200 grams (Study 1) to 400 grams (Study 2), it simply enhanced total plant growth to almost two-fold (from average 58 cm on 200 gm vermicompost to average 104 cm on 400 gm vermicompost) within the same period of study i.e. 6 weeks. Corn plants with double dose of vermicompost achieved maturity in much shorter time. However, our subsequent studies on potted and farmed wheat crops showed that once the ‘natural fertility’ of the soil is restored with vermicompost application it no longer requires higher doses of vermicompost subsequently to maintain or enhance productivity [27].

Table 6. Agronomic impacts of earthworms, worms with vermicompost vis-a-vis chemical fertilizers on corn plants (average growth in cm).

| Parameters Studied | CONTROL (No Input) | Treatment 1 EARTHWORMS Only (25 Nos.) (Without Feed) | Treatment 2 Soluble CHEMICAL FERTILIZERS | Treatment 3 EARTHWORMS + VERMICOMPOST (200 gm) |
|---|----------------------------|---|--|---|
| Seed Sowing | 29 th July 2007 | Do | Do | Do |
| Seed Germination | 9 th Day | 7 th Day | 7 th Day | 7 th Day |
| Avg. Growth in 4 wks | 31 | 40 | 43 | 43 |
| Avg. Growth in 6 wks | 44 | 47 | 61 | 58 |
| App. Of Male Rep. Organ (In wk 12) | None | None | Male Rep. Organ | Male Rep. Organ |
| Avg. Growth in 12 wks | 46 | 53 | 87 | 90 |
| App. Of Female Rep. Organ (In wk 14) | None | None | None | Female Rep. Organ |
| Avg. Growth in 15 wks | 48 | 53 (App. Of Male Rep. Organ) | 88 | 95 |
| App. Of New Corn (In wk 16) | None | None | None | New Corn |
| Avg. Growth in 19 wks | 53 | 56 | 92 | 105 |
| Color & Texture of Leaves | Pale & thin leaves | Green & thin | Green & stout leaves | Green, stout & broad leaves |

Source: Sinha et al. [27]

Table 7. Agronomic impacts of earthworms (with feed), vermicompost vis-a-vis conventional compost on corn plants (average growth in cm)

| Parameters Studied | Treatment 1 Earthworms (25) With Feed (400 gm) | Treatment 2 Conventional COMPOST (400 gm) | Treatment 3 VERMICOMPOST (400 gm) |
|---|---|--|---|
| Seed Sowing | 9 th Sept. 2007 | Do | Do |
| Seed Germination | 5 th Day | 6 th Day | 5 th 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 & Texture of Leaves | Green & thick | Light green & thin | Deep green, stout, thick & broad leaves |

Source: Sinha et al. [27]

13.1.4. Potted Wheat Crops (Griffith University, Australia)

This was designed to compare the agronomic impacts of vermicompost with conventional compost & chemical fertilizers on wheat crops. Results are given in **Table 8**.

Key Observations, Findings & Discussion

Wheat crops maintained very good growth on vermicompost & earthworms from the very beginning & achieved maturity in 14 weeks. The striking rates of seed germination were very high, nearly 48 hours (2 days) ahead

Table 8. Growth of wheat crops promoted by vermicompost, conventional compost and chemical fertilizers

| Treatments | Week 1 | Week 5 | Week 10 | Week 12 |
|------------|--------|--------|---------|---------|
| 1) Control | 17 | 22 | 26 | 26 |
| 2) CC | 17 | 31 | 32 | 32 |
| 3) CF | 16 | 36 | 39 | 43 |
| 4) VC + EW | 19 | 39 | 43 | 47 |

(VC 500 gm; EW 25 Nos.; CC 500 gm; CF 5 gm x 3 times; Av. Growth in cm); **Key:** CC = Conventional Compost; CF = Chemical Fertilizer; VC = Vermicompost; EW = Earthworms Source: Sinha et al. [27]

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 & long seed ears were formed at maturity. Seeds were healthy and nearly 35-40% more as compared to plants on chemical fertilizers. What they achieved in just 5 weeks, was achieved by others in 10 weeks. More significant was that the pot soil with vermicompost was very soft & porous and retained more moisture. Pot soil with chemicals were hard and demanded more water frequently [27].

13.2. Vegetable Crops

This was designed to compare the growth impacts of earthworms, worms with vermicompost and chemical fertilizers on egg plants. Results are given in **Table 9**.

13.2.1. Potted Egg Plants (University of Rajasthan, Jaipur, India 1998)

Key Observations, Findings and Discussion

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.

