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Miracle of earthworms in the service of man and environment : resolve food, waste and water problems, provide medicines for combating deadly human diseases and mitigate global warming

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Abstract: *A revolution is unfolding in 'vermiculture biotechnology' for achieving quicker and cheaper solutions to several environmental, economic and social problems plaguing the human society from sustainable 'waste management' (converting waste into resource), 'land and soil remediation' to 'safe, chemical-free and health protective food production' (without recourse to dangerous agro-chemicals). Vermicomposting of solid wastes can divert 60-70 % MSW from landfills. Vermifiltration involves very 'low energy' and there is no formation of 'sludge' which plagues all conventional STPs. Vermiremediation is 'on-site' without earth cutting and soil excavation. Earthworms and their excreta (vermicast) are 'miracle growth promoters' producing highly nutritive and health protective foods while also protecting crop plants from pests and diseases. We have successfully experimented in 'vermicomposting of solid wastes', 'vermifiltration of 'municipal and industrial wastewater', 'vermiremediation of chemically contaminated soils' and 'vermi-agroproduction of cereal and vegetables crops' with amazing results. Wastes are degraded by over 75% faster, BOD and TDSS of wastewater is reduced by over 95%, PAHs from contaminated soils are removed by 80 % in just 12 weeks, and growths of crop plants are enhanced by 30–40% higher over chemical fertilizers by vermicompost.*

Sir Charles Darwin wrote that 'no other creature on earth has done so much for mankind' as the earthworms. Their role as 'waste and soil managers', and 'plant growth promoters' were known for long, but some 'new discoveries' about their role in 'wastewater treatment', 'remediation of chemically contaminated soil', and more recently about their potential use in modern medicine for protection of 'human health' from some deadly diseases like 'cancers and cardiovascular diseases' and as a rich source of 'high quality protein' have brought a revolution in the vermiculture studies.

Key words: *Waste Vermi-composting; Wastewater Vermi-filtration; Vermi-remediation of Chemically Contaminated Soil; Vermi-agriculture Production of Organic Foods; Vermi-industrial Production of Medicines and Materials; Earthworms – Chest of Medicines for Heart Diseases and Combating Cancers; Earthworms Bio-accumulate, Biodegrade and Bio-transform Chemicals; Earthworms Disinfect and Detoxify Environment; Earthworms Mitigate Global Warming and Climate Change.*

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Introduction:

Earthworms, whom Sir Charles Darwin called as *'unheralded soldiers of mankind'* promises to resolve several problems mankind resulting from modernization. They are both 'protective and productive' - protect human health and environment (degrade, detoxify and disinfect all human wastes - solid wastes and wastewater), produce 'chemical-free', 'nutritive' and 'health protective' foods and useful 'industrial materials' and 'medicines' for the society. Earthworm processed wastes (vermicompost) are proving as a 'miracle plant growth promoter and protector' and sustainable alternative to the destructive agrochemicals. Vermicompost use in farm soils would also 'sequester' huge amounts of atmospheric carbon (CO_2) and bury them into the soil as 'soil organic carbon' (SOC) mitigating global warming. Earthworms have protected the 'earth' for over 600 million years now as 'ecosystem engineers' and have fed people as 'farm managers' since mankind arrived on earth. Vermiculture scientists all over the world knew about the role of earthworms as 'waste managers', as 'soil managers and fertility improvers' and 'plant growth promoters' for long time. But some comparatively 'new discoveries' about their role in the 'sustainable management of municipal solid wastes (MSW) with 'low greenhouse gas emissions', 'treatment of municipal and some toxic industrial wastewaters', 'remediation of chemically contaminated soils', as 'powerful plant growth promoters and plant protectors' with potential to replace the 'destructive agro-chemicals' and development of 'life saving medicines' (for heart diseases and combating cancers), 'nutritive feed materials' for fishery and dairy industries and raw materials for 'rubber, lubricants, soaps and detergent industries' have revolutionized the studies into vermiculture biotechnology.

The Vermiculture Biotechnologies

Six (6) biotechnologies have been developed from the scientific use of earthworms.

