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Special Issue on

'VERMICULTURE & SUSTAINABLE AGRICULTURE'

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Our work on 'Vermiculture Studies' has always been inspired by the great visionary scientists **Sir Charles Darwin** who called 'Earthworms' as 'Friends of Farmers' and the ancient Indian scientist **Surpala** who recognized the value of earthworms in plant growth in 10th Century A.D in his book 'Vrikshayurveda' (Science of Tree Growing). We are trying to revive their dreams & scientifically validate their visions.

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The Concept of Sustainable Agriculture: An Issue of Food Safety and Security for People, Economic Prosperity for the Farmers and Ecological Security for the Nations

Key words: Green revolution by chemical agriculture . curse in disguise . second green revolution by vermiculture revolution . organic farming . backbone of sustainable agriculture . earthworms vermicompost . superb organic fertilizers . miracle growth promoter . bio-villages in Bihar (India) embracing organic farming . sustainable agriculture

INTRODUCTION: THE IMPENDING THREAT OF CHEMICAL AGRICULTURE TO HUMAN HEALTH AND ENVIRONMENT

Chemical agriculture triggered by widespread use of agro-chemicals in the wake of 'green revolution' of the 1950s-60s came as a 'mixed-blessing' rather a 'curse in disguise' for mankind. It dramatically increased the 'quantity' of the food produced but severely 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. The early response to chemical fertilizers is 'levelling off' after a 3% annual increase between 1950-1984. There is evidence that a plateau has been reached in global efforts to increase the yield per hectare through agro-chemicals.

Increased use of agro-chemicals have virtually resulted into 'biological droughts' (severe decline in beneficial soil microbes and earthworms which help to renew the natural fertility of soil) in soils in the regions of green revolution in world where heavy use of agro-chemicals were made. Higher uses of agro-chemicals also demands high use of water for irrigation putting severe stress on ground and surface waters. Soil and water pollution due to seepage and drainage especially after heavy rainfall were other ill-effects on farmlands.

Widespread use of chemical pesticides became a necessity for the growth of high-yielding varieties of crops which was highly 'susceptible to pests and diseases'. Continued application of chemical pesticides induced 'biological resistance' in crop pests and diseases and lograthmatically much higher doses are now required to eradicate them.

Studies indicate that there is significant amount of 'residual pesticides' contaminating our food stuff long after they are taken away from farms for human consumption. Vegetable samples were contaminated 100% with HCH and 50 per cent with DDT (143). Bhatnager (25) reported pesticide residues in wheat flour samples. Contamination with HCH was 70%, Heptachlore 2 was 45%, Aldrin 45% and DDT 91%. 60% of water samples were found to be contaminated with Aldrin and 50% with DDT. They were all higher than permissible limits of WHO. A study made by the Society for Research and Initiative for Sustainable Technologies and Institutions (SRISTI), Ahmedabad, India, to analyse the residual pesticide in soils of croplands of Gujarat found that 41 out of 70 samples contained insecticidal residues of *Phosphamidon, DDVP, Methyl parathion, Malathion, Chlorpyriphos* and three different *pyrethroids*. Rao (143) also reported residues of pesticides in meat, fish, eggs, butter, milk including in mother's milk and human fat. The contamination was 100% with HCH, 69% with DDT and 43% with aldrin. In human fat DDT residue ranged from 1.8 ppm in Lucknow to 22.4 ppm in Ahmedabad; HCH ranged from 1.6 ppm in Bombay to 7 ppm in Bangalore.

Adverse effects of agro-chemicals on the agricultural ecosystem (soil, flora, fauna & water bodies in farms) and also on the health of farmers using them and the society consuming the chemically grown food have now started to become more evident all over the world. According to United Nation Environment Program (UNEP) and the World Health Organization (WHO) nearly 3 million people suffer from 'acute pesticide poisoning' and some 10 to 20 thousands people die every year from it in the developing countries (196). US scientists predict that up to 20,000 Americans may die of cancer, each year, due to the low levels of 'residual pesticides' in the

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chemically grown food. (196). The farmers today are caught in a 'vicious circle' of higher use of agrochemicals to boost crop productivity at the cost of declining soil fertility. This is also adversely affecting their economy as the cost of agrochemicals has been rising all over the world.

EMBRACING THE CONCEPT OF 'SUSTAINABLE AGRICULTURE': EMBARKING ON A 'SECOND GREEN REVOLUTION' THROUGH 'ORGANIC FARMING' BY VERMICULTURE

The term 'Sustainable Development' was coined by Bruntdland Commisssion Report 'Our Common Future' in 1982 which redefined the concept of human development as the development (both social & economic) to- 'meet the 'needs' (but not the 'greed') of the present generation without compromising with the abilities of the future generations to meet their own needs and that should improve the total quality of all life (human beings, plants and animals) on Earth now and in the future too, while maintaining the social and ecological integrity (natural and man-made ecosystems) of the earth upon which all life depends and which can provide good quality of life to all the people born on Earth, while protecting their basic life-support systems (air, water, soil, flora and fauna) and also safely disposing all the wastes generated by them' (195 & 198).

The scientific community all over the world is desperately looking for an 'economically viable, socially safe & environmentally sustainable' alternative to the destructive 'chemical agriculture' which would not only 'maintain' but also 'enhance' farm production per hectare of available land as the farmlands all over the world is shrinking in the wake of rapid urbanization. Then, it is not enough to produce 'sufficient food' to feed the civilization (which was the primary objectives of chemical based green revolution) but also to produce a 'high quality of food' which should be 'safe' (chemical free) and also 'protective' to human health (good combination of macro and micro nutrients and vitamins) and do it in a sustainable manner to ensure 'food security' for all, but most for them in the poor Third World nations in the long term. 'Food Safety & Security' is a major issue everywhere in the world. This will amount to embarking on a 'Second Green Revolution' and this time by 'Organic Farming' practices completely giving up the use of agro-chemicals (33; 44; 77; 78; 102 & 172).

The new concept of farm production against the destructive 'Chemical Agriculture' has been termed as 'Sustainable Agriculture'. This is about growing 'nutritive and protective foods' with the aid of biological based 'organic fertilizers' without recourse to agro-chemicals. This is thought to be the answer for the 'food safety and security' for the human society in future. The U.S. National Research Council (1989) defined sustainable agriculture as 'those alternative farming systems and technologies incorporating natural processes, reducing the use of inputs of off-farm sources, ensuring the long term sustainability of current production levels and conserving soil, water, energy and farm biodiversity'. It is a system of food production which avoids or largely excludes the use of systematically compounded chemical fertilizers and pesticides and use of environmentally friendly organic inputs. To the maximum extent feasible, organic farming systems rely upon crop rotations, crop residues, animal manures, legumes and green manures to maintain soil productivity and tilth to supply plant nutrients. It emphasizes on both preventive and curative methods of pest control such as the use of pest resistant cultivars, bio-control agents and cultural methods of pest-control.

In the US, the top 25% of sustainable agriculture farmers practicing 'organic farming' now have better gross margins and better yields than the top 25% of their counterparts still practicing chemical agriculture (1). Swedish farmers are practicing the 'Cleanest Agriculture' in world now since 1972. They have developed an alternative system of agriculture based upon the vision of '*kretslopp*'--'agriculture which aims to be in harmony with the cycle of nature' and therefore, highly sustainable. They have drastically cut the use of pesticides, herbicides and fungicides by 70 per cent since 1985 (196 & 197).

Vermicompost (metabolic products of earthworms feeding on organic wastes) is proving to be highly nutritive 'organic fertilizer' and a 'miracle growth promoter' rich in NKP (nitrogen 2-3%, potassium 1.85-2.25% and phosphorus 1.55-2.25%), micronutrients, beneficial soil microbes and also contain 'plant growth hormones & enzymes'. Evidences are accumulating all over the world including our own studies (discussed later in chapters) that the earthworms and their vermicompost can do the miracle. They can 'build up soil', 'restore soil fertility', 'sustain farm production' and also deliver 'safe food' for the civilization.

Agenda 21 on sustainable agriculture: The Chapter on 'Sustainable Agriculture' in Agenda 21 adopted at the Earth Summit in Rio de Janeiro, Brazil, June 1992, makes it obligatory for international agencies and governments of all nations to give incentives to farmers to shift away from the environmentally destructive high-tech chemical agriculture to the environmentally friendly sustainable agriculture by improving upon the traditional technologies with modern scientific knowledge. The International Movement for Ecological Agriculture held in Penang, Malaysia (Jan. 10-13, 1990) has also called for alternative technology in agriculture.

MOVEMENT FOR ORGANIC FARMING AND SUSTAINABLE AGRICULTURE

The International Institute of Environment and Development (IIED), London, examined the extent and impact of 'Non-Chemical Sustainable Agriculture' in a number of countries. Sustainable agriculture is synonymous with 'Cleaner Agriculture' as the objective is to reduce or even eliminate the use of dangerous agro-chemicals from food production and also to reduce the use of other precious farm inputs like water and energy whose indiscriminate use to boost food production (to feed the growing masses) has led to widespread environmental destruction by way of soil salinity, waste and pollution (139 & 140).

According to IIED there are some 1.82 million households farming 4.1 mha with cleaner chemical-free agriculture technologies in 20 developing countries. All have used resource conserving technologies and practicing organic farming. In the U.S. some 69 large scale farmers had switched over to 'organic farming' by 1980 (1). The figure must have increased significantly by now. In India several farmers are being motivated to shift to 'organic farming & sustainable agriculture' through vermiculture and give up 'chemical agriculture' (172). A number of villages in the districts of Samastipur, Hazipur and Nalanda in Bihar have been designated as 'BIO-VILLAGES' where the farmers have completely embraced ORGANIC FARMING by use of earthworms and vermicompost. They have completely given up the use of chemical fertilizers for the last four years since 2005. They are growing both cereal (rice, wheat & corn), fruits (banana, guava, mango & lemons) and vegetable crops (potato, tomato, onion, brinjal, cucumber, okra etc) on vermicompost. Farmers of bio-villages feel proud of their food products and they sell at a higher price in market due to their good appearance and taste (Personal Interview by Rajiv Sinha, December, 2008).

In the OECD countries, a shift to cleaner sustainable agriculture is expected to bring a slight short-term decline in productivity of around 5-15%. But the decline in the 'cost of input' of cleaner agriculture is sharper and therefore more profitable to the farmers practicing cleaner chemical-free agriculture than the farmers practicing chemical agriculture where the cost of inputs were several times high (170 & 172). Evidences are gathering that in the long term (5 to 10 years) yields in cleaner chemical-free agriculture will recover to former levels as the soil regenerates slowly with the use of local biological farm inputs (instead of dangerous agro-chemicals), natural soil fertility is renewed, pests becomes isolated, farmers becomes more skilled and able to understand and manage their new production system and agro-ecosystem (139 & 140).

VERMICULTURE CAN PROMOTE ORGANIC FARMING & SUSTAINABLE AGRICULTURE

Sustainable agriculture is a process of learning new and innovative methods developed by both farmers and the farm scientist and also learning from the traditional knowledge and practices of the farmers and implementing what were good in them and also relevant in present times. Vermiculture was practiced by traditional and ancient farmers with enormous benefits accruing for them and their farmlands. There is need to revive this 'traditional concept' through modern scientific knowledge-a 'Vermiculture Revolution'. Sir Charles Darwin called the earthworms as 'farmer's friends'. There is great wisdom in this statement of the great visionary scientist who advocated to use the earthworms, the 'nature's gift' in farm production.

It is necessary to adopt and implement food & agriculture production system which must ensure:

- Maintenance of soil microbiology and fertility by greater use of biofertilizers.
- High productivity and stability of yield over the years.
- Productivity with 'minimum' or 'no' tilling; 'low' use of agro-chemicals (only as helping hand) and integration with biofertilizers and biopesticides.
- Productivity with minimum use of water and even sustain dryness or heavy rainfall.

- Preservation of crop diversity (biotopes).
- Preservation of soil, water and air quality in the farm ecosystem.
- Preservation of benevolent organisms (predators) flora & fauna in the farm ecosystem.
- Preservation of groundwater table.
- Preservation of good health for all.
- Reduction of water and energy use.

These are the objectives of organic farming & sustainable agriculture. Sustained vermiculture practices and use of vermicompost in farm soil over the years would meet several of the above requirements for a truly sustainable agriculture (168). Vermicompost is rich in microbial diversity and plant available nutrients; improve moisture holding capacity of soils thus reducing water for irrigation; improve physical, biological and chemical properties of soil; increase soil porosity & softness thus requiring minimum tillage. They have been discussed in later chapters.

Environmental and economic benefits of vermiculture: There will also be ample opportunity to reduce energy use and reduction of greenhouse gas (GHG) emissions in vermicompost production locally at farms by the farmers themselves. Huge amount of energy is used and GHG emitted at chemical fertilizer factories apart from 'toxic and hazardous wastes' that is generated. Farm energy requirements might be reduced by 40% by more efficient methods of food production through vermiculture technology.

If there is decline in the use of external inputs (agro-chemicals), with more use of locally produced biofertilizers (vermicompost) the costs of food produced by farmers practicing sustainable agriculture will be reduced significantly. There will be more useful trees, more farm wildlife, increased groundwater in wells and ponds, cleaner non-polluted water bodies, more soft & nutritive soils with biological organisms in and around the farmlands in the farm ecosystem where sustainable agriculture is practiced by vermiculture. These will help boost the 'economic prosperity' of farmers.

CONCLUSIONS AND REMARKS

Planning global organic farming and sustainable agriculture can truly bring in 'economic prosperity' for the farmers, 'ecological security' for the farms and 'food security' for the people. This will require embarking on a 'Second Green Revolution'- and this time through 'Vermiculture Revolution'- by the earthworms - Darwin's children & the 'miracle of nature' (27; 168 & 172).

Organic food products **produced** through organic farming systems are the fastest growing food sector in the world food market. Australia is a small player in the global organic food market. It was estimated to be AU $ 33 billion in 2003. And the foundation of organic farming is 'healthy soil'. Organic farming practices aim to increase soil humus (and thus encourage increased biological activity within the soil) and in-built systems of 'plant protection' within the farm ecosystem (natural pest control by soil & farm biodiversity) without recourse to agro-chemicals. And both these objectives can be achieved by integrating vermiculture in farming systems.

A shift to organic farming driven sustainable agriculture would require immense patience on the part of farmers during the transition period and till the productivity is restored to original level. It will be another challenge for the scientific community as great as it was in the 1950' & 60's when the 1st 'Green Revolution' was launched with the aid of 'agrochemicals' to boost farm productivity and save the growing human population from starvation (56). It would also require a huge investment by the government in building 'local capacity' to the farmers in developing countries. But this investment, would be an investment both in the current as well as in the future 'capacity building' of the farmers to feed the world (105; 198; 199 & 202).

Earthworms: The 'Unheralded Soldiers of Mankind' and 'Farmer's Friend' Working Day and Night Under the Soil: Reviving the Dreams of Sir Charles Darwin for Promoting Sustainable Agriculture

Key words: Vermiculture biotechnology . key to sustainable agriculture . earthworms converts most organic waste into nutritive compost . earthworms improves physical . chemical and biological properties of soil . earthworms are disinfecting . neutralizing, protective . productive agents of nature

INTRODUCTION: REVIVING THE TRADITIONAL VERMICULTURE TECHNOLOGY FOR PROMOTING ORGANIC FARMING & SUSTAINABLE AGRICULTURE

Earthworms are an important organism in the soil doing great service for mankind for millions of years now. It combines immense social, economic and environmental values together which is now being realized and recognized. A newer branch of biotechnology called 'Vermiculture Technology' is emerging by the use of earthworms to solve various environmental problems from waste management to land (soil) improvement. Sir Charles Darwin, the great visionary biological scientist highlighted about its role in 'soil improvement and farm production' long time ago and traditional farming community was also practicing vermiculture in their farms. Unfortunately, very little attention was given to it by post-Darwin biological scientists and the modern agricultural scientists and also the farming community of world who saw 'agrochemicals' as a technological boon to produce more food in shorter time.

Biological and agricultural scientists all over the world, after getting utterly disappointed by modern chemical agriculture which is destroying the soil and also adversely affecting human health (the 'boon' turning into 'bane') is now looking back into the 'traditional wisdom' and trying to revive the dreams of Charles Darwin. Earthworms when present in soil inevitably work as 'soil conditioner' to improve its physical, chemical and biological properties and also its nutritive value for healthy plant growth. This they do by soil fragmentation and aeration, breakdown of organic matter in soil & release of nutrients, secretion of plant growth hormones, proliferation of nitrogen-fixing bacteria, increasing biological resistance in crop plants and all these worm activities contribute to improved crop productivity. Worms swallow large amount of soil with organics everyday and digest them by enzymes. Only 5-10 percent of the digested 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 NKP (nitrates, phosphates and potash), micronutrients and beneficial soil microbes (24 & 35).

Value of earthworms in plant propagation was emphasized by the great Indian author Surpala in his epic 'Vriksha-ayurveda' (Science of Tree Growing) as early as in the 10^{th} century A.D. He recommended to incorporate earthworms in soil of pomogranate plants to obtain high quality fruits (150). This traditional wisdom has been scientifically verified today for successful & sustainable growth of several fruits, vegetables and cereal crops today without the use of agrochemicals (168).