13.2.2. Potted Okra Plants (University of Rajasthan, Jaipur, India 1998)

This was designed to compare the growth impacts of earthworms, worms with vermicompost and chemical fertilizers on okra plants. Results are given in **Table 10**.

Key Observations, Findings and Discussion

Potted okra plants grown on vermicompost (with live worms in soil) bore on average 45 fruits/plant with average weight being 48 gm. Whereas, those grown on chemical fertilizers (NPK) bore 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.

13.2.3. Potted Tomato Plants (Griffith University, Australia 2009)

This was designed to compare the agronomic impacts of vermicompost & worms with composted cow manure from market & chemical fertilizers on tomato plants. Results are given in **Table 11**.

Key Observations, Findings and Discussion

Tomato plants on vermicompost & 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 agro-chemicals and conventional compost. Presence of earthworms in soil made a significant difference in 'flower and fruit formation' in tomato plants. This was obviously

Table 9. Agronomic impacts of vermicompost, earthworms & vermicompost vis-a-vis chemical fertilizer on growth & development of egg plants.

| 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 |

(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 & ending with over 120 days); Source: Sinha et al. [27]; Key: VC = Vermicompost

Table 10. Agronomic impacts of vermicompost, worms with vermicompost vis-a-vis chemical fertilizer on growth & development of okra plants.

| Treatment | 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 |

(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); Source: Sinha et al. [27]

Table 11. Growth of tomato plants promoted by vermicompost, vermicompost with earthworms, conventional compost (composted cow manure) & chemical fertilizers (All seedlings measured 5 cm; Average growth in cm).

| Parameters Studied | Control | Chemical Fertilizers (5 gm × 3 times) | Composted Cow Manure (500 gm) | Vermicompost (250 gm) | Vermicompost (250 gm) + Earthworms (50) |
|-------------------------------|---------|---------------------------------------|-------------------------------|-----------------------|---|
| 1). Avg. Growth in 2 Wks. | 10 | 16 | 16 | 18 | 19 |
| 2). Avg. Growth in 4 Wks. | 30 | 49 | 35 | 60 | 60 |
| 3). Number of flowers (Wk.5) | 8 | 17 | 10 | 27 | 31 |
| 4). Avg. Growth in 6 Wks. | 40 | 70 | 51 | 118 | 125 |
| 5). Avg. Growth in 8 Wks. | 48 | 108 | 53 | 185 | 188 |
| 6). Number of fruits (Wk. 9) | 4 | 16 | 6 | 22 | 27 |
| 7). Avg. Growth after 10 Wks. | 50 | 130 | 53 | 207 | 206 |

Source: Sinha & Valani [27]

due to more 'growth & flowering hormones' (auxins and gibberellins) available in the soil secreted by live earthworms. Very disappointing was the results of composted cow manure obtained from the market with branded name. It could not compete with vermicompost (indigenously prepared from food waste) even when applied in 'double dose'.

14. VERMIWASH: A NUTRITIVE GROWTH PROMOTING PESTICIDAL LIQUID PRODUCED DURING VERMICOMPOST PRODUCTION

The brownish-red liquid which collects in all vermicomposting practices is also productive and protective for farm crops. This liquid partially comes from the body of earthworms (as worm's body contain plenty of water) and is rich in amino acids, vitamins, nutrients like nitrogen, potassium, magnesium, zinc, calcium, iron and copper and some growth hormones like 'auxins', 'cytokinins'.

It also contains plenty of nitrogen fixing and phosphate solubilising bacteria (nitrosomonas, nitrobacter and actinomycetes). Vermiwash has great 'growth promoting' as well as 'pest killing' properties. Study reported that weekly application of vermiwash increased radish yield by 7.3% [73,74]. Another study also reported that both growth and yield of paddy increased with the application of vermiwash and vermicast extracts [75].

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

George [76] studied the use of vermiwash for the management of 'Thrips' (*Scirtothrips dorsalis*) and 'Mites' (*Polyphagotarsonemus latus*) on chilli amended with vermicompost to evaluate its efficacy against thrips

and mites. Vermiwash was used in three different dilutions e.g. 1:1, 1:2 and 1:4 by mixing with water both as 'seedling dip' treatment and 'foliar spray'. Six rounds of vermiwash sprays were taken up at 15 days interval commencing at two weeks after transplanting. Among the various treatments, application of vermicompost @ 2.5 ton/ha with 6 sprays of vermiwash at 1:1 dilution showed significantly lower incidence of thrips and mites attack. It registered very low mean population of thrips and mites as 0.35 and 0.64 per leaf respectively. It also registered significantly maximum dry chilli yield @ 2.98 quintal/ha. Giraddi *et al.* [74] also reported significantly lower pest population in chilli applied with vermiwash (soil drench 30 days after transplanting, and foliar spray at 60 and 75 days after transplanting) as compared to untreated crops.