(1) 'THE VERMICOMPOSTING TECHNOLOGY' (VCT) for efficient management of municipal and industrial organic wastes (inc. sewage sludge and fly-ash) by biodegradation and stabilization and converting them into useful resource (vermicompost - a nutritive biofertilizer);

2) 'THE VERMIFILTRATION TECHNOLOGY' (VFT) for treatment of municipal and some industrial wastewater, to produce 'detoxified and disinfected' nutritive water for reuse in agriculture and non-potable purposes;

3) 'THE VERMIREMEDIATION TECHNOLOGY' (VRT) for cleaning up chemically contaminated lands and soils while also improving the total physical, chemical and biological properties of soil for reuse;

4) 'THE VERMI-AGRICULTURE PRODUCTION TECHNOLOGY' (VAPT) for restoring and improving farm soil fertility to produce safe, chemical-free nutritive and protective food for the society by the use of vermicompost and without recourse to the agro-chemicals;

5) 'THE VERMI-INDUSTRIAL PRODUCTION TECHNOLOGY' (VIPT) for using worm biomass as valuable source of raw materials for promoting piggery, poultry, fishery and dairy development and production of biodegradable good's for societal consumption.

6) 'THE VERMI-HEALTH PROTECTION TECHNOLOGY' (VHPT) for using worms as valuable source of 'bio-active compounds' for production of modern medicines for various diseases and for cure of heart diseases and combating cancers.

We have successfully worked on vermicomposting of 'organic wastes'; vermifiltration of 'municipal sewage and some industrial wastewater' (innovative works); vermiremediation of chemically contaminated soils; and vermi-agriculture production of some 'cereal and vegetables crops' with excellent results at Griffith University, Australia (Sinha et al 2010 c). Solid wastes are degraded by over 75% faster than conventional composting systems; BOD and TDSS of wastewater is reduced by over 95% (without formation of 'sludge' which plagues all conventional wastewater treatment systems); and growths and yield of crop plants are enhanced by 30-40 % higher over chemical fertilizers by worms and its vermicast. And in all the above developmental activities application of vermiculture biotechnologies leads to significant reduction in the emission of greenhouse gases (GHG). Accounting for the emission of GHG which induce 'global warming' has become essential in all modern technologies and developmental activities.

Vermicomposting Technology to Convert Solid Wastes into Disinfected and Detoxified Nutritive Vermicompost and Reducing the Need of Waste Landfills

Vermicomposting of wastes organics by waste eater earthworms is proving to be economically and environmentally preferred technology over the conventional microbial composting technology as it is 60-80 % rapid and nearly odorless process, reducing composting time by more than half and the end product is both 'disinfected', 'detoxified' and 'highly nutritive' vermicompost (a bio-fertilizer) which is a sustainable alternative to the destructive chemical fertilizers (Discussed below). Earthworms have dual action on waste organics – secrete enzymes (amylase, lipase, cellulase and chitinase) to degrade organics and engineers the growth of 'decomposer microbes' in billions and trillions in short time. Given the optimum conditions of temperature (20-30 °C) and moisture (60-70 %), about 5 kg of worms (numbering approx.10, 000) can vermiprocess 1 ton of organic wastes into vermicompost in just 30 days and the process becomes faster with time. Vermicomposting leads to generation of 'huge worm biomass' as the worms multiply rapidly. It is a valuable resource now finding new applications in feed and pharmaceutical industries. (Sinha et al 2002; Sinha et al 2011 a).

Economic and Environmental Advantages of Vermicomposting in Safe Disposal of Community Wastes

Several tons of municipal solid wastes (MSW) are being generated every day in cities of world requiring safe disposal. Over the past years the cost of 'LANDFILL DISPOSAL' of solid waste has increased significantly. In developing countries including India there are no 'TRUE ENGINEERED LANDFILLS' which incurs about US $ 30 to 40 million for construction even before the first load of waste is dumped. Waste dumping, compacting and covering every day by soils before sun set and 'leachate collection' costs extra. In India and in all developing nation wastes are simply 'dumped' on 'Open Dumpsites' without caring for the environment. That is the situation in all cities of Bihar including Patna. Recently, Bangladesh has developed 'Closed Waste Dumpsite'.

Of greater environmental and human health concern is that landfill or waste dumpsites emit huge and more powerful GREENHOUSE GASES like methane (22 times) and nitrous oxides (312 times) than carbon dioxides and also highly toxic trace gases like 'toluene and xylene'. INCINERATION emits dangerous 'dioxins and furans' (mainly due to plastics) for which WHO has 'no safe limits' for mankind.