VERMICULTURE REVOLUTION FOR SAFE WASTE MANAGEMENT AND SUSTAINABLE FOOD PRODUCTION

A revolution is unfolding in vermiculture studies (rearing of useful earthworms species) for multiple uses in sustainable waste management and sustainable agriculture. (36; 80;122 & 151). Earthworms have over 600 million years of experience in waste & 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'.

Vermiculture biotechnology promises to provide cheaper solutions for:

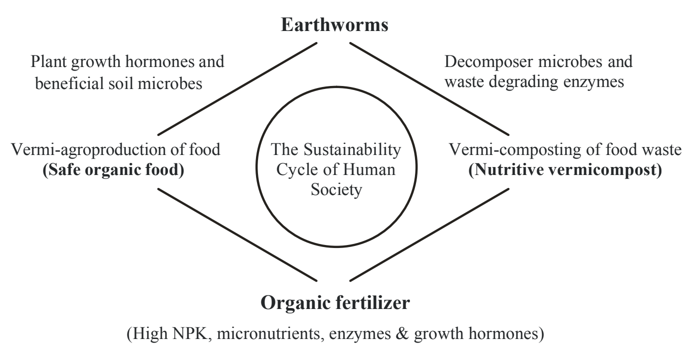
- Management of municipal & industrial solid wastes (organics) by biodegradation & stabilization and converting them into nutritive organic fertilizer (vermicompost)-'THE VERMI-COMPOSTING

TECHNOLOGY' (VCT). It amounts to converting 'trash into treasure' or getting 'wealth from waste' or 'gold from garbage' (29; 34; 36; 37; 63; 66; 160; 173: 200 & 201). (Value of earthworms in waste management was emphasized by Greek Philosopher Aristotle who called as 'intestine of earth' which meant that they can digest wide variety of materials from earth).

- Restoring & improving soil fertility and boosting food productivity by worm activity and use of vermicompost (miracle growth promoter) without recourse to the destructive agro-chemicals-'THE VERMI-AGRO-PRODUCTION TECHNOLOGY' (VAPT). It amounts to getting 'green gold' (crops) from 'brown gold' (vermicompost).

Palainsamy (133) indicated that in the tropics earthworms improve the growth and yield of wheat grown with wormcasts. According to him, fertilizing soils with worms can increase crop yield by more than 40%. Baker & Barrett (28) at CSIRO, Australia found that the earthworms can increase growth of wheat crops by 39%, grain yield by 35%, lift protein value of the grain by 12% & fight crop diseases. Bhawalkar & Bhawalkar (35) experimented that an earthworm population of 0.2-1.0 million per hectare can be established within a short period of three months. This is the only key to a quick change over to sustainable agriculture without loss of crop yield. Gunathilagraj (92) noted that the association between plant and earthworms induced significant variation among the plants. He reported that small doses of NPK fertilizers and earthworms + cowdung + mulch significantly increased the chlorophyll protein, potassium, iron, manganese and zinc contents in the field crops.

Nations of world today is seeking the most cost-effective, economically viable, environmentally sustainable & socially acceptable technology that can convert all 'organic waste' into a valuable 'resource' to be used back into the human society. Earthworms have potential of generating NPK equal to 10 million tonnes annually in India (and other nations too) as huge amount of organic waste is generated every year and 1,000 tonnes of organic wastes can be degraded to 300 tonnes of nutritive vermicompost rich in NPK and all essential micronutrients by about few million worms whose population almost double every year (34). 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. Vermicomposting of all waste organics especially the 'food & garden waste' of society and using the nutritive end-product to grow 'food' again will establish the concept of 'circular metabolism' for a sustainable society.



(Circular Metabolism & the Sustainability Cycle of Human Society)

Vermi-composting and Vermi-agroproduction is self-promoted, self-regulated, self-improved & self-enhanced, low or no-energy requiring zero-waste technology, easy to construct, operate and maintain. It excels all 'bio-conversion', 'bio-degradation' & 'bio-production' technologies by the fact that it can utilize organics that otherwise cannot be utilized by others. It excels all 'bio-treatment' technologies because it achieves greater utilization than the rate of destruction achieved by other technologies. It involves about 100-1000 times higher 'value addition' than other biological technologies (9 & 10).

About 4,400 different species of earthworms have been identified and quite a few of them are versatile waste eaters and bio-degraders and several of them are bio-accumulators & bio-transformers of toxic chemicals from contaminated soils rendering the land fit for productive uses (57; 64 ; 66; 146; 171& 181).

Versatile waste eater and decomposer *Eisinia fetida*

NATURAL ATTRIBUTES & ADAPTATIONS OF EARTHWORMS TO PERFORM THE DUAL ROLES OF WASTE & LAND (SOIL) MANAGERS

Earthworms are long, narrow, cylindrical, bilaterally symmetrical, segmented animals without bones measuring few centimeters. Tropical worms are bigger & robust. An exceptionally big species about a meter long is reported from Victoria in Australia. The body is dark brown, glistening and covered with delicate cuticle. They weigh over 1400-1500 mg after 8-10 weeks. On an average, 2000 adult worms weigh 1 kg and one million worms weigh approximately 1 ton. Usually the life span of an earthworm is about 3 to 7 years depending upon the type of species and the ecological situation (65 & 92).

Earthworms love to feed upon 'cattle dung' which is preferred food for them. When given a choice between various foods the worms consumed 10 mg dry weight of dung per gram body weight per day together with smaller amount of leaf litter. In about 13 days *Allolobophora caliginosa* consumed 13.1 gram of dung while only 1.3 gram of grass leaves (30). However, firm leaves particularly the grass leaves are not eaten until they had decayed to a moist, brown condition. Worms have 'chemoreceptors' which aid in search of food (65).

Earthworms harbor millions of 'nitrogen-fixing' and 'decomposer microbes' in their gut. They have to necessarily feed upon microbes, particularly fungi, to meet their protein/nitrogen requirement essential for growth and reproduction. Earthworms also produce huge amount of 'intestinal mucus' composed of glyco-proteins and small glucosidic and proteic molecules. The microbes entering the gut of worms consume all these nitrogenous compounds of the mucus, which largely increase their activity, which in turn enables them to contribute enzymes in the digestive process of earthworms (214). The microbes not only mineralize the complex substances into plant-available form but also synthesize a whole series of 'biologically active' substances.

Worm's body contains 65% protein (70-80% high quality 'lysine rich protein' on a dry weight basis), 14% fats, 14% carbohydrates and 3% ash (205). Earthworms act as an aerator, grinder, crusher, chemical degrader and a biological stimulator wherever they inhabit (57; 171).

Enormous power of reproduction and rapid rate of multiplication: Earthworms multiply very rapidly. They are bisexual animals and cross-fertilization occurs as a rule. After copulation the clitellum (a prominent band) of each worm eject lemon-shaped 'cocoon' where sperms enter to fertilize the eggs. Up to 3 cocoons per worm per week are produced. From each cocoon about 10-12 tiny worms emerge. Studies indicate that they double their number at least every 60 days. 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 (96). A mature adult can attain reproductive capability within 8-12 weeks of hatching from the cocoon. Red worms takes only 4-6 weeks to become sexually mature (205). Earthworms continue to grow throughout their life and the number of segments continuously proliferates from a growing zone just in front of the anus.

Table 1: Reproductive capacity of some environmentally supportive worms

Species	Sexual maturity time (days)	No. of cocoon.	Cocoons hatching time (days)	Egg maturity days	Hatching (%)	No. of hatchlings	Net reproduction rate/week
E. fetida	53-76	3.8	32-73	85-149	83.2	3.3	10.4
E. eugeniae	32-95	3.6	13-27	43-122	81.0	2.3	6.7
P. excavatus	28-56	19.5	16-21	44-71	90.7	1.1	19.4
D. veneta	57-86	1.6	40-126	97-214	81.2	1.1	1.4

Source: Edwards (1988)

Sensitive to light, cold and dryness: Earthworms are very sensitive to light, cold and dryness. They tend to migrate away temporarily into deeper layers of soil when subjected to light, too cold or too hot situations. This is of great survival to them especially in cold winters and hot summers.

Adapted to survive in harsh environment: Some species e.g. *Eisinea fetida* are highly adapted to survive in 'harsh' conditions where no creature on earth can survive. After the Seveso chemical plant explosion in 1976 in Italy, when vast inhabited area was contaminated with certain chemicals including the extremely toxic TCDD (2, 3, 7, 8-tetrachlorodibenzo-*p*-dioxin) several fauna perished but for the earthworms that were alone able to survive. Earthworms which ingested TCDD contaminated soils were shown to bio-accumulate dioxin in their tissues and concentrate it on average 14.5 fold (151).

E. fetida was used as the test organisms for different soil contaminants and several reports indicated that *E. fetida* tolerated 1.5% crude oil (containing several toxic organic pollutants) and survived in this environment (129). Earthworms also tolerate high concentrations of heavy metals in the environment. The species *Lumbricus terrestris* was found to bio-accumulate in their tissues 90-180 mg lead (Pb)/gm of dry weight, while *L. rubellus* and *D. rubida* it was 2600 mg/gm and 7600 mg/gm of dry weight respectively (103).

Ability to degrade most organic wastes rapidly into nutritive vermicompost: Researches into vermiculture have revealed that worms can feed upon wide variety of organic wastes and provides sustainable solution for total waste management (80; 112). The farm wastes, animal wastes, garden wastes from homes and parks, the sewage sludge from the municipal wastewater and water treatment plants, the wastewater sludge from paper pulp and cardboard industry, brewery and distillery, sericulture industry, vegetable oil factory, potato and corn chips manufacturing industry, sugarcane industry, guar gum industry, aromatic oil extraction industry, logging and carpentry industry offers excellent feed material for vermi-composting by earthworms. (59; 67; 68; 72; 81; 85; 89; 93; 109; 110; 114; 116; 119; 120; 157; 158; 159 ;173 ; 181 & 200). Even the 'flyash' (rich in nitrogen) from the coal power plants once considered as a 'biohazard' can be composted by earthworms and converted into organic faertilizer. (153). The worms digest the waste and convert a good part of it into mineral rich nutritive vermicompost which is much superior to all the conventional composts.

Livestock rearing waste such as cattle dung, pig and chicken excreta makes excellent feedstock for earthworms. Animal excreta containing excessive nitrogen component may require mixing of carbon rich bulking agents (straw, saw dust, dried leaves and grasses, shredded paper waste etc.) to maintain proper C/N ratio. Paunch waste materials (gut contents of slaughtered ruminants) from abattoir also make good feedstock for earthworms.

The worms secrete enzymes proteases, lipases, amylases, cellulases and chitinases in their gizzard and intestine which bring about rapid biochemical conversion of the cellulosic and the proteinaceous materials in the waste organics. Earthworms convert cellulose into its food value faster than proteins and other carbohydrates. They ingest the cellulose, pass it through its intestine, adjust the pH of the digested (degraded) materials, cull the unwanted microorganisms and then deposit the processed cellulosic materials mixed with minerals and microbes as aggregates called 'vermicasts' in the soil (57).

Most earthworms consume, at the best, half their body weight of organics in the waste in a day. *Eisenia fetida* is reported to consume organic matter at the rate equal to their body weight every day (205). Earthworm participation enhances natural biodegradation and decomposition of organic waste from 60 to 80%. Study indicates that given the optimum conditions of temperature (20-30 °C) and moisture (60-70%), about 5 kg of worms (numbering approx.10,000) can vermiprocess 1 ton of waste into vermi-compost in just 30 days (205). Upon vermi-composting the volume of solid waste is significantly reduced from approximately 1 cum to 0.5 cum of vermi-compost.

Vermicompost is a nutritive 'organic fertilizer' rich in NKP (nitrogen 2-3%, potassium 1.85-2.25% and phosphorus 1.55-2.25%), micronutrients, beneficial soil microbes like 'nitrogen-fixing bacteria' and 'mycorrhizal fungi' & plant growth hormones. Kale & Bano (108) reports as high as 7.37% nitrogen (N) and 19.58% phosphorus as P_2O_5 in worms vermicast. They are scientifically proving as 'miracle plant growth promoters' much superior to conventional composts and chemical fertilizers (175; 176 & 177).

Reinforce decomposer microbes to promote rapid waste degradation: Earthworms promotes the growth of 'beneficial decomposer aerobic bacteria' in waste biomass and this they do by several ways-by improving 'aeration' through burrowing actions, by releasing 'chemical mediators' along their gut and body surface and indirectly through protozoa which they activate, which act at low concentrations on microbial metabolism, as vitamins or as chemical catalysts (38). Earthworms hosts millions of decomposer (biodegrader) microbes in their gut (as they devour on them) and excrete them in soil along with nutrients nitrogen (N) and phosphorus (P) in their excreta (169). The nutrients N & P are further used by the microbes for multiplication and vigorous action. Edward and Fletcher (67) showed that the number of bacteria and 'actinomycetes' contained in the ingested material increased up to 1000 fold while passing through the gut. A population of worms numbering about 15,000 will in turn foster a microbial population of billions of millions. (123). Singleton (169) studied the bacterial flora associated with the intestine and vermicasts of the earthworms and found species like *Pseudomonas, Mucor, Paenibacillus, Azoarcus, Burkholderia, Spiroplasm, Acaligenes and Acidobacterium* which has potential to degrade several categories of organics. *Acaligenes* can even degrade PCBs and *Mucor* can degrade dieldrin.

Under favorable conditions, earthworms and microorganisms act 'symbiotically & synergistically' to accelerate and enhance the decomposition of the organic matter in the waste. It is the microorganisms which break down the cellulose in the food waste, grass clippings and the leaves from garden wastes (123).

Ability to kill pathogens & disinfect its surroundings: The earthworms release coelomic fluids that have anti-bacterial properties and destroy all pathogens in the media in which it inhabits (137). They also selectively devour the protozoa, bacteria and fungus as food. They seems to realize instinctively that anaerobic bacteria and fungi are undesirable (causing rotting and foul odor) and so feed upon them preferentially. They also produce 'antibiotics' and kills the pathogenic organisms in their surroundings. This attribute of earthworms is very useful in composting of waste where the end-product becomes 'disinfected', 'odorless' and free of harmful microbes. The removal of pathogens, faecal coliforms (*E. coli*), *Salmonella* spp., enteric viruses and helminth ova from human waste appear to be much more rapid when they are processed by *E. fetida*. Of all *E.coli* and *Salmonella* are greatly reduced (23).

Ability to bio-accumulate toxic chemicals and detoxify the medium in which it lives: Several studies have found that earthworms effectively bio-accumulate or biodegrade several organic and inorganic chemicals including ‘heavy metals’, ‘organochlorine pesticide’ and the lipophilic organic micropollutants like ‘polycyclic aromatic hydrocarbons’ (PAHs) residues in the medium in which it inhabits. No farmlands in the world today where heavy use of agrochemicals were made in the wake of ‘green revolution’ are free of organic pesticides. 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 (103).

The ability of heavy metals removal by earthworms is of particular significance while using vermicomposts made from urban solid wastes. Urban waste may contain considerable heavy metals and when processed by earthworms only that they can become free of heavy metals (106).

Ability to tolerate & reduce soil salinity: 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%. Farmer in Sangli district of Maharashtra, India, grew grapes on eroded wastelands and applied vermicasting @ 5 tones/hectare. 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 (134 & 209).

EARTHWORMS CAN IMPROVE SOIL FERTILITY & PROMOTE CROP PRODUCTIVITY WITHOUT RECOURSE TO AGRO-CHEMICALS: HARBINGERS OF SUSTAINABLE AGRICULTURE

Worms improves total physical, chemical & biological quality of soil: Earthworms are found in wide range of soils representing 60-80% of the total soil biomass. Significantly, the worms lead to total improvement in the quality of soil and land where they inhabit and also enhance total plant growth and crop productivity (43; 54; 61; 91; 100; 101; 107; 117; 118; 126; 141; 149; 164; 185; 211 & 212). One acre of fertile land may contain more than 50, 000 earthworms of diverse species. They play major role in ‘renewing soil fertility’ by continuously burrowing, ingesting, turning, mixing, aerating and improving drainage of the soil and are regarded as ‘biological indicator’ of soil fertility (75 & 76). Even they have been introduced into reclaimed soils successfully to restore its fertility (41 & 174). Earthworm activity is so prolific that, on average, 12 tonnes/ha/year soil or organic matter is ingested by this population, leading to upturning of 18 tons of soil/year and world over at this rate it may mean a 2 inch humus layer over the globe (35). 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% (58).

After Darwin published his observations in 1837 on the earthworms about how it mixed plant residues & dung with the farm soil and its grinding action in the gut to comminute soil aggregates and expose fresh soil surfaces to microbial attacks many people started studying about the role of worms in soil improvement and crop production. Worms select those parts of the soil which are rich in organic matter. This was studied and reported by several authors since (30; 31; 35; 58; 126; 133; 142; 190; 191; 192 & 193).