Suthar [77] has reported hormone like substances in vermiwash. He studied its impact on seed germination, root & shoot length in *Cyamopsis tetragonoloba* and compared with urea solution (0.05%). Maximum germination was 90% on 50% vermiwash as compared to 61.7% in urea solution. Maximum root and shoot length was 8.65 cm & 12.42 cm on 100% vermiwash as compared to 5.87 & 7.73 on urea. The seedlings with 100% vermiwash foliar spray showed the maximum level of total protein and soluble sugars in their tissues.

15. AMOUNT & APPLICATION TIME OF VERMICOMPOST IN CROPS

Vermicompost can be used in any crop and in any amount as it is 'completely safe' for soils and crops in all amounts. However, several studies including ours, indicate that vermicompost is required in much 'lesser amount' as compared to all other bulky organic fertilizers e.g. composted cattle dung (cow, horse & pig manures and sheep & goat droppings) composted MSW and composted plant residues to promote optimal growth and yield. This is because they contain 'high nutrients with growth hormones' and are 4-5 times more powerful growth promoters than all other organic fertilizers and over 30-40% higher over the chemical fertilizers (NPK).

Study made by Central Research Institute for Dryland Agriculture, Hyderabad, India have provided a report which is given in **Table 12**.

16. THE GLOBAL MOVEMENT FOR USE OF VERMICOMPOST TO REPLACE DESTRUCTIVE CHEMICAL FERTILIZERS FROM AGRICULTURE

Worldwide farmers are desperate to get rid of the vicious

Table 12. Recommended quantity and time of application of vermicompost in some crops.

| Crop | Quantity | Time of Application |
|------------------------|----------------|-------------------------------------|
| 1). Rice (Paddy) | 1 ton/acre | After Transplanting |
| 2). Maize (Corn) | 1 ton/acre | Last Ploughing |
| 3). Sugarcane | 1.5 ton/acre | Last Ploughing |
| 4). Groundnut | 0.5 ton/acre | Last Ploughing |
| 5). Sunflower | 1.5 ton/acre | Last Ploughing |
| 6). Chilli | 1 ton/acre | Last Ploughing |
| 7). Potato | 1-1.5 ton/acre | Last Ploughing |
| 8). Tomato | 1-1.5 ton/acre | Last Ploughing |
| 9). Brinjal | 1-1.5 ton/acre | Last Ploughing |
| 10). Okra | 1-1.5 ton/acre | Last Ploughing |
| 11). Cauliflowers | 1-1.5 ton/acre | Last Ploughing |
| 12). Cabbage | 1-1.5 ton/acre | Last Ploughing |
| 13). Garlic | 1-1.5 ton/acre | Last Ploughing |
| 14). Onion | 1-1.5 ton/acre | Last Ploughing |
| 15). Grape (Vineyards) | 1 ton/acre | Summer time |
| 16). Citrus | 2 kg/tree | At planting time & before flowering |
| 17). Pomegranate | 2 kg/tree | At planting time & before flowering |
| 18). Guava | 2 kg/tree | At planting time & before flowering |
| | 2 kg/tree | At planting time |
| 19). Mango & Coconut | 5 kg/tree | 1-5 years old trees |
| | 10 kg/tree | 6-9 years old trees |
| | 20 kg/tree | Trees older than 10 years |
| 20). Cotton | 1 ton/acre | Last Ploughing |

Source: CRIDA (2009), Hyderabad, India [78]

circle of the use of chemical fertilizers as their cost have been constantly rising and also the amount of chemicals used per hectare has been steadily increasing over the years to maintain the yield & productivity of previous years. Nearly 3-4 times of agro-chemicals are now being used per hectare what was used in the 1960s. In Australia, the cost of MAP fertilizer has risen from AU \$ 530.00 to AU \$ 1500.00 per ton since 2006. So is the story everywhere in world because the chemical fertilizers are produced from 'vanishing resources' of earth. Farmers urgently need a sustainable alternative which is both economical and also productive while also maintaining soil health & fertility. The new concept is 'Ecological Agriculture' which is by definition different from

'Organic Farming' that was focused mainly on production of chemical-free foods. Ecological agriculture emphasize on total protection of food, farm & human ecosystems while improving soil fertility & development of secondary source of income for the farmers. UN has also endorsed it. Vermiculture provides the best answer for ecological agriculture which is synonymous with 'sustainable agriculture'.