Earthworms have real potential to both increase the rate of aerobic decomposition and composting of organic matter by over 75 % and also to stabilize the organic residues in the MSW and sludge – removing the harmful pathogens and heavy metals from the compost (Hartenstein et al, 1980; Pierre et al 1982; Ireland 1983).The quality of compost is significantly improved, rich in key minerals and beneficial soil microbes (Edwards, 2000). In fact in the conventional aerobic composting process which is thermophilic (temperature rising up to 55°C) many beneficial microbes are killed and nutrient especially nitrogen is lost (due to gassing off of nitrogen). Earthworms create aerobic conditions in the waste materials by their burrowing actions, inhibiting the action of anaerobic micro-organisms which release foul-smelling hydrogen sulfide and mercaptans. The earthworms release coelomic fluids that have anti-bacterial properties and destroy all pathogens in the resulting compost. (Pierre et al 1982). The greatest advantage over the conventional composting system is that the end product is more homogenous, richer in 'plant-available nutrients and humus' and significantly low contaminants (disinfected and detoxified). They are 'soft', 'highly porous' with greater 'water holding capacity' (Appelhof 1997;Lotzof 2000).

Commercialization of Vermicomposting Technology (VCT) to Resolve Waste Problems

Commercial vermicomposting was started in the middle of 20th century and the first VCT

plants were established in Holland in 1970, and subsequently in England, and Canada. Vermicomposting for diverting wastes from landfills and use of vermicompost in agriculture is being commercialized all over the world for mid to large scale vermicomposting of most organic wastes (food and farm wastes and green wastes and also the hazardous wastes like sewage sludge and fly-ash) from developed countries like U.S., Canada, U.K., France, Australia, Russia and Japan to developing countries like India, China, Chile, Korea, Thailand, Brazil, Mexico, Argentina and the Philippines (Sherman 2000; Lotzof 2000). UK is promoting vermicomposting mainly for waste management and to reduce the needs of 'waste landfills'. Large, 1000 mt vermicomposting plants have been erected in Wales (Frederickson 2000). Large scale vermicomposting plants have been installed in US and Canada to vermicompost municipal and farm wastes and use the vermicompost and other vermiproducts for 'organic farming' (GEORG 2004; Hahn 2011). The American Earthworm Technology Company started a 'vermicomposting farm' in 1978-79 with 500 tons /month of vermicompost production (Edward 1988). Japan imported 3000 mt of earthworms from the USA during the period 1985-87 for cellulose waste degradation (Kale 1991). The Aoka Sangyo Co. Ltd., has three 1000 tons /month plants processing waste from paper pulp and the food industry (Kale 1998). This produces 400 tons of vermicompost and 10 tons 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 produce 2-3 thousands tons per month (Edward 1988). In Italy vermiculture is used to biodegrade municipal and paper mill sludge. France is also promoting vermicomposting on commercial scale to manage all its MSW and reduce the needs of landfills. In France, several tons of mixed household wastes are being vermicomposted everyday using 1000 to 2000 million red tiger worms (*Elsenia andrei*). (Visvanathan et al 2005). The 'Envirofert Company' of New Zealand is vermicomposting about 5-6 thousand tons of green waste every year. They are also vermicomposting approximately 40,000 tons of food wastes from homes, restaurants and food processing industries every year.

In India vermiculture revolution is going on to produce VERMICOMPOST and replace the deadly agrochemicals from farming. Large vermicomposting units have come up in Punjab, Harayana, Gujarat, Karnataka and Tamil Nadu. The Karnataka Compost Development Corporation in India established a first vermicomposting unit in the country to handle all municipal urban solid wastes and is producing 150 to 200 tons of vermicompost every day from city garbage. (Kale 2005). Bihar is also making rapid progress in vermiculture with encouragements given by Agriculture Ministry. I have been involved in educating farmers and unemployed agriculture and engineering graduates of Bihar to undertake commercial vermicomposting as their profession since 2006. This will resolve the dual problem of community 'waste management' and elimination of the 'poisonous agrochemicals' from farms and food production. (Personal Communication; Er. Syed

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Solid waste from paper pulp and cardboard industry, food processing industries including brewery and distillery; vegetable oil factory, sugarcane industry, aromatic oil extraction industry, sericulture industry, logging and carpentry industry also make excellent feedstock for commercial vermicomposting. Worms can also degrade 'fly-ash and sewage sludge' (a biohazard from coal power and sewage treatment plants) into wonderful vermicompost (Saxena et al 1998; Scholder 2011; Sinha et al 2010 b). They have also been found to degrade toxic 'asphaltens' from the oil drilling sites.(Schaefer 2005) .

