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

Author
Sinha, Rajiv, Herat, Sunil, Valani, Dalsukhbhai, Chauhan, Krunalkumar

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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 convert most organic waste into nutritive compost, earthworms improve physical 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.

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 10th century A.D. He recommended to incorporate earthworms in soil of pomegranate plants to obtain high quality fruits. 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.

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

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. *Eisine 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 vermi-moprocess 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 antibacterial 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 *Esonia 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 RE COURSE 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 mucro-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 NO3-N which is bio-available form on nitrogen to crop roots. The release of mineral N after death of earthworms could be significant since worm biomass can turn over up to 3 times a year in farm soil. Study estimated direct flux of nitrogen through earthworm biomass in farm soils (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 cast is richer in ‘inorganic phosphorus compounds’ extractable in water than the surface soil ingested. Graff (88) and Sharples & 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)

<table>
<thead>
<tr>
<th>Phosphorus (P)</th>
<th>Control</th>
<th>Culture residues (Relative increase)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water-soluble P</td>
<td>11.14</td>
<td>19.08 (x 1.71)</td>
</tr>
<tr>
<td>Total extractable P</td>
<td>251.72</td>
<td>311.90 (x 1.24)</td>
</tr>
<tr>
<td>Extractable Inorganic P</td>
<td>177.94</td>
<td>244.76 (x 1.38)</td>
</tr>
</tbody>
</table>

Source: Satchell and Martin (1984)
Worms stimulate high levels of beneficial and biologically active soil microbes: Earthworms host 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 vermiculture 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. Sprayer 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 Toyohira 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, vermiculure 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 (Eisenia 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’.
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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.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).

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