A movement is going on in India, China, Philippines, Brazil, Mexico, Argentina, Australia, U.S., Canada, Russia and Japan to vermicompost the organic fractions of all their municipal solid wastes (MSW) and among the farmers to vermicompost their farm wastes and use them as a complete 'organic fertilizer' for crops as an alternative to the chemical fertilizers or supplement them with highly reduced doses of chemical fertilizers. Municipal councils, NGOs and composting companies are also participating in vermicomposting business, composting all types of organic wastes on commercial scale and selling them to the farmers. This has dual benefits. Cutting cost on landfill disposal of waste while earning revenues from sale of worms & vermicompost [17, 27,79]. 'Vermicycle Organics' in the U.S. produces 7.5 million pounds of vermicompost every year in high-tech greenhouses and sell to the farmers. Its sale of vermicompost grew by 500% in 2005. 'Vermitechnology Unlimited' in U.S. has doubled its business every year since 1991 [80].

A 'Vermiculture Movement' is going on in India with multiple objectives of community waste management, highly economical way of crop production replacing the costly chemical fertilizers and poverty eradication programs in villages [81].

17. IMPORTANT FEEDBACKS FROM FARMERS USING VERMICOMPOST IN INDIA

Farmers in India are being motivated to embrace vermiculture in farming. This is mainly in the States of Karanatka, Tamil Nadu, Gujarat, Maharashtra, Punjab, Harayana, Himachal Pradesh and Bihar. Apple growers in Himachal are using vermicompost on large scale with very good profit.

A number of villages in the districts of Samastipur, Hazipur and Nalanda in the State of Bihar have been designated as 'Bio-Village' where the farmers have completely switched over to organic farming by vermicompost and have given up the use of chemical fertilizers since 2005. Some of them asserted to have harvested three (3) different crops in a year (reaping 2-3 times more harvest) due to their rapid growth & maturity, and reduced harvest cycle. (*Authors takes pride in moti-*

vating farmers in Bihar through personal contacts under a collaborative research program between Griffith University, Australia and Rajendra Agriculture University, Bihar).

Some of the important revelation by farmers about use of vermicompost were

- 1) Reduced use of 'water for irrigation';
- 2) Reduced 'pest attack' (by at least 75%) especially after spray of vermiwash (liquid drained during vermicomposting);
- 3) Reduced 'termite attack' in farm soil especially where worms were in good population;
- 4) Reduced 'weed growth';
- 5) Faster rate of 'seed germination' and rapid seedlings growth and development;
- 6) 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;
- 7) 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;
- 8) Fodder growth was increased by nearly 50% @ 30 to 40 quintal/hectare;
- 9) Flower production (commercial floriculture) was increased by 30%-50% @ 15-20 quintal/hectare. Flower blooms were more colorful and bigger in size;

18. ENVIRONMENTAL-ECONOMICS OF FOOD PRODUCTION BY VERMICOMPOST VIS-À-VIS CHEMICAL FERTILIZERS

A matter of considerable economic and environmental significance is that the 'cost of food production' by vermicompost (produced locally on-farm from organic wastes diverted from landfill disposal at high cost) will be significantly low by more than 60-70% as compared to chemical fertilizers (produced in factories from vanishing petroleum products using huge electricity) and the food produced will be a 'safe chemical-free food' for the society. Due to enhanced colour, taste, smell and flavour of food products farmers gets higher price for their farm products. It is a 'win-win' situation for both producers (farmers) and the consumers (feeders).

And with the growing global popularity of 'organic foods' which became a US \$ 6.5 billion business every year by 2000, there will be great demand for vermicompost in future. US Department of Agriculture estimates 25% of Americans purchase organically grown foods at least once a week. The cost of production of vermicom-

post is simply insignificant as compared to chemical fertilizers. While the vermicompost is produced from 'human waste'—a raw material which is in plenty all over the world, chemical fertilizers are obtained from 'petroleum products' which is a vanishing resource on earth. Vermicompost can be produced 'on-farm' at low-cost by simple devices, while the chemical fertilizers are high-tech & high-cost products made in factories [17, 82].

Use of vermicompost in farm soil eventually leads to increase in the number of earthworm population in the farmland over a period of time as the baby worms grow out from their cocoons. It infers that slowly over the years, as the worms build up the soil's physical, chemical & biological properties, the amount of vermicompost can be slowly reduced while maintaining the same yield. The yield per hectare may also increase further as the soil's natural fertility is restored & strengthened. On the contrary, in chemical agriculture, 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.