Earthworms when present in soil inevitably work as ‘soil conditioner’ to improve its physical, chemical and biological properties and also its nutritive value for healthy plant growth. This they do by soil fragmentation and breakdown of organic matter in soil & release of nutrients, secretion of plant growth hormones, proliferation of nitrogen-fixing bacteria, increasing biological resistance in crop plants and all these worm activities contribute to improved crop productivity. Worms 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 NKP (nitrates, phosphates and potash), micronutrients and beneficial soil microbes (35). The organic matter in the soil undergo 'humification' in the worm intestine in which the large organic particles are converted into a complex amorphous colloid containing 'phenolic' materials. About one-fourth of the organic matter is converted into humus. The humic acid has very good impact on plant growth (19). The colloidal humus acts as 'slow release fertilizer' in the soil (190).

Worms provide high levels of bio-available nutrients in balanced form for plants: Earthworms excretion (vermicastings) in soil carry ammonia, nitrates, nitrogen, phosphorus, magnesium and other micronutrients and nitrogen fixing microbes. Earthworm mix organic and inorganic, living and nonliving elements indiscriminately and smear the milieu with mucus, urine and faeces to form balanced plant nutrient. They produce 'extra soil nutrients' from grinding rock particles and by enhancing atmospheric nitrogen fixation. They mineralize the nitrogen (N) and phosphorus (P) in the waste to make it bio-available to plants as nutrients (46). They ingest nitrogen from the waste and excrete it in the mineral form as ammonium and muco-proteins. The nitrogenous waste excreted by the nephridia of the worms is plant-available as it is mostly urea and ammonia. The ammonium in the soil is bio-transformed into nitrates. What is more significant is that it is 'organic nitrogen' that do not accumulate in food products in a concentration that accumulates in food grown on chemical nitrogen (urea) posing health risk.

Nitrogen (N) contribution to soil: Barley & Jennings (31) reported that worms significantly contribute nitrogen (N) contents to soil by over 85%. When the young growing worms were fed with a soil containing finely ground leaf litter (containing nitrogen in non-bioavailable forms for plants), about 6% of the ingested nitrogen was excreted in bio-available forms for the plants. After 28 weeks soil with living worms contained 75 ppm of nitrate nitrogen, compared with the control soil which contained 45 ppm. Patil (136) found that earthworm recycle nitrogen in the soil in very short time and the quantity of nitrogen recycled is significant ranging from 20 to 200 kg N/ha/year. Worms increase nitrogen levels in soil by adding their metabolic & excretory products (vermicast), mucus, body fluid, enzymes and decaying tissues of dead worms. They also contribute nitrogen indirectly through fragmentation of organic materials and grazing on soil microorganisms (7; 52; 55 & 135; 155).

Earthworms tissues contains about 10% N on a dry weight basis. Whalen (208) reported that living worms release nitrogen from their bodies and after death it is rapidly decomposed releasing all nitrogen into the soil. Christensen (53) found that 50% of the N in dead worm tissues was mineralized in 7 days while Satchell (151 & 152) found it to be 70% in 10-20 days and the N was converted to NO_3-N which is bio-available form on nitrogen to crop roots. The release of mineral N after death of earthworms could be significant since worm biomass can turn over up to 3 times a year in farm soil. Study estimated direct flux of nitrogen through earthworm biomass in farm soils (agro-ecosystems) ranging from 10-74 kg N/ha/year. Stinner (179), estimated that total N uptake by corn crops in organic and inorganic fertilized farm soils was about 90 kg N/ha/year.

Phosphorus (P) contribution to soil: It is well established that worm casts are richer in 'inorganic phosphorus compounds' extractable in water than the surface soil ingested. Graff (88) and Sharpley & Syers (162) found that exchangeable phosphorus (P) measured isotopically was three (3) times greater in worms vermicasts than in the underlying soils.

Lee (118) 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 (152).

Table 2: Effect of earthworm (*E. fetida*) activity on phosphorus mineralization in soil (µg/gram dry weight and difference from control)

Phosphorus (P)	Control	Culture residues (Relative increase)
Water-soluble P	11.14	19.08 (x 1.71)
Total extractable P	251.72	311.90 (x 1.24)
Extractable Inorganic P	177.94	244.76 (x 1.38)

Source: Satchell and Martin (1984)

Worms stimulate high levels of beneficial and biologically active soil microbes: Earthworms hosts millions of beneficial microbes (including the nitrogen fixers) in their gut and excrete them in soil along with nutrients nitrogen (N) and phosphorus (P) in their excreta i.e. vermicast. The nutrients N & P and the intestinal mucus excreted by worms are further used by the microbes for multiplication and vigorous soil remediation and fertility improvement action (38; 45; 118 & 151). Teotia (187) reported bacterial count of 32 million per gram in fresh vermicast compared to 6-9 million per gram in the surrounding soil. The mycorrhizal fungi stimulated and encouraged by the earthworms transfer phosphorus by increasing solubilisation of mineral phosphate by the enzyme phosphatase. Morgan & Burrows (123), showed that the number of beneficial bacteria and 'actinomycetes' contained in the ingested material increased up to 1000 fold while passing through the gut. A population of worms numbering about 15,000 will in turn foster a microbial population in billions in soil (151).

Worms secrete plant growth hormones: Neilson (127) reported the presence of 'plant growth substances' in earthworms. Tomati (191 & 192) had also reported that worm worked soil & compost contained growth promoting hormone 'auxins' and flowering hormone 'gibberlins' secreted by earthworms.

Worms protects plants against various pests and diseases: There has been considerable evidence in recent years regarding the ability of worms 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 (3). The actinomycetes fungus excreted by the earthworms in their vermicast produce chemicals that kill parasitic fungi such as *Pythium* and *Fusarium.* (74).

VERMIWASH: THE NUTRITIVE LIQUID FILTERED THROUGH BODY OF WORMS PROMOTE GROWTH AND WORKS AS ORGANIC PESTICIDES

The brownish-red liquid which collects in all vermculture practices should be collected. 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).

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. These farmers are using vermicompost and vermiwash in all their crops since last 4 years completely giving up the use of chemical fertilizers & pesticides. (Personal Communication With Farmers in India).

VERMICULTURE: A GLOBAL MOVEMENT

The movement was started in the middle of 20th century and the first serious experiments for management of municipal/industrial organic wastes were established in Holland in 1970 and subsequently in England and Canada. Later vermiculture were followed in USA, Italy, Philippines, Thailand, China, Korea, Japan, Brazil, France, Australia and Israel (71 & 72). However, the farmers all over the world have been using worms for composting their farm waste and improving farm soil fertility since long time.

In UK, large 1000 mt vermi-composting plants have been erected in Wales (82). The American Earthworm Technology Company started a 'vermi-composting farm' in 1978-79 with 500 t/month of vermicompost production (39 & 40). Hartenstein & Bisesi (97) reported on the management of sewage sludge and effluents from intensively housed livestock by vermiculture in USA. Japan imported 3000 mt of earthworms from the USA during the period 1985-87 for cellulose waste degradation (111). The Aoka Sangyo Co. Ltd., has three 1000 t/month plants processing waste from paper pulp and the food industry (111). This produces 400 ton of vermicompost and 10 ton of live earthworms per month. The Toyhira Seiden Kogyo Co. of Japan is using rice straw, municipal sludge, sawdust and paper waste for vermicomposting involving 20 plants which in total produces 2-3 thousands tons of vermicompost per month (72). In Italy, vermiculture is used to biodegrade municipal and paper mill sludge. Aerobic and anaerobic sludge are mixed and aerated for more than 15 days and in 5000 cum of sludge 5 kg of earthworms are added. In about 8 months the hazardous sludge is converted into nutritive vermicompost. In France, 20 tons of mixed household wastes are being vermi-composted everyday using 1000 to 2000 million red tiger worms (*Elsenia andrei*) in earthworm tanks. (205). Rideau Regional Hospital in Ontario, Canada, vermi-compost 375-400 kg of wet organics mainly food waste everyday. The worm feed is prepared by mixing shredded newspaper with the food waste (205). In Wilson, North Carolina, U.S., more than 5 tons of pig manure (excreta) is being vermi-composted every week (39). In New Zealand, Envirofert is a large vermicomposting company operating in over 70 acre site in Auckland converting thousands of tons of green organic waste every year into high quality compost (www.envirofert.co.nz).

Vermiculture is being practiced and propagated on large scale in Australia too as a part of the 'Urban Agriculture Development Program' (to convert all the municipal urban wastes into compost for local food production) and 'Diverting Waste from Landfills Program' (for reducing landfills in Australia).

CONCLUSIONS AND REMARKS

Earthworms act as 'Ecosystem Engineer' converting 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 (104; 105 & 168).

Earthworms and its metabolic products (vermicompost) may work as the 'driving force' in sustainable food production while improving soil health and fertility and protecting crop plants from pests and diseases. They can completely 'replace' the use of agrochemicals in crop production. This is what is being termed as 'sustainable agriculture'. (170 & 172).

Tribute to the earthworms: Earthworms are justifying the beliefs and fulfilling the dreams of the great visionary scientist Sir Charles Darwin as 'unheralded soldiers' of mankind and 'friend of farmer's. Darwin wrote a book in which he emphasized that '*there may not be any other creature in world that has played so important a role in the history of life on earth'*.

One of the leading authorities on earthworms and vermiculture studies Dr. Anatoly Igonin of Russia has said: 'Nobody and nothing can be compared with earthworms and their positive influence on the whole living Nature. They create soil and everything that lives in it. They are the most numerous animals on Earth and the main creatures converting all organic matter into soil humus providing soil's fertility and biosphere's functions: disinfecting, neutralizing, protective and productive'.

Earthworms Vermicompost: A Powerful Crop Nutrient over the Conventional Compost & Protective Soil Conditioner against the Destructive Chemical Fertilizers for Food Safety and Security

Key words: Chemical fertilizers . destructive to soils . vermicompost protective . chemical fertilizers . decrease natural soil fertility . composts . a slow-release organic fertilizer . build up and improve soil fertility . earthworms vermicompost promote growth and protect plants . vermicompost richer in nkp and micronutrients and several times powerful growth promoter over conventional composts

INTRODUCTION: VERMICOMPOST-THE MIRACLE PLANT GROWTH PROMOTER

Earthworms vermicompost is proving to be highly nutritive 'organic fertilizer' and more powerful 'growth promoter' over the conventional composts and a 'protective' farm input (increasing the physical, chemical & biological properties of soil, restoring & improving its natural fertility) against the 'destructive' chemical fertilizers which has destroyed the soil properties and decreased its natural fertility over the years. Vermicompost is rich in NKP (nitrogen 2-3%, potassium 1.85-2.25% and phosphorus 1.55-2.25%), micronutrients, beneficial soil microbes and also contain 'plant growth hormones & enzymes'. It is scientifically proving as 'miracle growth promoter & also plant protector' from pests and diseases. Vermicompost retains nutrients for long time and while the conventional compost fails to deliver the required amount of macro and micronutrients including the vital NKP to plants in shorter time, the vermicompost does.

PROTECTIVE COMPOST VERSUS THE DESTRUCTIVE CHEMICAL FERTILIZERS

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 & society. It dramatically increased the 'quantity' of the food produced but decreased its 'nutritional quality' and also the 'soil fertility' over the years. 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 & diseases. Over the years it has worked like a 'slow poison' for the soil with a serious 'withdrawal symptoms'. The excessive use of 'nitrogenous fertilizer' (urea) has also led to increase in the level of 'inorganic nitrogen' content in groundwater (through leaching effects) and in the human food with grave consequences for the human health. Chemically grown foods have adversely affected human health.

Organic farming systems with the aid of various nutrients of biological origin such as compost are thought to be the answer for the 'food safety and farm 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. Composts also contain plenty of 'beneficial soil microbes' which help in 'soil regeneration' & 'fertility improvement' and protect them from degradation while also promoting growth in plants (60 & 207). Composts also protect plants from pests and diseases (99 & 156).

Properties of farm soil using compost vis-a-vis chemical fertilizers: Suhane (182) 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.

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 &

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

Chemical and 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)	273.0	217.0

Source: Suhane (2007)

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).

COMPOSTS: THE MIRACLE PLANT GROWTH PROMOTER & PROTECTOR

Composts 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). Bombatkar (42) called them as 'miracle' for plant growth. They supply balanced nutrients to plant roots and stimulate growth; increase organic matter content of the soil including the 'humic substances' that affect nutrient accumulation and promote root growth (49 & 165). 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 (131 & 163). One ton of 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 contains highest nutrient level among all compost (42).

There are other agronomic benefits of composts application, such as high levels of soil-borne disease suppression and removal of soil salinity (99). Ayres (20) 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. Webster (206) reported that with application of compost in vineyards, levels of exchangeable sodium (Na) under vine were at least reduced to 50%. Treated vines produced 23% more grapes due to 18% increase in bunch numbers. The yield in grapes was worth additional AU $ 3,400/ha. 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.

All 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 in 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. With continued application of compost the organic nitrogen tends to be released at constant rate from the accumulated 'humus' and the net overall efficiency of nitrogen over a period of years is considerably greater than 50% of that of chemical fertilizers. Availability of phosphorus is sometimes much greater (42 & 145). Moreover, significant amount of nitrogen is lost from soil due to oxidation in sunlight. Suhane (182) calculated 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.

VERMICOMPOST VIS -À-VIS CONVENTIONAL COMPOST & CHEMICAL FERTILIZERS

Conventional composting and vermicomposting are quite distinct processes particularly with respect to optimum temperatures for each process and the type of decomposer microbial communities that predominate

Table 2: Properties and nutrient value of compost produced from MSW

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: Sinha (2004)

during active processing. While ‘thermophilic bacteria’ predominate in conventional composting, ‘mesophilic bacteria & fungi’ predominate in vermicomposting. 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. Vermicomposting takes nearly half the time of conventional composting and vermicompost do not require any curing and can be used straightway after production (62). Vermicomposts have much ‘finer structure’ than ordinary compost and contain nutrients in forms that are readily available for plant uptake. Vermicomposts have outstanding chemical and biological properties with ‘plant growth regulators’ (lacking in other composts) and significantly larger and ‘diverse microbial populations’ than the conventional thermophilic composts (70; 73; & 193).

Atiyeh (16) found that the conventional compost was higher in ‘ammonium’, while the vermicompost tended to be higher in ‘nitrates’, which is the more available form of nitrogen. 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 (17 & 18). Vermicompost retains nutrients for long time and while the conventional compost fails to deliver the required amount of macro and micronutrients including the vital NKP (nitrogen, potassium & phosphorus) to plants in shorter time, the vermicompost does (43; 94 & 180). This was verified by Bhatia (26 & 27), Sinha & Bharambe (175), Chauhan (51) and Valani (203).

Arancon (13) studied the agronomic impacts of vermicompost and inorganic (chemical) fertilizers on strawberries when applied separately and also in combination. Vermicompost was applied @ 10 tons/ha while the inorganic fertilizers (nitrogen, phosphorus, potassium) @ 85 (N)-155 (P)-125 (K) kg/ha. While there was not much difference in the ‘dry shoot weight’ of strawberries, the ‘yield’ of marketable strawberries and the ‘weight’ of the 'largest fruit' was greater on plants in plots grown on vermicompost as compared to inorganic fertilizers in 220 days after transplanting. Also there were more 'runners' and 'flowers' on plants grown on vermicompost. Strawberries grown on inorganic fertilizers amended with vermicompost had significantly greater dry shoot weight, leaf areas and more number of flowers than grown exclusively on inorganics in 110 days after transplanting. Also, farm soils applied with vermicompost had significantly greater 'microbial biomass' than the one applied with inorganic fertilizers.

VERMICOMPOST: A SOIL CONDITIONER

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. Experiments conducted in India at Shivri farm of 'U.P. Bhumi Sudhar Nigam' (U.P. Land Development Corporation) to reclaim 'sodic soils' gave very good results. Application of vermicompost @ 6 tons/ha resulted in reduction of 73.68 in sodicity (ESP) and increase of 829.33 kg/ha of available nitrogen (N) leading to significant improvement in soil quality (174).

VERMICOMPOST: THE MIRACLE PLANT GROWTH PROMOTER & PROTECTOR

Vermicompost is a nutritive 'organic fertilizer' rich in NKP (nitrogen 2-3%, potassium 1.85-2.25% and phosphorus 1.55-2.25%), micronutrients, beneficial soil microbes like 'nitrogen-fixing bacteria' and 'mycorrhizal fungi' and are scientifically proving as 'miracle growth promoters & protectors' (177). Kale and Bano (108) reports as high as 7.37% nitrogen (N) and 19.58% phosphorus as P_2O_5 in worms vermicast. Suhane (182) showed that exchangeable potassium (K) was over 95% higher in vermicompost. There are also good amount of calcium (Ca), magnesium (Mg), zinc (Zn) and manganese (Mn). Additionally, vermicompost contain enzymes like amylase, lipase, cellulase and chitinase, which continue to break down organic matter in the soil (to release the nutrients and make it available to the plant roots) even after they have been excreted. (50; 121 & 188). Annual application of adequate amount of vermicompost also lead to significant increase in soil enzyme activities such as 'urease', 'phosphomonoesterase', 'phosphodiesterase' and 'arylsulphatase'. The soil treated with vermicompost has significantly more electrical conductivity (EC) and near neutral pH. (188).

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 & lighter and never compacted. Increase in porosity has been attributed to increased number of pores in the 30-50 μm and 50-500 size ranges and decrease in number of pores greater than 500 μm (121 & 128).