Vermicompost is able to retain more soil moisture and also protects crops from pests & diseases thus reducing the demand of water for irrigation by nearly 30-40% and pest & disease control by almost 75%. This significantly cut down on the cost of production. As it also helps the crops to attain maturity and reproduce faster, it shortens the 'harvesting time'. This further cuts on the cost of production and also adds to the economy of farmers as they can grow more crops every year in the same farm plot.

While vermicompost production & use is an 'environmentally friendly' practices (salvaging waste & improving soil properties), production of chemical fertilizers is 'environmentally damaging' (generating hazardous wastes & pollutants and greenhouse gases) in its entire life-cycle, since harnessing of raw materials from the earth crust, to their processing in factories (generating huge waste and pollution) and application in farms (polluting soil & killing beneficial organisms) with severe economic & environmental implications. Production and use of 1 kg of chemical nitrogen fertilizer emits 2,500 gm of CO₂, 10 gm N₂O & 1 gm CH₄. Molecule to molecule, N₂O and CH₄ are 310 & 22 times more powerful GHG than CO₂. Earthworms converts a product of 'negative' economic & environmental value i.e. 'waste' into a product of 'highly positive' economic & environmental values i.e. 'highly nutritive organic fertilizer' (brown gold) and 'safe food' (green gold). Vermiculture can maintain the global 'human sustainability cycle'—producing food back from food & farm wastes.

Earthworms biomass comes as a valuable by-product in all vermicomposting practices and they are good source of nutritive 'worm meal'. They are rich in proteins (65%) with 70-80% high quality essential amino acids 'lysine' and 'methionine' and are being used as feed material to promote 'fishery' and 'poultry' industry. They are also finding new use as a source of 'bioactive compounds' (enzymes) for production of modern medicines for cardiovascular diseases and cure for cancer in the making of 'antibiotics' from the ceolic fluid as it has anti-pathogenic properties. On commercial scale tons of worm biomass can result every year as under favorable conditions worms 'double' their number at least every 60-70 days.

If vermi-products (worms, vermicompost & vermi-wash) are able to replace agrochemicals in food production and protein rich worms provide nutritive feeds for fishery and poultry production it would truly help achieve greater sustainability in production of 'safe food' for mankind in future [83,84].

19. CONCLUSIONS AND REMARKS

Our studies and those of other learned authors have conclusively proved that earthworms and its excreta (vermicast) or even its body fluids (vermiwash) have tremendous crop growth promoting and protecting potential and may work as the main 'driving force' in sustainable food production while maintaining soil health and fertility and can completely replace the use of agro-chemicals from farm production or just require them as 'helping hand' [83,84]. Vermicompost also reinforce plants physiologically to attain maturity and reproduce faster, thus reducing the 'life-cycle' of crops and also shortening the 'harvesting time'. Reduced incidence of 'pest and disease attack', 'controlling pests without pesticides' and 'better taste of chemical-free organic food products especially 'fruits and vegetables' grown with earthworms and vermicompost are matter of great socio- economic and environmental significance.

In case of fruits and vegetable crops presence of earthworms in soil make a big difference in growth performance. It looks worms have more positive impacts on flowering of horticultural crops and significantly aid in fruit development obviously due to secretion of growth hormones 'auxins' and 'gibberellins' [22,69,85]. No wonder then, Surpala, in 10th century A.D. recommended to add earthworms in pomegranate plants to obtain good fruits.

Use of vermicompost in farm soil eventually leads to increase in the number of earthworm population in the farmland over a period of time as the baby worms grow out from their cocoons. Slowly over the years, as the

worms & vermicompost build up the soil's physical, chemical and biological properties of soil and restore its natural fertility, reduced amount of vermicompost will be required to maintain productivity. This is contrary to those with chemical fertilizers whose amount of use has gradually increased over the years.

More studies is required to develop the potential of vermicompost teas (vermiwash) as a sustainable, non-toxic and environmentally friendly alternative to 'chemical pest control' or at least its application in farming practices can also lead to significant reduction in use of chemical pesticides.

Earthworms are truly justifying the beliefs and fulfilling the dreams of Sir Charles Darwin who called earthworms as '*unheralded soldiers' of mankind*' and '*friends of farmers*'. It is also justifying the beliefs of Dr. Anatoly Igonin one of the great contemporary vermiculture scientist from Russia who said '*Earthworms create soil & improve soil's fertility and provides critical biosphere's functions: disinfecting, neutralizing, protective and productive*' [86].

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