There have been several reports that worm worked waste and their excretory products (vermicast) can induce excellent plant growth (14; 15; 16; 17; 18; 19; 21; 22; 26; 49; 73;115; 144;154; 194 & 210). It has been found to influence on all yield parameters such as-improved seed germination, enhanced rate of seedling growth, flowering and fruiting of major crops like wheat, paddy, corn, sugarcane, tomato, potato, brinjal, okra, spinach, grape and strawberry as well as of flowering plants like petunias, marigolds, sunflowers, chrysanthemums and poinsettias. In all growth trials the best growth responses were exhibited when the vermicompost constituted a relatively small proportion (10%-20%) of the total volume of the container medium. Surprisingly, greater proportions of vermicomposts in the plant growth medium have not always improved plant growth (180).

Suhane (182) asserts that vermicompost is at least 4 times more nutritive than cattle dung compost. In Argentina, farmers who use vermicompost consider it to be seven (7) times richer than conventional composts in nutrients and growth promoting values (Pajon (Undated); Munroe (124). Suhane (183) reported that exclusive application of vermicompost @ 25 quintal/ha in farm wheat crops supported yield better than chemical fertilizers. It was 40 quintal/ha on vermicompost and 34.2 Q/ha on chemicals. And when same amount of agrochemicals were supplemented with vermicompost 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.

Sinha & Bharmbe (175); Chauhan (51) & Valani (203) also reported extraordinarily good growth of potted corn & wheat crops on vermicompost as compared to conventional composts and chemical fertilizers. Singh (167) reported good yields in farmed wheat crops grown on vermicompost (comparable with chemical fertilizers) which increased upon successive applications of same amount of vermicompost. (They have all been discussed later in the chapters).

SOME SIGNIFICANT PROPERTIES OF VERMICOMPOST OF GREAT AGRONOMIC VALUES

a) High levels of bio-available nutrients for plants: Vermicompost contains most nutrients in plant-available forms such as 'nitrates' (N), 'phosphates' (P), 'soluble' potassium (K), & magnesium (Mg) and 'exchangeable' phosphorus (P) & calcium' (Ca) (70 & 73). Vermicomposts have large particulate surface areas that provides many micro-sites for microbial activities and for the strong retention of nutrients (13 & 14).

b) High level of beneficial soil microorganisms promoting plant growth: Vermicomposts are rich in 'microbial populations & diversity', particularly 'fungi', 'bacteria' and 'actinomycetes' (45; 50; 154; 166 & 188). Teotia (187) and also Parle (134) reported bacterial count of 32 million per gram in fresh vermicast compared to 6-9 million per gram in the surrounding soil. Scheu (154) reported an increase of 90% in respiration rate in fresh vermicast indicating corresponding increase in the microbial population. Suhane (182) found that the total bacterial count was more than 10^{10} per gram of vermicompost. It included *Actinomycetes, Azotobacter, Rhizobium, Nitrobacter* & 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 (147). Although phosphates are available in soils in rock forms but are not available to plant roots unless solubilized.

Pramanik (138) studied the microbial population in vermicompost prepared from cow dung and municipal solid wastes (MSW) as substrates (raw materials) and found that it was in highest abundance in cow dung vermicompost. The total bacterial count was 73 x 10^8, the cellulolytic fungi was 59 x 10^6 and the nitrogen-fixing bacteria was 18 x 10^3. It was least in vermicompost obtained from MSW. The total bacterial count was 16 x 10^8, the cellulolytic fungi were 21 x 10^6 and the nitrogen-fixing bacteria were 5 x 10^3. Application of lime in the substrate enhanced the population of all above mentioned microbes irrespective of the substrates used for vermicomposting.

Plant growth promoting bacteria (PGPB) directly stimulates growth by nitrogen (N) fixation, solubilization of nutrients, production of growth hormones such as 1-aminocyclopropane-1-carboxylate (ACC) deaminase and indirectly by antagonising pathogenic fungi by production of siderophores, chitinase, ß-1,3-glucanase, antibiotics, fluorescent pigments and cyanide (95).

There is also substantial body of evidence to demonstrate that microbes, including bacteria, fungi, actinomycetes, yeasts and algae, also produce 'plant growth regulators' (PGRs) such as 'auxins', 'gibberellins', 'cytokinins', 'ethylene' and 'ascorbic acids' in appreciable quantities and as their population is significantly boosted by earthworms large quantities of PGRs are available in vermicompost (79).

c) Rich in growth hormones: Biochemical stimulating total plant growth: Researches show that vermicompost further stimulates plant growth even when plants are already receiving 'optimal nutrition'. Vermicompost has consistently improved seed germination, enhanced seedling growth and development and increased plant productivity much more than would be possible from the mere conversion of mineral nutrients into plant-available forms. Arancon (12) found that maximum benefit from vermicompost is obtained when it constitutes between 10 to 40% of the growing medium. Neilson (126 & 127) and Tomati (192) have also reported that vermicompost contained growth promoting hormone 'auxins', 'cytokinins' and flowering hormone 'gibberellins' secreted by earthworms. It was demonstrated by Grappelli (90) & Tomati (190;191 & 192) that the growth of ornamental plants after adding aqueous extracts from vermicompost showed similar growth patterns as with the addition of auxins, gibberellins and cytokinins through the soil.

d) Rich in humic acids: Biochemical promoting root growth & nutrient uptake: Atiyeh (17; 18 & 19) speculates that the growth responses of plants from vermicompost appears more like 'hormone-induced activity' associated with the high levels of humic acids and humates in vermicompost rather than boosted by high levels of plant-available nutrients. This was also indicated by Canellas (49) who found that humic acids isolated from vermicompost enhanced root elongation and formation of lateral roots in maize roots. Pramanik (138) also 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'.

e) Vermicompost is free of pathogens: Nair (125) studied that 21 days of a combination of thermocomposting and vermicomposting produced compost with acceptable C:N ratio and good homogenous consistency of a fertilizer. The study also indicated that vermicomposting leads to greater reduction of pathogens after 3 months upon storage. Whereas, the samples which were subjected to only thermofilic composting, retained higher levels of pathogens even after 3 months.

f) Vermicompost is free of toxic chemicals: Several studies have found that earthworms effectively bio-accumulate or biodegrade several organic and inorganic chemicals including 'heavy metals', 'organochlorine pesticide' and 'polycyclic aromatic hydrocarbons' (PAHs) residues in the medium in which it inhabits.

g) Vermicompost protects plants against various pests and diseases: There has been considerable evidence in recent years regarding the ability of vermicompost to protect plants against various pests and diseases either by suppressing or repelling them or by inducing biological resistance in plants to fight them or by killing them through pesticidal action (3 & 5).

i) Induce biological resistance in plants: Vermicompost contains some antibiotics and actinomycetes which help in increasing the 'power of biological resistance' among the crop plants against pest and diseases. Pesticide spray was significantly reduced where earthworms and vermicompost were used in agriculture.(168 & 182).

ii) Repel crop pests: There seems to be strong evidence that worms varmicastings sometimes repel hard-bodied pests (3 & 12). Edwards & Arancon (74) reports statistically significant decrease in arthropods (aphids, buds, mealy bug, spider mite) populations and subsequent reduction in plant damage, in tomato, pepper and cabbage trials with 20% and 40% vermicompost additions. George Hahn, doing commercial vermicomposting in California, U.S., claims that his product repels many different insects pests. His explanation is that this is due to production of enzymes 'chitinase' by worms which breaks down the chitin in the insect's exoskelton (124).

iii) Suppress plant disease: Edwards & Arancon (74) have found that use of vermicompost in crops inhibited the soil-born fungal diseases. They also found statistically significant suppression of plant-parasitic nematodes in field trials with pepper, tomatoes, strawberries and grapes. 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 (74) reported the agronomic effects of small applications of commercially produced vermicompost, on attacks by fungus *Pythium* on cucumber, *Rhizoctonia* on radishes in the greenhouse, by *Verticillium* on strawberries and by *Phomposis* and *Sphaerotheca fulginae* on grapes in the field. In all these experiments vermicompost applications suppressed the incidence of the disease significantly. They also found that the ability of pathogen suppression disappeared when the vermicompost was sterilized, convincingly indicating that the biological mechanism of disease suppression involved was 'microbial antagonism.

Szczech (186), Orlikowski (130) Rodriguez (148) and Zaller (213) also found that the aqueous extracts of vermicomposts depress soil-borne pathogens and pests. They found in their field experiment that only half as many plants of tomatoes sprayed with aqueous extract of vermicompost were infected with Phytopthora infestans (that cause 'late-blight' disease) as those of control ones.

FACTORS DETERMINING THE NUTRITIONAL QUALITY OF VERMICOMPOST

The nutritional quality of vermicompost is determined primarily by the type of the substrate (raw materials) and species of earthworms used for composting, along with microbial inoculants, liming, aeration, humidity, pH and temperature. Cattle dung has been found to yield most nutritive vermicompost when composted by *Eisinea fetida*. Pramanik (138) found that application of lime @ 5 gm/kg of substrate and 'microbial inoculation' by suitable 'cellulolytic', 'lignolytic' and 'N-fixing' strains of microbes not only enhance the rate of vermicomposting but also results into nutritionally better vermicompost with greater enzymatic (phosphatase & urease) activities. Kaushik and Garg (113) found that inoculation with N-fixing bacteria significantly increased the 'nitrogen' (N) content of the vermicompost. Liming generally enhance earthworm activities as well as microbial population. Earthworms after ingesting microbes into its gut proliferate the population of microbes to several times in its excreta (vermicast). It is therefore advantageous to use beneficial microbial inoculants whose population is rapidly increased for rapid composting and also better compost quality.

Pramanik (138) studied the vermicomposting of four (4) substrates viz. cow dung, grass, aquatic weeds and municipal solid wastes (MSW) to know the 'nutritional status & enzymatic activities' of the resulting vermicomposts in terms of increase in total nitrogen (N), total phosphorus (P) & potassium (K), humic acid contents and phosphatase activity.

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

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

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

Phosphatase Activity: Vermicompost obtained from cow dung showed the highest 'acid phosphatase' (200.45 µg *p*-nitrophenol/g/h) activities followed by vermicompost from grasses (179.24 µg *p*-nitrophenol/g/h), aquatic weeds (174.27 µg *p*-nitrophenol/g/h) and MSW (64.38 µg *p*-nitrophenol/g/h). The 'alkaline phosphatase' activity was highest in vermicompost obtained from aquatic weeds (679.88 µg *p*-nitrophenol/g/h) followed by cow dung (658.03 µg *p*-nitrophenol/g/h), grasses (583.28 µg *p*-nitrophenol/g/h) and MSW (267.54 µg *p*-nitrophenol/g/h). This was irrespective of lime application and microbial inoculation. However, when inoculated by fungi all showed maximum phosphatase activities under both limed and non-limed conditions. This was also indicated by Vinotha (204).

Studies by Agarwal (4) also found that the NPK value of vermicompost processed by earthworms from the same feedstock (cattle dung) significantly increases by 3 to 4 times. It also enhances several micronutrients.

Table 3: 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 (1999); Ph. D Thesis, University of Rajasthan, India

Table 4: Important nutrients present in vermicompost vis-à-vis conventional composts prepared from the same feed stock 'food and garden wastes' (In mg/g)

Nutrients	Vermicompost	Aerobic compost	Anaerobic compost
1) Nitrogen (N)	9.500	6.000	5.700
2) Phosphorus (P)	0.137	0.039	0.050
3) Potassium (K)	0.176	0.152	0.177
4) Iron (Fe)	19.730	15.450	17.240
5) Magnesium (Mg)	4.900	1.680	2.908
6) Manganese (Mn)	0.016	0.005	0.006
7) Calcium (Ca)	0.276	0.173	0.119

Source: Singh (2009); Master's Degree Project Report, Griffith University, Australia

Similar was findings of Singh (166). Vermicompost processed by earthworms showed higher values of important plant nutrients as compared to those available in composts made from the same feed stock 'food & garden wastes 'by aerobic & anaerobic methods.

IMPORTANT FEEDBACKS FROM FARMERS USING VERMICOMPOST IN BIHAR (INDIA)

Sinha interviewed some farmers in India using vermicompost for agriculture. Most of them asserted to have switched over to organic farming by vermicompost completely eliminating the use of chemical fertilizers in the last 3-4 years with very encouraging results, benefiting both, their economy (reduced cost of inputs and significantly high outputs from good crop production, sale of vermicompost and worms) and the environment (reduced use of chemical pesticides, improved physical, chemical & biological properties of farm soil). 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. Several villages have become 'BIO-VILLAGE' using only vermicompst in crop production and completely giving up chemical agriculture.

Some of the important revelation by farmers were:

- Reduced use of 'water for irrigation' as application of vermicompost over successive years improved the 'moisture holding capacity' of the soil;
- Reduced 'pest attack' (by at least 75%) in crops applied with vermicompost. Cauliflowers grown on vermicompost remains 95% 'disease free'. Late Blight (fungal disease) in banana was almost reduced by over 95%;
- Reduced 'termite attack' in farm soil especially where worms were in good population;
- Reduced 'weed growth';
- Faster rate of 'seed germination' and rapid seedlings growth and development;
- Greater numbers of fruits per plant (in vegetable crops) and greater numbers of seeds per ear (in cereal crops), heavier in weight-better in both, quantity and quality as compared to those grown on chemicals;
- Fruits and vegetables had 'better taste' and texture and could be safely stored up to 6-7 days, while those grown on chemicals could be kept at the most for 2-3 days;
- Wheat production increased from 35 to 40%;
- Fodder growth was increased by nearly 50% @ 30 to 40 quintal/hectare;
- Flower production (commercial floriculture) was increased by 30-50% @ 15-20 quintal/hectare. Flower blooms were more colorful and bigger in size;

CONCLUSIONS AND REMARKS

Earthworms vermicompost work as a 'slow-release fertilizer' and also 'protect plants' against pest & diseases. With their continued application the 'organic nitrogen' & other nutrients in compost tends to be

A B

Photo showing disease resistance in cauliflower induced by vermicompost
(A). Cauliflower grown on chemical fertilizers (Susceptible to diseases)
(B). Cauliflower grown on vermicompost (Resistant to diseases)
(Hazipur, Bihar, India. December 2008)

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. Availability of phosphorus is sometimes much greater. Vermicompost will also be a 'recipe' to restore the 'degenerated & chemically contaminated soils' of world agricultural ecosystems resulting from the heavy use of agrochemicals in the wake of green revolution. Use of vermicompost would significantly reduce or even replace the use of 'dangerous agrochemicals', reduce the demand of water for irrigation and pest & disease control, thus benefiting the farmers and the economy and ecology of the nation in every way.

It also appears that vermicompost functions more effectively when covered by mulch. Mulch keep them moist and allows the worm 'cocoons' to germinate faster into baby worms and the beneficial microbes to multiply and act faster. Apparently, it is both earthworms and its excreta (vermicast) that plays combined role in growth promotion. Worms & microbes secrete growth promoting plant hormones 'gibberlins', 'auxins' and 'cytokinins', help mineralise the nutrients and make them 'bioavailable'. In a glasshouse trial, Buckerfield (47 & 48) found that the 'stimulatory effect' of vermicompost on plant growth was apparently destroyed when it was 'sterilized'.

Vermiculture Can Promote Sustainable Agriculture and Completely Replace Chemical Agriculture: Some Experimental Evidences by Studies on Potted and Farmed Cereal and Vegetable Crops

Key words: Vermicompost nutritionally superior to conventional composts . vermicompost excel chemical fertilizers in plant growth promotion and productivity . continued application of vermicompost increases yield with reduced use of vermicompost

INTRODUCTION: THE SCIENTIFIC EVIDENCE OF THE POTENTIAL OF VERMICOMPOST TO REPLACE CHEMICAL FERTILIZERS

Experimental studies on the agronomic impacts of earthworms & its vermicompost on crop plants all over the world is conclusively proving that their application in farm soil over subsequent years can lead to enhanced production of 'safe food', both in 'quantity & quality' without recourse to agro-chemicals. Several scientists working on vermiculture throughout the world have confirmed the positive role of earthworms and its metabolic products (vermicast) on crop growth and development. Important among them are Alam (6); Ansari (8); Atiyeh (17 & 18); Arancon (11; 12 & 13); Bhat & Khambata (24); Bhatia (26 & 27); Baker & Barrett (28); Buckerfield (48); Chauhan (51); Canellas (49); Edwards & Burrows (70); Ghabbour, (87); Garg & Bhardwaj (84); Krishnamoorthy & Vajranabhaiah (115); Palanisamy (133); Pajon (132); Reddy (144); Scheu (154); Singh (168); Sharma (161); Suhane (183); Spain (178); Sukumaran (184); Tomar (194); Valani (203); Wilson & Carlie (210); and Webster (206).

Our studies on vegetable and cereal crops done in India at University of Rajasthan (1997-2001) & at Bihar Agriculture University (2007-2009) and in Australia at Griffith University (2007-2009), has also testified and strengthened the views of other workers. Application of vermicompost in potted and field crops displayed excellent growth performances in terms of height of plants, color & texture of leaves, appearance of fruiting structures etc. as compared to chemical fertilizers and the conventional compost. There is also less incidences of pest & disease attack & reduced demand of water for irrigation.

SOME EXPERIMENTAL STUDIES TESTIFYING THE AGRONOMIC VALUE OF VERMICOMPOST AS SUPERIOR TO CONVENTIONAL COMPOST AND A SUSTAINABLE ALTERNATIVE TO CHEMICAL FERTILIZERS

(A) Studies on potted cereal & vegetable crops

(1) Agronomic impact studies of earthworms and vermicompost vis-a-vis conventional cattle dung compost and chemical fertilizers on potted vegetable crops (University of Rajasthan, Jaipur, India, 1997-99): Agarwal (4) studied this for Ph. D program on potted egg plant *(Solanum melongena)* and okra *(Abelmoschus esculentus)*. There were three (3) treatments with five (5) replicas of each and a control. About 8 kg of near neutral soil devoid of any organic matter was used in each pot. 250 gm of vermicompost was used. It was prepared indigenously by mixed species of earthworms *Eisinea fetida, Perionyx excavatus & Eudrilus euginae* feeding on kitchen waste and cattle dung. Chemical fertilizers were used as urea for nitrogen (N =1.40 gm), single super phosphate (P = 2.50 gm) and murate of potash (K = 1.04 gm). While vermicompost was applied only once, chemicals were applied three times during the period of growth & maturation. Results are given in Tables 1 and 2

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, 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.

Table 1: Agronomic impacts of vermicompost, earthworms and vermicompost vis-a-vis chemical fertilizer on growth and development of potted 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) +Vermicompost (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: Agarwal (1999); Ph.D Thesis; University of Rajasthan, Jaipur, India

Table 2: Agronomic impacts of vermicompost, worms with vermicompost vis-a-vis chemical fertilizer on growth and development of potted 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) + Vermicompost (250 gm)	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: Agarwal (1999); Ph.D Thesis; University of Rajasthan, Jaipur, India

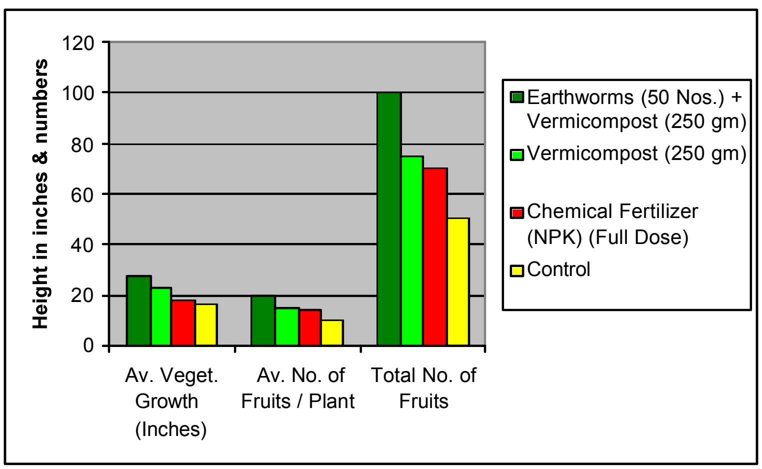


Fig. 1: Graph showing growth & development of egg plants promoted by vermicompost with earthworms, only vermicompost and those by chemical fertilizers

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

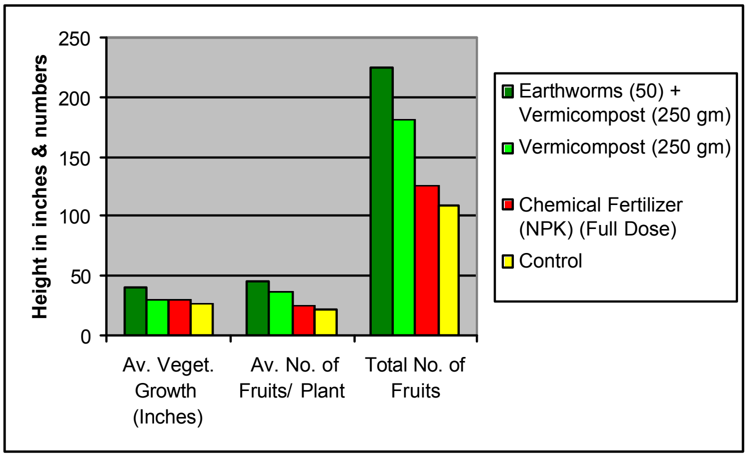


Fig. 2: Graph showing growth & development of okra plants promoted by vermicompost with earthworms, only vermicompost and those by chemical fertilizers

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.

DISCUSSION

Both vegetable crops performed exceedingly well when 'live earthworms' were present along with its vermicompost. They made excellent impact on 'fruit development' justifying the beliefs of Surpala (150). Vermicompost when used alone also promoted good growth but not as much when worms were themselves present in soil in significant numbers. Both were significantly better over chemical fertilizers. Another significant finding was the 'less incidence of pest and disease attack', better taste of fruits of vegetable crops grown with earthworms and vermicompost alone or together.

(2) Agronomic Impact Studies of Earthworms & Vermicompost Vis-a-vis Conventional Cattle Dung Compost & Chemical Fertilizers on Potted Wheat Crops (University of Rajasthan, Jaipur, India, 2000-03): Bhatia (26) studied it for Ph. D program. Three (3) treatments with four (4) replicas of each were prepared and one kept as control. About 8 kg near neutral soil devoid of any organic matter was used in each pot. 250 gm of vermicompost and same amount of cattle dung compost was used. Compost was obtained from local farmer. Vermicompost was prepared indigenously by mixed species of earthworms *E. fetida, P. excavatus & E. euginae* feeding on kitchen waste and cattle dung. Chemical fertilizers were used as urea for nitrogen (N =1.40 gm), single super phosphate (P = 2.50 gm) and murate of potash (K = 1.04 gm). While vermicompost and cattle dung compost was applied only once, chemicals were applied three times during the period of growth & maturation. Results are given in Table 3.

Important observations, findings and discussion: The potted wheat crops with 'earthworms & vermicompost' made excellent progress from the very beginning of seed germination up to 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 & bored over 55% more seed grains) over those grown on chemical fertilizers. Although the wheat crops grown on cattle dung compost were very close to those on chemical fertilizers but could not catch up with vermicompost. This conclusively proves that vermicompost store and retains more nutrients (and too in plant-available forms), have more beneficial microbes and other growth promoting factors than the conventional compost over a period of time.

Table 3: Agronomic impacts of earthworms and vermicompost vis-a-vis cattle dung compost and chemical fertilizers on growth and yield of potted wheat crops

Parameters studied	Control	Treatment-1 earthworms and vermicompost	Treatment-2 chemical fertilizer	Treatment-3 cattle dung compost
1 Number of seed germinated out of 100	50.00	90.00	60.00	56.0
2 Total height of plant (Av. cm)	34.16	85.22	39.97	37.3
3 Ear length (Av. Cm)	4.82	8.77	5.45	5.1
4 Number of seed grains per ear (Av. Nos.)	11.80	31.10	19.90	17.4
5 Number of tillers per plant	1.00	2-30	1-20	1-2

Source: Bhatia (2000); Ph.D Thesis, University of Rajasthan, Jaipur, India

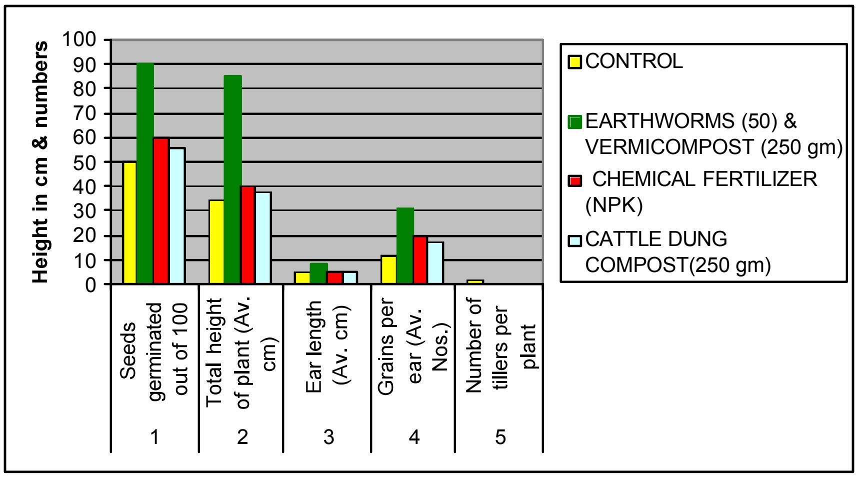


Fig. 3: Graph showing growth & yield of potted wheat crops promoted by earthworms & vermicompost, conventional cattle dung compost & chemical fertilizers

Table 4: Agronomic impacts of earthworms (with feed), vermicompost vis-a-vis conventional compost on growth and development of potted corn crops (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	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 & texture of leaves	Green & thick	Light green & thin	Deep green, stout, thick & broad leaves

Source: Sinha & Bharambe (2007); Griffith University, Australia

3) Agronomic Impacts Studies of Earthworms & Vermicompost Vis-à-vis Conventional Compost on Potted Corn Crops (Griffith University, Brisbane, Australia, 2006-07): This study was designed to test the growth promoting capabilities of earthworms added with 'feed materials' and 'vermicompost', as compared to 'conventional compost'. Vermicompost was prepared indigenously by degrading food & garden wastes by earthworms *Eisinia fetida*. Conventional compost was obtained from local nursery. It had three (3) treatments with three (3) replicas of each. Crushed dry leaves (400 gm) were used as feed materials. Results are given in Table 4.

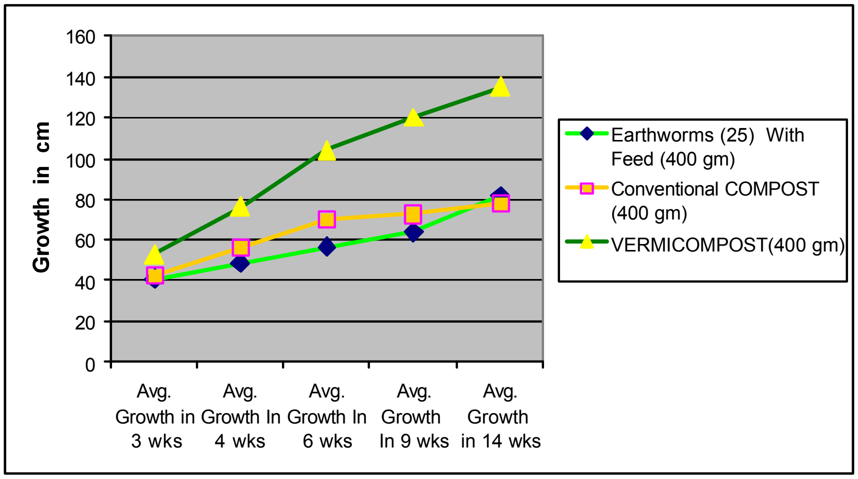


Fig. 4: Graph showing growth performances of corn plants influenced by earthworms (with feed), vermicompost and conventional compost in 14 weeks period

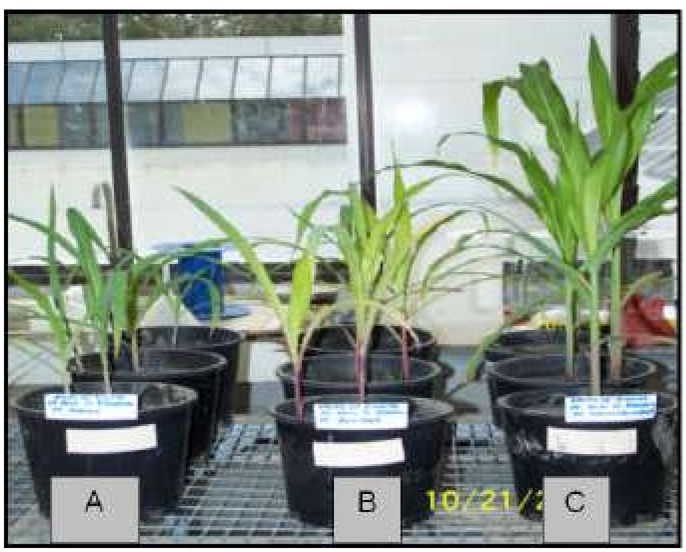


Photo showing growth of corn plants after 6 weeks

Keys: (A)-Corn plants with EARTHWORMS (50 Nos.) & FEED MATERIALS (400 gm) → 57 cm
(B)-Plants with CONVENTIONAL COMPOST (400 gm) in soil → 70 cm
(C)-Plants with VERMICOMPOST (400 gm) in soil → 104 cm

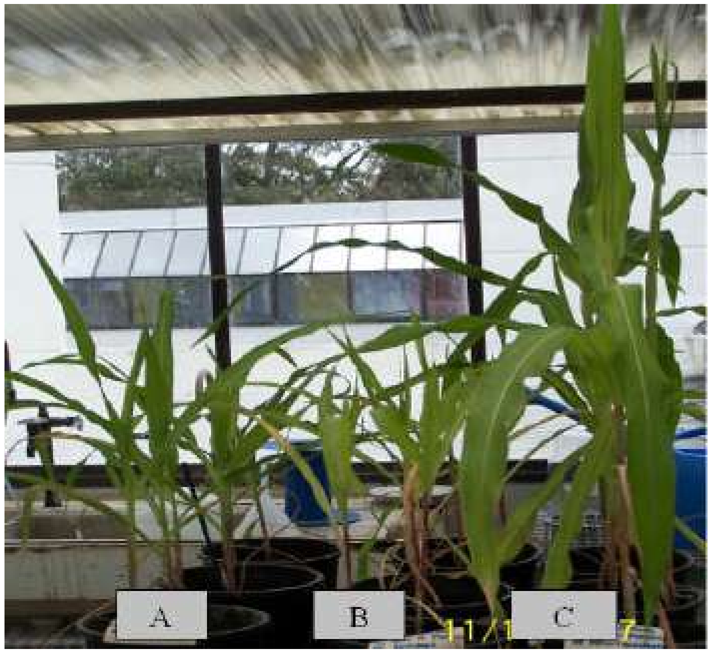


Photo showing growth of corn crops after 14 weeks

Keys: (A)-Corn plants with EARTHWORMS (50) & FEED (400 gm) in soil → 82 cm
(B)-Plants with CONVENTIONAL COMPOST (400 gm) in soil → 78 cm
(C)-Plants with VERMICOMPOST (400 gm) in soil (App. of MALE & FEM ALE reproductive organs & the NEW CORN) → 135 cm

Important observations, findings and discussion: Corn plants with vermicompost in soil (Pot C) achieved rapid and excellent growth and attained maturity (appearance of male & female reproductive organs) very fast. Plants on conventional compost (Pot B) could not achieve maturity until the period of study (week 14). Plants with worms provided with 'feed materials' (Pot A) performed better than those on conventional compost (Pot B) 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.

4) Agronomic Impact Studies of Vermicompost Vis-a-vis Conventional Compost & Chemical Fertilizers on Potted Wheat Crops (Griffith University, Brisbane, Australia, 2008): Chauhan (51) studied it as a part of 40 CP honours project. It was designed to compare the growth promoting abilities of vermicompost & earthworms with conventional compost (composted cow manure) & chemical fertilizers on wheat crops. About 7 kg of near neutral soil devoid or organic matter was used. It had three (3) treatments with two (2) replicas of each and a control. Treatment 1 was with chemical fertilizers (NPK + Mg+S+Fe+B+Zn), Treatment 2 with composted cow manure and Treatment 3 with vermicompost and earthworms. Chemical fertilizer (supplied by Brunnings, Australia) & composted cow manure (produced by Kriedemann Company, Australia) were bought from nursery. Vermicompost was prepared by composting MSW (food and garden wastes) by *Eisinea fetida*). Five (5) gm of chemicals was applied in three (3) doses at three different times of growing period-first at the time of seed sowing, second after a month and the third after another month. It had total nitrogen (N) 14.8%, total phosphorus (P) 4.3% and potassium (K) as potassium sulphates 12.5%. Fifty (50) earthworms & 500 gm of vermicompost and same amount of composted cow manure were applied only once at the time of seed sowing. 5 x 3 gm of chemical fertilizers and 500 gm of composts applied in 7 kg of soil is considered normal dose. Results are given in Table 5.

Table 5: Agronomic impacts of earthworms and vermicompost vis-a-vis chemical fertilizers and composted cow manure on growth and development of potted wheat crops (average growth in cm)

Parameters studied	Control (No input)	Treatment-1 chemical fertilizers (5 gm x 3 times)	Treatment-2 composted cow manure (500 gm)	Treatment-3 earthworms + vermicompost (500 gm)
Seed sowing	11th Sep. 2008	Do	Do	Do
Seed germination	5th Day	5th Day	5th Day	3rd Day
Avg. growth in 2 wks	17	17	16	19
Avg. growth in 4 wks	20	29	30	31
Avg. growth in 5 wks	22	36	31	39
Avg. growth in 7 wks	24	37	32	41
Avg. growth in 8 wks	24	39	32	42
Avg. growth in 9 wks	26	39	32	43
Appearance of seed ears in wk 10	None	None	None	Yes
Avg. growth in 11 wks	26	39	32	43
Appearance of seed ears in wk 11	None	Yes	None	Yes
Avg. growth in 12 wks	26	43	32	47
Appearance & size of Seed ears (In wk 12)	Yes. Small & unhealthy	Small, but healthy	Yes. Small but healthy	Grew bigger in size and very healthy

Source: Chauhan (2009); Griffith University, Australia

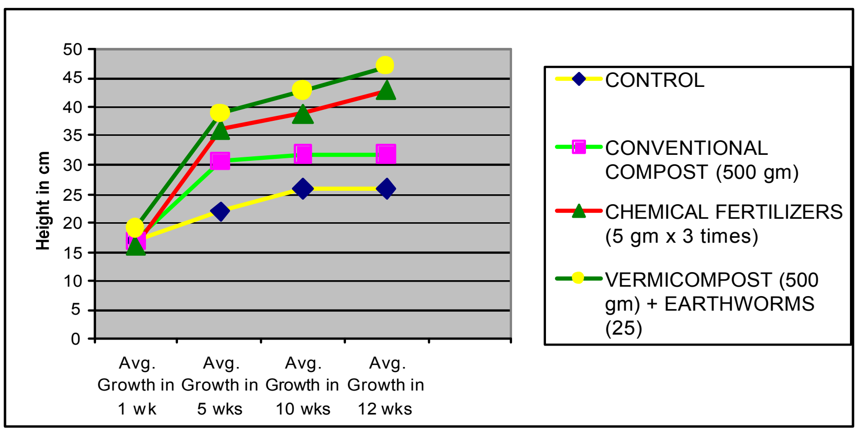


Fig. 5: Graph showing growth performances of wheat crops on vermicompost & earthworms, conventional compost (cow manure) & chemical fertilizers in 12 weeks period

Important observations, findings and discussion: Wheat crops maintained very good growth on vermicompost & earthworms from the very beginning & achieved maturity in just 12 weeks. The striking rates of seed germination were very high, nearly 48 hours (2 days) ahead of others and the numbers of seed germinated were also high by nearly 20%. Plants were greener and healthier over others, with large numbers of tillers & long seed ears were formed at maturity. Seeds were healthy and nearly 35-40% more as compared to plants on chemical fertilizers. The total growth performances of wheat crops (in terms of health, color and texture of shoots & leaves) on vermicompost & earthworms was significantly better over the chemical fertilizers. What they achieved in 8-9 weeks, was achieved by those on chemicals in 12 weeks. More significant was that the pot soil with vermicompost was very soft & porous and retained more moisture. Pot soil with chemicals were hard and demanded more water frequently.

A B C D

Photo showing final growth of wheat crops and development of seed ears after 12 weeks

Keys: (A). Chemical Fertilizer (NPK + Mg+ S+Fe+B+Zn 5 gm x 3 times) $\rightarrow$ 43 cm

(B). Composted cow manure (500 gm) $\rightarrow$ 32 cm

(C). Control (No input) $\rightarrow$ 26 cm

(D). Vermicompost (500 gm) + Earthworms (25 Nos.) $\rightarrow$ 47 cm

A B C D

Photo showing ripe and mature seed ears in wheat crops after 14 weeks

Keys: (A). Vermicompost + Earthworms

(B) Chemical Fertilizer

(C) Composted cow manure

(D) Control

5) Agronomic Impact Studies of Vermicompost Vis-a-vis Conventional Compost & Chemical Fertilizers on Potted Corn Crops (Griffith University, Brisbane, Australia, 2008): Valani (203) studied it as a part of 40 CP honours project. It was designed to compare the growth promoting abilities of vermicompost & earthworms with conventional compost (composted cow manure) & chemical fertilizers on corn crops. Conventional compost & chemical fertilizers were bought from nursery while vermicompost was prepared by composting food & garden wastes. The pots were organised in the same way as described above and same inputs were applied in same amounts. Results are given in Table 6.

Table 6: Agronomic impacts of earthworms and vermicompost vis-a-vis chemical fertilizers and composted cow manure on growth and development of potted corn crops (average growth in cm)

Parameters studied	Control (No input)	Treatment-1 chemical fertilizers (5 gm x 3 times)	Treatment-2 composted cow manure (500 gm)	Treatment-3 Earthworms+ vermicompost (500 gm)
Seed sowing	22nd sep. 2008	Do	Do	Do
Seed germination	3rd day	3rd day	4th day	4th day
Avg. growth in 2 wks	35	26	33	31
Avg. growth in 4 wks	45	45	35	60
Avg. growth in 5 wks	62	60	41	66
Avg. growth in 6 wks	70	90	69	120
Avg. growth in 7 wks	75	110	83	160
Avg. growth in 8 wks and app. of rep. organs	80 none	158 male rep. organ.	85 none	187 male rep. organ
Avg. growth in 9 wks and app. of rep. organs	No Growth male rep. organ	No growth	No growth male rep. organ	No growth female rep. organ
Avg. growth in 10 wks & Appearance of rep. organs	No growth	165 female rep. organ	No growth	195
App. of new corn (in wk 11)	None	None	None	New corn
Color & texture of leaves	Pale & thin leaves	Green & thin	Pale & thin leaves	Green, stout & broad leaves

Source: Valani (203); Griffith University, Australia

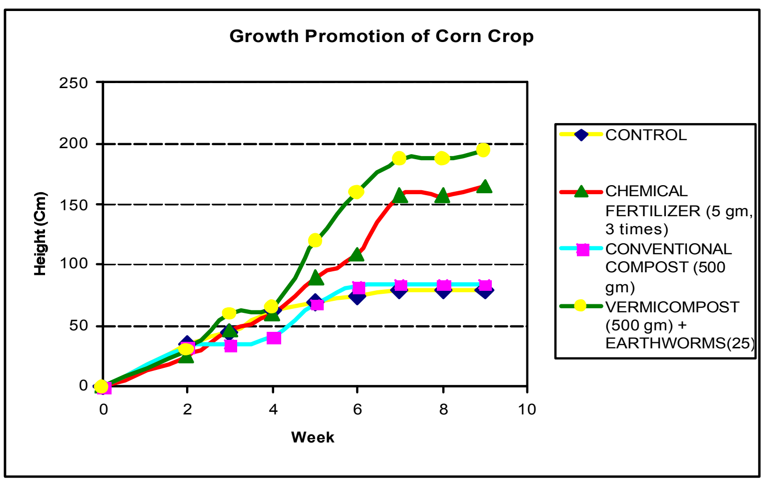


Fig. 6: Graph showing growth of corn crops promoted by vermicompost, conventional compost (composted cow manure) and the chemical fertilizers

Important observations, findings and discussion: Corn plants maintained very good growth on vermicompost & earthworms with male and female reproductive organs appearing in just 9 weeks. There were four (4) 'new corns' appearing on each plant in the two replicas. Corn plants on chemical fertilizers also grew well and had both reproductive organs appearing in 10th week. However, there were only two (2) 'new corns' appearing on each plant in the two replicas. The growth performances of corn plants on vermicompost & earthworms was nearly 15% better over the chemical fertilizers.

A B C D

Photo showing final growth of corn crops after 10 weeks

Keys: (A). Control (No input) → 80 cm

(B). Composted cow manure (500 gm) → 85 cm

(C). Chemical Fertilizer (NPK + Mg+ S+Fe+B+Zn 5 gm x 3 times) → 165 cm

(D). Vermicompost (500 gm) + Earthworms (50) → 195 cm

Photo showing large 'new corn' appearing on corn plant grown on vermicompost & earthworms (After 11 Weeks)

A very significant observation was that the SOIL condition in the pots applied with vermicompost & worms was highly porous and SOFT while the one added with chemical fertilizers was non-porous and HARD.

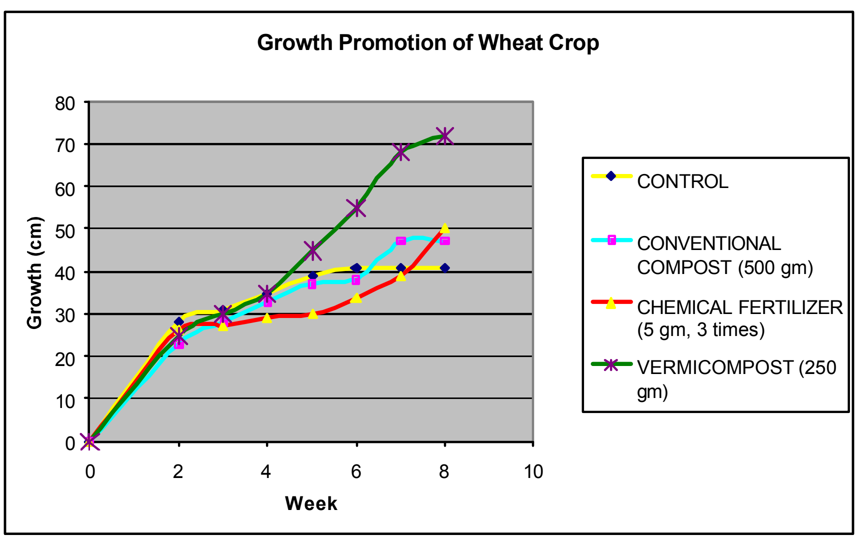
AGRONOMIC IMPACT STUDIES OF VERMICOMPOST VIS-A-VIS CONVENTIONAL COMPOST & CHEMICAL FERTILIZERS ON POTTED WHEAT CROPS (GRIFFITH UNIVERSITY, BRISBANE, AUSTRALIA, 2008)

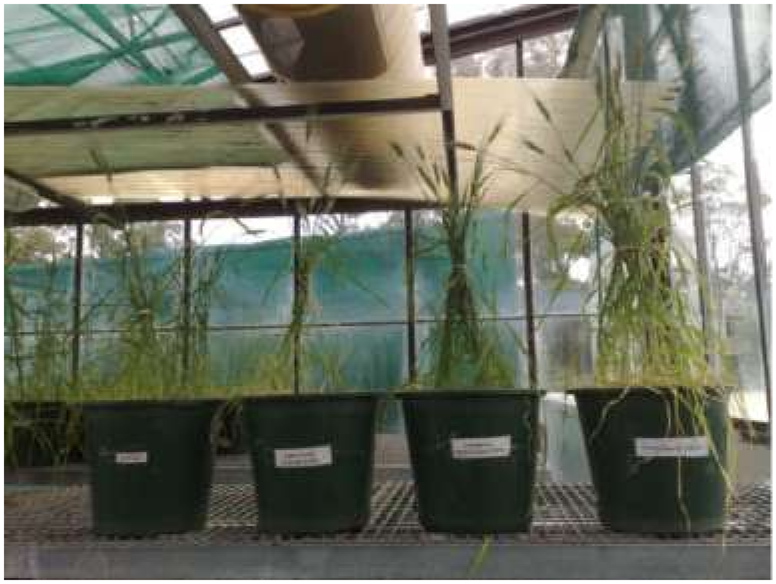
Valani (203) also studied it as a part of 40 CP honours project. It was designed to compare the growth promoting abilities of 'lower doses of vermicompost' (250 gm-half of the amount used in earlier study on wheat crops) with full doses of conventional compost (500 gm) and normal dose of chemical fertilizers. This time vermicompost was prepared from 'food & garden wastes' mixed with 'cattle dung' and added with lime. The pots were organised in the same way as above. Results are given in Table 7.

Table 7: Agronomic impacts of 50% reduced doses of vermicompost vis-à-vis normal doses of conventional compost and chemical fertilizers on potted wheat crops (average growth in cm)

Parameters studied	Control (No input)	Treatment-2 composted cow manure (500 gm)	Treatment-3 soluble chemical fertilizers (5 gm x 3 times)	Treatment-4 vermicompost (250 gm) (no worms)
Seed sowing	17th, March 2009	Do	Do	Do
Seed germination	4th Day	4th Day	5th Day	3rd Day
Avg. growth in 2 wks	28	23	26	25
Avg. growth in 3 wks	31	28	27	30
Avg. growth in 4 wks	35	33	29	35
Avg. growth in 5 wks	39	37	30	45
Avg. growth in 6 wks and Appearance of seed ears	41 None	38 None	34 None	55 Yes
Avg. growth in 7 wks and Appearance of seed ears	No growth Yes	47 Yes	39 Yes	68
Avg. growth in 8 wks	No growth	47	50	72
Size & health of seed ears (Wk 8)	Small and unhealthy	Small and unhealthy	Small, but healthy	Big in size and very healthy

Source: Valani (203); Griffith University, Australia





A B C D

Photo showing final growth of wheat crops and development of seed ears after 10 weeks

Keys: A) Control → 41 cm

B) Composted Cow Manure (500 gm) → 47 cm

C) Chemical Fertilizer (NPK + Mg+ S+Fe+B+Zn; 5 gm x 3 times) → 50 cm

D) Vermicompost (250 gm) → 72 cm

Important observations, findings and discussion: Vermicompost applied wheat crops again excelled in growth over both conventional compost and the chemical fertilizers and also attained maturity faster. But more important finding was that this was achieved at 'HALF' the dose of vermicompost used in earlier studies for wheat crops (51). This clearly establishes that vermicompost prepared from 'cattle dung' as one of the raw materials and added with 'lime' contains more NPK and other growth promoting 'biochemical factors' and testifies the findings of Pramanik (138).

AGRONOMIC IMPACT STUDIES OF VERMICOMPOST IN LOWER & HIGHER DOSES (100 GM-500 GM) ON POTTED WHEAT CROPS (GRIFFITH UNIVERSITY, BRISBANE, AUSTRALIA, 2009)

Valani (203) also studied it as a part of 40 CP honours project. It was designed to compare the growth promoting abilities of vermicompost in lower to higher doses (100-500 gm) in pot soil to ascertain the 'optimum amount' of vermicompost that should be applied to wheat crops to achieve best growth and development. About 7 kg of near neutral soil devoid of any organic matter was used in pots. It had five (5) treatments with two (2) replicas of each and a control. Vermicompost was again prepared from food & garden wastes mixed with 'cattle dung' and added with lime. Results are given in Table 8.

Important observations, findings and discussion: Although the wheat crops grown in all pots from 100 gm to 500 gm of vermicompost showed good growth over the control, the one on 200 gm of vermicompost (C) exhibited overall best growth performance in terms of height & health (Avg. 72 cm) of individual plants, number of tillers (Avg. 2 in each plant), size of seed ears and seed grains which was distinctly larger & bigger over all others. Plants on 400 & 500 gm of vermicomposts (E & F) also gained good growth but the seed ears & grains were not as big & healthy as the one on 200 gm of vermicompost (C).

The inference drawn from the above study is that there is an 'optimum amount of vermicompost' in soil that can promote 'best growth' in wheat crops. Less than that becomes 'inadequate' in maintaining the appropriate

Table 8: Growth promoted by low and high doses of vermicompost on potted wheat crops (average growth in cm)

Parameters studied	Control (No input)	T-1 VC (100 gm)	T-2 VC (200 gm)	T-3 VC (300 gm)	T-4 VC (400 gm)	T-5 VC (500 gm)
Seed sowing	20th, March 2009	Do	Do	Do	Do	Do
Seed germination	4th Day	4th Day	3rd Day	4th Day	3rd Day	3rd Day
Avg. growth in 2 wks	22	22	25	19	19	20
Avg. growth in 3 wks	32	33	32	35	38	37
Avg. growth in 4 wks	32	34	39	38	40	39
Avg. growth in 5 wks	35	35	40	39	41	40
Avg. growth in 6 wks and appearance of seed ears	40	43	50 Yes	45	45	47 Yes
Avg. growth in 7 wks and appearance of seed ears	50 Yes	55 Yes	68 Yes	61 Yes	70 Yes	66 Yes
Avg. growth in 8 wks; Size of seed ears & grain	55 Small & unhealthy	60 Small & unhealthy	72 Bigger & healthy	70 Small & unhealthy	73 Big & healthy	71 Big & healthy

Source: Valani (203); Griffith University, Australia; Keys: T = Treatment; VC = Vermicompost

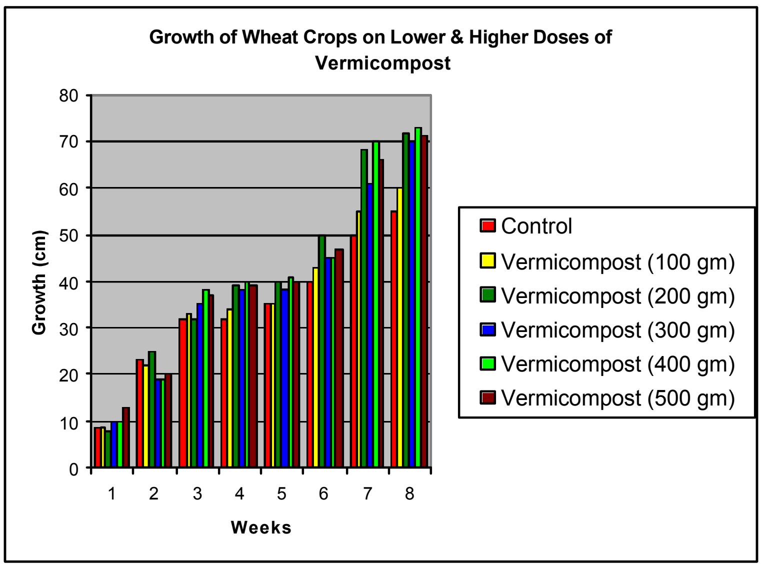
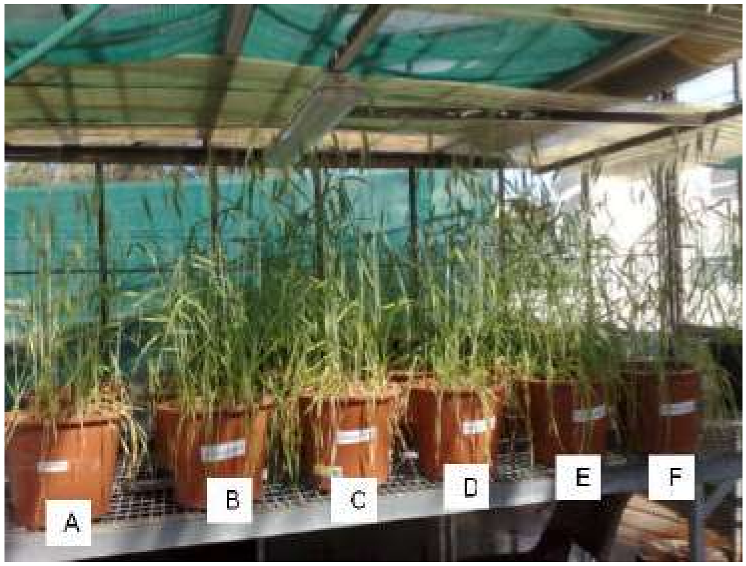


Fig. 8: Graph showing growth of wheat crops on lower & higher doses of vermicompost (100 gm-500 gm)

supply of nutrients and more than that may just remain in soil without contributing much to plant growth. More studies will be needed on these aspects. Again, the study established that vermicompost prepared from raw materials where 'cattle dung' is an important ingredient is superior and contain more nutrients for better growth promotion and thus, supporting the findings of Pramanik (138). This study also supports the findings of Subler (180) who found that the best growth responses were exhibited when the vermicompost constituted a relatively smaller proportion of the total volume of the container medium.

(B). Studies on farmed wheat crops

1) Agronomic impact studies of earthworms and vermicompost vis-a-vis conventional cattle dung compost and chemical fertilizers on farmed wheat crops (University of Rajasthan, Jaipur, India, 2000-03): Sharma (161) studied it for her Ph.D program. This facility was provided by Agriculture Research Institute at Jaipur. The



Final growth of wheat crops on lower & higher doses of vermicompost (100 mg-500 mg) after 8 weeks

Keys: A) Control → 55 cm

B) Vermicompost (100 gm) → 60 cm

C) Vermicompost (200 gm) → 72 cm (Overall Best)

D) Vermicompost (300 gm) → 70 cm

E) Vermicompost (400 gm) → 73 cm

F) Vermicompost (500 gm) → 71 cm

Photo showing size of seed ears & grains in wheat crops grown on increasing doses (100 gm-500 gm) of vermicompost

A) Control; B) Vermicompost (100 gm); C) Vermicompost (200 gm); D) Vermicompost (300 gm); E) Vermicompost (400 gm); F) Vermicompost (500 gm) farm was divided into eight plots of 25 x 25 sq m size. Four treatments were prepared with one control. All the treatments were replicated twice. Vermicompost was applied @ 2.5 tonnes/ha in the 1st treatment plot. One thousand mature adult earthworms (mixed species of *E. fetida, P. excavatus & E. euginae*) were spread evenly throughout the 2nd treatment plot. Chemical fertilizers as urea for nitrogen (N), single super phosphate (P) and murete of potash (K) were applied in reduced doses (90:75:60) in the 3rd treatment plot along with full dose of vermicompost @ 2.5 tons/ha. In the 4th treatment plot full dose of NPK (120:100:80) was applied. Urea was applied in two split doses (first half at the time of sowing and second half dose after 21 days of sowing) whereas the phosphate and potash were applied as single dose at the time of sowing. They were used @ kg/hectare. Wheat seed was grown @ 100 kg/ha. Results are given in Table 9.

Table 9: Agronomic impacts of earthworms, vermicompost vis-a-vis chemical fertilizers on growth and yield of farmed 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.)	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: Sharma (2001): Ph.D Thesis; University of Rajasthan, Jaipur, India

Keys: VC = Vermicompost; N = Urea; P = Phosphate; K = Potash (In Kg/ha)

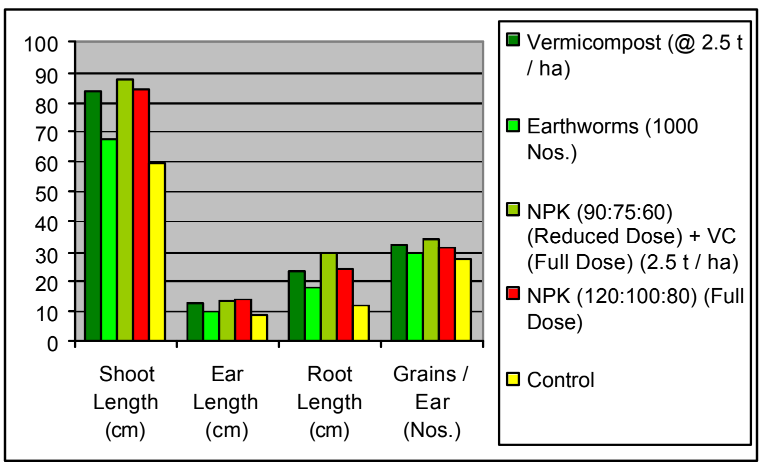


Fig. 9: Graph showing growth & yield of farmed wheat crops promoted by earthworms & vermicompost in exclusive application & chemical fertilizers in full & reduced doses

Important 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. 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). Although vermicompost alone can work as 'driving force' but when chemical fertilizers are added as 'helping hand' it can perform little better. Earthworms alone in soil, are not able to promote growth to any significant extent, but its metabolic products (vermicast) can. It infers therefore, that the worms cast (vermicompost) in soil works as the 'storehouse' of growth promoting factors e.g. the nutrients mineralised & the plant growth hormones secreted by the worms. Worms would need sufficient feed materials (organic residues of crops) in farm soil to feed upon and excrete out their vermicast into the soil.

2) Agronomic impact studies of vermicompost vis-a-vis conventional cattle dung compost and chemical fertilizers on farmed wheat crops

(Collaborative Research Program, Griffith University, Brisbane, Australia and Rajendra Agriculture University, Bihar, India) a) Study-1 (2007-2008): This facility was provided by RAU, (Pusa campus). We studied the agronomic impacts of vermicompost and compared it with cattle dung compost & chemical fertilizers in exclusive application and also in combinations on farmed wheat crops. Cattle dung compost was applied four (4) times more than that of vermicompost as it has much less NPK values as compared to vermicompost. Vermicompost was prepared primarily from 'cattle dung' mixed with 'food & farm wastes'. That is the usual practice in India. Results are given in Table 10

Table 10: Agronomic impacts of vermicompost, cattle dung compost vis-a-vis chemical fertilizers on growth & yield of 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: Suhane et. al., (2008): Keys: N = Urea; P = Single Super Phosphate; K = Murete of Potash (In Kg/ha)

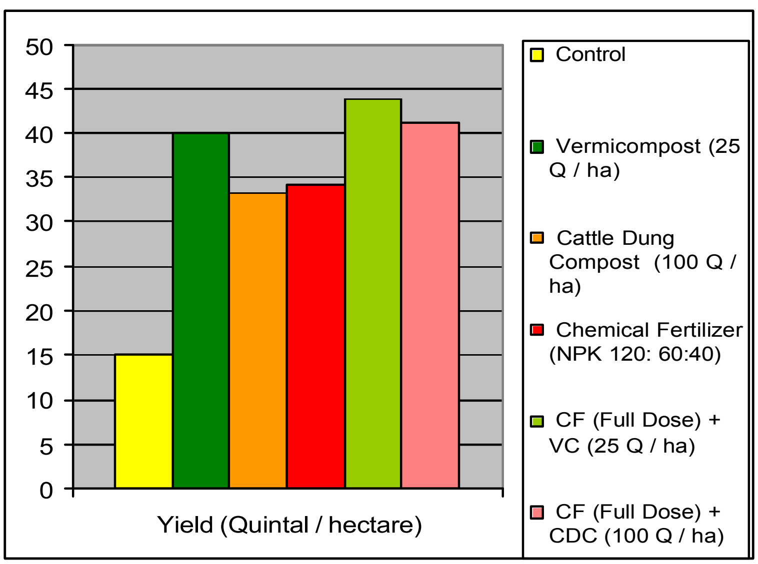


Fig. 10: Graph showing growth & yield of farmed wheat crops on vermicompost, cattle dung compost & chemical fertilizers in exclusive applications & on composts in combination with chemical fertilizers

Observations, findings and discussion: Exclusive application of vermicompost promoted yield of wheat crops in farms significantly higher (40.1 Q/ha) over the chemical fertilizers (34.2 Q/ha) applied in full dose. This was nearly 18% higher over chemical fertilizers. And when same amount of agrochemicals were supplemented with vermicompost @ 25 quintal/ha the yield increased to about 44 Q/ha which is only about 10% higher over the wheat crops grown on exclusive application of vermicompost. This 10% increase in production do not make much economic sense as it will be neutralized by the high cost of agrochemicals and hence the high cost of crop production.

On cattle dung compost applied @ 100 Q/ha (4 times of vermicompost) the yield was just over 33 Q/ha which is about 18% less than that on vermicompost and that too after using 400% more conventional composts.

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

Study-2 (2008-2009): This facility was provided by College of Horticulture, RAU, (Noorsarai Campus). This time we studied the agronomic impacts of vermicompost on wheat crops on a lower dose applied @ 20 Q/ha against 25 Q/ha applied in Study-1 and compared it with chemical fertilizers applied in full dose as in Study-1. Four (4) types of farm plots were selected for vermicompost studies. In three of them (2nd, 3rd, & 4th plots) vermicomposts were applied in previous 1, 2 and 3 years successively by farmers for growing various cereal and vegetables crops. This was the 2nd, 3rd and 4th year of farming respectively by vermicompost in plots 2, 3 & 4. In plot 1, it was 1st year of farming by vermicompost. Previously chemical fertilizers were used for farming in this plot. Vermicompost was prepared from 'cattle dung' mixed with 'food & farm wastes'. Results are given in Table 11

Table 11: Agronomic impacts of vermicompost on growth and yield of farmed wheat crops upon successive applications over 1-4 years

Treatment	Input/Hectare	Yield/Hectare
1) Control	(No Input)	15.8 Q/ha
2) Vemicompost	20 Q/ha (1st Year Farming by VC)	35.3 Q/ha
3) Vemicompost	20 Q/ha (2nd Year Farming by VC)	36.2 Q/ha
4) Vermicompost	20 Q/ha (3rd Year Farming by VC)	37.3 Q/ha
5) Vermicompost	20 Q/ha (4th Year Farming by VC)	38.8 Q/ha
6) Chemical Fertilizers	NPK (120:60:40) kg/ha	35.4 Q/ha

Source: Singh *et al*., (2009): Keys: VC = Vermicompost; N = Urea; P = Single Super Phosphate; K = Murete of Potash

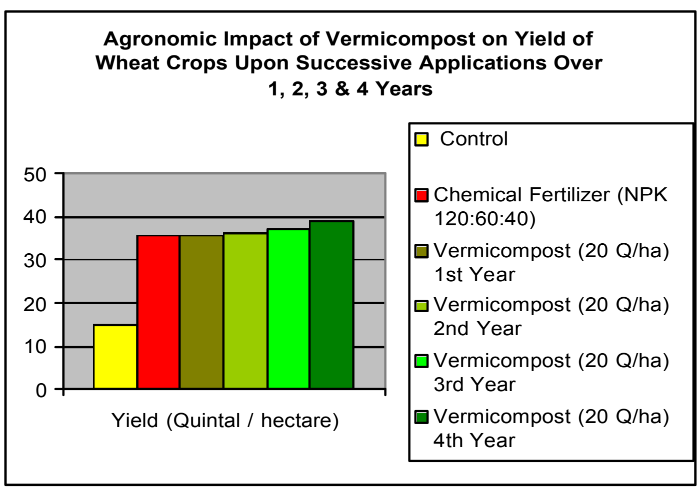


Fig. 11: Graph showing yield of farmed wheat crops on successively applied vermicompost in soil over 1-4 years

Important observations, findings and discussion: Vermicompost excelled chemical fertilizers in promoting crop growth in all types of plots studied. But what was most significant and exciting observation, was that in the farm plots 2, 3 & 4 where vermicompost was applied in the 2nd, 3rd and 4th successive years, the growth & yield of wheat crops increased gradually over the years even at the same amount of vermicompost applied i.e. @20 Q/ha. In the 4th successive year the yield was 38.8 Q/ha which was close to one where vermicompost was applied @ 25 Q/ha in Study-1 (40.1 Q/ha). However, the plot with 1st year of farming by lower dose (20 Q/ha) of vermicompost (after a changeover from chemical fertilizers) the yield was significantly lower (35.3 Q/ha) than those in Study-1 (40.1 Q/ha), but still close to those on chemical fertilizers (35.4 Q/ha). Crop yield on chemical fertilizer this time was little higher (35.4 Q/ha) as compared to Study-1, where it was 34.2 Q/ha on the same amount of chemicals used (NPK-120:60:40 kg/ha). This could be due to better farm soil in this region of the state. Increased yield in control plot (without any input) also indicate better soil conditions.

Above study conclusively prove that application of vermicompost 'build the soil quality' and 'improve its natural fertility' over successive years of application and over the years the total yield of crops should increase even at the same rate of application of vermicompost. It is also inferred from this study that over years of application, the amount of vermicompost could be reduced gradually while maintaining same levels of yield & productivity. However, more studies will be needed on these aspects.

CONCLUSIONS AND REMARKS

Results of our studies on vermiculture made in Australia and in India, both in potted and farm crops, established beyond doubt that the 'earthworms vermicompost' works as an 'excellent organic fertilizer' and is nutritionally much superior and more powerful growth promoter (especially if prepared from 'cattle dung' as a raw material) than the conventional composts and can compete with chemical fertilizers as a 'nutritive', 'protective', 'cheaper' and 'sustainable' alternative to the 'destructive' chemical fertilizers for safe food production. Vermicompost provide more 'bio-available nutrients' to crops over time and also have some critical growth promoting 'biochemical factors' not found in conventional composts and cannot be made available by chemical fertilizers. Vermicompost applied crops may show slower growth in the beginning but as they slowly release nutrients & growth hormones and the baby worms grow from their cocoons and multiply in numbers, increase their metabolic activities & build up soil fertility, plants picks up rapid growth. Vermicompost applied soils are more 'soft' and 'porous' that facilitate better root growth and penetration. It also has better 'water holding' capacity. Use of vermicompost also induces crops to attain maturity faster and bear flowers, fruits and seeds.

The 18% increase (over chemical fertilizers) in yield of wheat crops grown on vermicompost in our farm studies made in India (2007-08) has great significance. This was in the beginning years while the farm soil was still recovering from the ill-effects of agro-chemicals used for several long years. In one of the study where chemical fertilizers were supplemented with vermicompost the yield exceeded. However, it do not make any big economic and ecological sense in using chemical fertilizers (even in reduced doses) with vermicompost for achieving small gain in crop yield. The cost of food production will go much higher as the cost of chemical fertilizers (produced from vanishing & costly geological resources) is much higher (and is rising throughout the world) as compared to vermicompost which is produced from 'organic wastes' including municipal solid wastes (MSW) of which there is no dearth and is easily available in plenty in every country needing safe disposal. The ill effects that the agrochemicals have on farm soils and water bodies also cannot be undermined.

Then there is an 'optimum value' of vermicompost per kg of soil in pots or per hectare of land in agriculture farms that can promote best growth in any crop. And this is relatively 'smaller' as compared conventional composts. Higher doses of vermicompost e.g. 300-500 gm did not necessarily exhibit higher growth performances in potted wheat crops as compared to those on 200 gm (203). In farm production, 20-25 quintal of vermicompost per hectare appears to be an 'optimal' amount for a good crop yield in the initial years but which should go down subsequently over 5-10 years as soil's physical, chemical and biological properties is improved and its natural fertility is restored. Our study shows that over successive years of application of vermicompost the yield of crops increases even at the same rate of application of vermicompost, also inferring that the amount of vermicompost could be gradually reduced after some years while maintaining same yield. Webster (206) found that vermicompost increased yield of 'cherries' for three (3) years after 'single application' inferring that 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. Such growth performances of crops in response to smaller doses of vermicompost was also indicated by Subler (180) and Valani, (203). In all growth trials the best growth responses were exhibited when the vermicompost constituted a relatively small proportion (10%-20%) of the total volume of the container medium. Surprisingly, greater proportions of vermicomposts in the plant growth medium not always improved plant growth (180) but also never had any adverse impact on the plants. Our studies on potted wheat crops where 200 gm of vermicompost performed better over 500 gm of vermicompost also supports this contention (203).These findings are contrary to the growth responses of chemical fertilizers whose rate of application per hectare have gradually increased over the years since the green revolution of 1960s to maintain the same yield of previous years and higher doses of chemical fertilizers always made 'adverse impact' on crops rather than benefiting them.

Our studies also testified the findings of Pramanik (138) who reported that vermicompost prepared from 'cattle dung' applied with 'lime' is nutritionally more superior. In cattle dung vermicompost nitrogen (N) was higher by 275%, humic acid by 0.7963 mg/g. In MSW vermicompost nitrogen (N) was higher by 178% & humic acid 0.3917 mg/g. Phosphorus (P) & Potassium (K) were also significantly higher in cattle dung vermicompost as compared to MSW vermicompost. Chauhan (51) studied the agronomic impacts of vermicompost prepared from MSW (food & garden wastes) on wheat crops. The plants achieved smaller growth (47 cm) and matured in 12 weeks on 500 gm of vermicompost. Valani (203) studied the agronomic impacts of vermicompost (prepared from MSW mixed with 'cattle dung' and added with 'lime') on wheat crops and found that the plants achieved better growth (55 cm) and also maturity, in just 6 weeks. More significant was that it was on 250 gm of vermicompost (half the dose used by Chauhan (51).

Another interesting observation in our studies has been the varied growth impacts of vermicompost when applied with & without worms. From the studies of Sharma (161) and Sinha & Bharambe (175) it became apparent that worms alone cannot promote significant growth. But that together they can reinforce good growth is established from all other studies. But again, other studies (161; 183 & 203) indicated that exclusive application of vermicompost in wheat crops can support very good growth and much better over chemical fertilizers. Vermicompost applied soils, however, eventually harbour large population of worms as it contains plenty of worms 'cocoons' that soon germinate in soil to produce baby worms. It is also a scientific fact that although the worms secrete the 'growth promoting biochemical factors' (plant enzymes, hormones and humic acids) and mineralise 'plant nutrients', it is eventually stored in its metabolic products (vermicast).

It is also a possibility, for which more studies will be needed, that earthworms and its vermicast respond differently to different crops. Agarwal (4) studied their growth impacts on vegetable crops (okra & egg-plants) where worms played very important role. Sharma (161), Sinha & Bharambe (175), Suhane (183), Valani (203) & Singh (167) studied it on cereal crops (wheat & corn) where presence or absence of earthworms in soil was not so important, but its 'metabolic product' was certainly important.

Earthworms and its vermicompost can work as the main 'driving force' in sustainable food production for food security while maintaining soil health and fertility. They can 'completely eliminate' the use of chemical fertilizers and 'significantly reduce' the use of chemical pesticides in crop production & also the huge water requirements for crop irrigation which became essential in chemical agriculture. This is being termed as 'Sustainable Agriculture' (2; 140 & 172).

Environmental-Economics of Crop Production by Vermiculture: Economically Viable & Environmentally Sustainable Over Chemical Agriculture

Key words: Environmental cost of food production . social cost of food production . vermicompost production and use . environmentally protective and economically productive . chemical fertilizer production and use . environmentally destructive and economically unproductive . lower use of vermicompost for higher productivity

INTRODUCTION: THE ECONOMIC EVIDENCES FOR VERMICOMPOST AS AN EFFICIENT AND AFFORDABLE CROP NUTRIENT FOR THE GLOBAL FARMING COMMUNITY

The new economic theory of development today is '*Environmental-Economics*' which advocates for judicious balance between 'economy and ecology' in all developmental programs including agricultural development and amalgamation of 'economic development' programs with 'ecological conservation' strategies to usher in the era of sustainable development. The new economic philosophy of development also stresses mankind to switch over from the 'fossil fuel (petroleum products) based economy' to 'renewable resource based & waste recycling based economy'.

We have to understand that every natural resource, commodity, goods and services that we use from the environment has an 'environmental cost' (the hidden cost of environmental damage & repair while the raw material is procured from the earthly resources) other than its 'economic cost' (the cost of processing, manufacturing and trading) and only after adding the two costs, we arrive at the true cost of the product. There may be 'social cost' as well in the form of impaired human health and quality of life. We only pay for the cost of food grown in farms and its processing and transport. We never pay for the damage done to the environment due to production and use of chemical fertilizers and pesticides in their factories. Conventional economists are not bothered to deduct the cost of environmental damage (e.g. degradation of farmland & soil) and the cost of environmental repair and restoration (e.g. soil regeneration and management of degraded lands) from the GNP of nations. But the environmental-economists do (189).

The cost of production of vermicompost is simply insignificant as compared to chemical fertilizers. While vermicompost is produced from a 'cheap raw material' (community wastes including farm wastes) which is in plenty all over the world and is growing in quantity with the growing human population, the chemical fertilizers are obtained from 'petroleum products' which are not only very 'costly raw materials' but also a 'vanishing resource' on earth. And while vermicompost can be produced 'on farms' by all farmers, big and small, the chemical fertilizers has to be produced in 'factories' at a high economic and environmental cost. This means vermicompost can be afforded by all farmers. The worms itself becomes an economically valuable products for the farmers to be sold to fishery, poultry, dairy and pharmaceutical industries.

PRODUCTION & USE OF VERMICOMPOST-ENVIRONMENTALLY PROTECTIVE AND ECONOMICALLY PRODUCTIVE

Vermicompost production & use is an 'environmentally friendly, protective and restorative' process as it diverts wastes from ending up in landfills & also reduces emission of greenhouse gases (GHG) due to very small amount of energy used in its production process. Application of vermicompost in farm soil works as soil conditioner and help in its regeneration by improving its physical, biological and chemical properties.

Vermicompost production is also an 'economically productive' process as it 'reduces wastes' at source and consequently save landfills space. Construction of engineered landfills incurs 20-25 million US dollars upfront before the first load of waste is dumped. Over the past 5 years the cost of landfill disposal of waste has increased from $ 29 to $ 65 per ton of waste in Australia. Then, landfills have to be monitored for at least 30 years for emissions of GHG and toxic gases & leachate (Waste Juice) which also incur cost. During 2002-2003, waste management services within Australia cost $ 2458.2 millions. Even in developing nations where there are no true landfills, dumping of wastes incurs high cost on local government.

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) which improve soil fertility and enhance farm productivity to produce 'safe food' (green gold) in farms. Vermiculture can maintain the global 'human sustainability cycle'-i.e. producing food in farms back from food & farm wastes.

Vermicomposting is a self-promoted, self-regulated, self-improved & self-enhanced, low or no-energy requiring zero-waste technology, easy to construct, operate and maintain. It excels all other waste conversion technologies by the fact that it can utilize waste organics that otherwise cannot be utilized by others. It excels all other biological or mechanical technologies for production of 'bio-fertilizer' because it achieves 'greater utilization' than the rate of 'destruction' achieved by other technologies and the process becomes faster with time as the army of degrader worms and the decomposer microbes multiply in millions in short time (171 & 174). Earthworms involves about 100-1000 times higher 'value addition' in any medium (composting wastes or soil) wherever it is present (9 & 10).

PRODUCTION & USE OF CHEMICAL FERTILIZERS -AN ENVIRONMENTALLY DESTRUCTIVE & ECONOMICALLY UNPRODUCTIVE PROCESS

Production of chemical fertilizers in industries is an 'environmentally damaging' process in its entire life-cycle, since harnessing of raw materials from the earth crust, to their processing in factories and their use in agriculture farms. It generates huge amount of toxic and hazardous wastes & pollutants at every stage of production and use. It also uses copious amount of energy in production process and emits huge volumes of greenhouse gases (GHG).

It is an 'economically unproductive' process of development. Huge money has to be spent on infrastructure development for production of chemical fertilizers and in installations of equipments for pollution control, transport and then on safe disposal of hazardous waste in engineered landfills. Its application in farms pollutes the soil and water bodies & kills beneficial soil organisms with severe economic & environmental implications.

LOWER COST OF FOOD PRODUCTION BY VERMICULTURE

A matter of considerable economic and environmental significance is that the 'cost of food production' by vermiculture will be significantly low by more than 60-70% as compared to chemical fertilizers and the food produced will be a 'safe chemical-free food' for the society. It is a 'win-win' situation for both producers (farmers) and the consumers (feeders). The cost of production of vermicompost is simply insignificant as compared to chemical fertilizers. While the former is produced from 'human waste'-a raw material which is in plenty all over the world, the latter is 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 (124).

As vermicompost also helps the crops to attain maturity and reproduce faster, it shortens the 'harvesting time' (175). 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.

Vermicompost application reduces use of chemical pesticides and cut cost: Widespread use of chemical pesticides became an important requirement for the growth of high-yielding varieties of crops which was more susceptible to pests and diseases. Continued application of chemical pesticides induced 'biological resistance' in crop pests and diseases and lograthmatically much higher doses are now required to eradicate them.

There has been considerable evidence in recent years regarding the ability of vermicompost to protect plants against various pests and diseases either by suppressing or repelling them or by 'inducing biological resistance' in plants to fight them or by killing them through pesticidal action. Pesticide spray was significantly reduced where earthworms and vermicompost were used in agriculture.(168 & 182). Our studies also indicate that use of vermicompost help in disease control by almost 75%. This significantly cut down on the cost of food production.

Vermicompost application reduces use of water for irrigation and cut cost: Studies indicate that vermicompost is able to retain more soil moisture thus reducing the demand of water for irrigation by nearly 30-40%. (175; 182 & 183).

BETTER GROWTH & HIGHER YIELD WITH LOWER AMOUNT OF VERMICOMPOST

Studies indicate that smaller amounts of vermicompost in fact promote better growth performances of crops. Subler (180) reported that in all growth trials the best growth responses were exhibited when the vermicompost constituted a relatively small proportion (10%-20%) of the total volume of the container medium. Valani (203) found that 200 gm of vermicompost applied in pot soils performed better growth in wheat crops than those with 400 gm & 500 gm of vermicompost. Singh (167) found that in the farm plots where vermicompost was applied in the 2nd, 3rd and 4th successive years, the growth & yield of wheat crops increased gradually over the years at the same rate of application of vermicompost i.e. @ 20 Q/ha. In the 4th successive year the yield was 38.8 Q/ha which was very close to the yield (40.1 Q/ha) where vermicompost was applied @ 25 Q/ha

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. In a study in Australia, Webster (206) found that vermicompost increased yield of 'cherries' for three (3) years after 'single application'. Yield was much higher when the vermicompost was covered by 'mulch'. At the first harvest, trees with 5 and 20 mm vermicompost plus mulch yielded cherries of the value of AU $ 63.92 and AU $ 70.42 respectively. After three harvests, yield per tree were AU $ 110.73 and AU $ 142.21 respectively for the 5 mm and 20 mm vermicompost with mulch. With vermicompost alone (without mulch), trees yielded cherries of AU $ 36.46 per tree with 20 mm vermicompost in the first harvest and after three harvest AU $ 40.48 per tree. Webster (206) also studied the agronomic impacts of compost in vineyards and found that the treated vines produced 23% more grapes due to 18% increase in bunch numbers. The yield in grapes was worth additional AU $ 3,400/ha.

INCREASINGLY GREATER AMOUNT OF CHEMICAL FERTILIZERS ARE NEEDED TO MAINTAIN GROWTH AND YIELD

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 of previous years as the soil became 'addict'. Nearly 3 - 4 times of agro-chemicals are now being used per hectare what was used in the 1960s. And the cost of chemical fertilizers has also been steadily increasing since then. In Australia, the cost of MAP fertilizer has risen from AU $ 530.00 to AU $ 1500.00 per ton since 2006. There is also significant loss of chemical fertilizer from the farm soil due to oxidation in sunlight. Suhane (182) calculated 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.

SIGNIFICANTLY LOWER AMOUNT OF VERMICOMPOST IS NEEDED TO SUPPORT CROP GROWTH AND YIELD AS COMPARED TO CONVENTIONAL COMPOST

Our studies indicate that vermicompost is several times more powerful crop nutrient than the conventional composts and hence significantly lower amount of vermicompost is required for crop growth and production. Suhane (182) asserts that is at least 4 times more nutritive than cattle dung compost. In Argentina, farmers who use vermicompost consider it to be seven (7) times richer than conventional composts in nutrients and growth promoting values (132).

Atiyeh (17) found that the conventional compost was higher in 'ammonium', while the vermicompost tended to be higher in 'nitrates', which is the more available form of nitrogen to promote better growth and yield. 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. Then. vermicompost retains nutrients for long time and while the conventional compost fails to deliver the required amount of macro and micronutrients including the vital NKP (nitrogen, potassium & phosphorus) to plants in shorter time, the vermicompost does (42 & 180).

Above findings were experimentally verified by Suhane (183) who found that while on application of vermicompost @ 25 quintal/hectare on farm wheat crops the yield was 40.1 Q/ha, on application of cattle dung compost @ 100 Q/ha (4 times of vermicompost) the yield was just over 33 Q/ha which is about 18% still less than that on vermicompost.

COMMERCIAL VERMICULTURE: A GOOD BUSINESS OPPORTUNITY, POTENTIAL TO CREATE & SUPPORT ALLIED INDUSTRIES & COMBAT POVERTY

Vermiculture is a growing industry not only for managing waste and land very economically but also for promoting 'sustainable agriculture' by enhancing crop productivity both in quantity & quality at significantly low economic cost than the costly agrochemicals (39).

Earthworms not only converts 'waste' into 'wealth' it itself becomes a valuable asset as worm biomass. Large-scale production of nutrient rich 'vermicompost' (especially from the municipal solid wastes) with potential to replace chemical fertilizers and protein rich 'earthworms' can be a good business opportunity today with awareness growing about use of these products in agriculture and other allied industries (86). MSW is growing in huge quantities in every country with growing population and there will be no dearth of raw materials for production of vermicompost.

Vermiculture have also enhanced the lives of poor in India and have generated self-employment opportunities for the unemployed. It has become good source of livelihood for many. In several Indian villages NGO's are freely distributing cement tanks and 1000 worms and encouraging men & women to collect waste from villages & farmers, vermicompost them and sell both worms and vermicompost to the farmers (98). People are earning from Rupees 5 to 6 lakhs (Approx. AU $ 15-20 thousands) every year from sale of both worms and their vermicompost to the farmers. Mostly they use farm waste and also municipal solid wastes (MSW) collected from streets & waste dumpsites.

It is estimated that one (1) ton of earthworm biomass on an average contain one (1) million worms approximately. One million worms doubling every two months can become 64 million worms at the end of the year. Considering that each adult worm (particularly *E. fetida*) consume waste organics equivalent to its own body weight everyday, 64 million worms (weighing 64 tons) would consume 64 tons of waste everyday and produce 30-32 tons of vermicompost per day at 40-50% conversion rate (205).

In any vermiculture practice, earthworms biomass comes as a valuable by-product and they are good source of nutritive 'worm meal'. They are rich in proteins (65%) with 70-80% high quality essential amino acids 'lysine' and 'methionine' and are being used as feed material to promote 'fishery', 'dairy' and 'poultry' industry. They are also finding new use as a source of 'collagen' in the manufacture of pharmaceuticals and in the making of 'antibiotics' from the ceolomic fluid as it has anti-pathogenic properties.

CONCLUSIONS AND REMARKS

If vermi-products (worms, vermicompost & vermiwash) are able to replace 'agrochemicals' in agriculture & horticulture production and protein rich worms becomes pro-biotic food for fishery, dairy and poultry production, it would truly help achieve greater 'sustainability' in production of 'safe chemical-free food' for mankind in future.

The technology is being commercialized all over the world for mid-to-large scale vermicomposting of most organic wastes (food & farm wastes & green wastes and also the sewage sludge) and several companies have come up in the last few years in U.S., Canada, New Zealand, Japan and France. The Envirofert Company, New Zealand, is vermicomposting thousands of tons of green waste every year. They claim that each worm eat the cooked green waste at least 8 times leaving an end product which is rich in key minerals, plant growth hormones, enzymes and beneficial soil microbes. Envirofert is also planning to vermicompost putrescible food waste from homes, restaurants and food processing industries in New Zealand. They intend to process approximately 40,000 tones of food wastes every year to produce vermicompost which would eventually replace chemical fertilizers in farm production in New Zealand. (www.envirofert.co.nz)

Switching over to sustainable agriculture by vermiculture can truly bring in 'economic prosperity' for the farmers and the nations with 'environmental security' for the earth.

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Useful websites on vermiculture studies

http://www.alternativeorganic.com (Good Earth People, Canada).
http://www.kvksmp.org (Farmers Training on Vermicomposting at RAU, Bihar, India).
http://www.rirdc.gov.au (Australian Govt. Pub. On EARTHWORMS).
http://www.vermitech.com (Australian Company in Vermiculture Business).
http://www.vermitechnology.com (U.S. Company in Vermiculture Business).
(http://www.wormwoman.com (Mary Appelhof: Author of Classic Book 'Worms Eat My Garbage-Sold over 3500 copies).
http://www.wormdigest.org ('Worm Digest'-A Quarterly Magazine).
http://www.wormresearchcentre.co.uk (Earthworm Research Center in UK).

Relevant Books by Dr. Rajiv K. Sinha

1. Sinha, Rajiv K and Rohit Sinha, 2008. Environmental Biotechnology (Role of Plants, Animals and Microbes in Environmental Management) (pages 315), Aavishkar Publishers, India; ISBN 978-81-7910-229-9.
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