Vermifiltration Technology to Treat Wastewater at Low Cost, Low Energy Use and Without Formation of Sludge, Producing Disinfected and Detoxified Water for Reuse in Agriculture

Vermifiltration of wastewater (sewage) using waste eater earthworms is a newly conceived innovative technology developed by us at Griffith University, Australia in 2006. It has several advantages over the costly conventional sewage treatment plants (STPs) like 'Activated Sludge', 'Aerated Lagoons' and 'Rotating Biological Contactors'. The biggest advantage is that there is no formation of 'sludge'. We have pioneered the technology in Australia (2007). Earthworms body work as a 'biofilter' removing BOD_5 by over 95 %, COD by 55 % - 85 %, TSS by 90-95 %, turbidity by over 95 % from wastewater. Worms also 'bio-accumulate' any toxic chemicals including heavy metals and bio-transform them and biodegrade the toxic organics by enzymatic actions. Worms kills the pathogens in the wastewater by their anti-pathogenic ceolomic fluid and the fecal coliforms are removed by over 99 %. The treated water becomes 'detoxified' and 'disinfected' and clean enough to be 'reused' for non-potable purposes e.g. washing, cleaning, industrial uses and for farm irrigation as they are highly 'nutritive' rich in NKP. (Xing et al 2005).

Earthworms in the vermifilter bed feed upon the solids in wastewater and excrete them as 'vermicast'. Worm vermicasts also provide wonderful sites for 'adsorption' of heavy metals and pollutants in wastewater. This is due the presence of 'hydrophilic' groups in the 'lignin contents' and 'humus' of the vermicompost. The vermicast also offers excellent 'hydraulic conductivity' of sand (being porous like sand) and also high 'adsorption power' of clay. (Bhawalkar 1995).

We have also successfully treated some municipal and industrial wastewater from dairy, brewery and fruit juice industry (with very high BOD loads) including most toxic 'petroleum wastewater' by *E. fetida*.

Table 1.
Removal of BOD, COD and TSS of Municipal Wastewater (Sewage) Treated by Earthworms (Vermifiltered) and Without Earthworms (In mg/L) (HRT: 1- 2 hrs)

Parameters Studied	Untreated Raw Sewage (mg/L)	Treated Sewage Values (mg/L)		% Reduction in by Earth-worms (Vermi-filtered)	% Reduction Without Earth-worms (Control)
		With Worms (Vermi-filtered)	Without Worms (Control)		
BOD_5	309	1.97	86.3	99.4 %	72.1 %
COD	293	132	245	54.9 %	16.4 %
TSS	438	22	184	94.97 %	57.99 %

Source : Sinha et al (2008 a)

Table 2.
Efficiency of Earthworms in Removal of Toxic Hydrocarbons from Petroleum Contaminated Wastewater Generated in Automobile Industries (In µg/L)

Parameters Studied	Raw Wastewater	Geofiltered Water (CONTROL Without Worms)	Vermi-filtered Water (By Earth-Worms)
Hydrocarbons (C 10 – C 14)	41,00000	37,00000	2,500
Hydrocarbons (C 15 – C 28)	1,70,00000	1,30,00000	22,000
Hydrocarbons (C 29 – C 36)	71,00000	68,00000	16,000

Source : Sinha et al (2012 a)

Economic and Environmental Advantages of Vermifiltration System Over Conventional Wastewater Treatment

Vermi-filtration of wastewater is low energy and efficient system and has distinct advantage over all the conventional wastewater treatment systems - the 'Activated Sludge Process', 'Trickling Filters' and 'Rotating Biological Contactors' which are highly energy intensive, costly to install and operate and do not generate any income. The greatest advantage of the system is that there is 'no sludge' formed, use much less 'energy' and hence very little emission of greenhouse gases. The capital and operating costs are hence much less by over 70 % than other sewage treatment plants (STPs) and is very suitable for developing nations where STPs often remains idle due to shortage of power.

In the vermifilter process there is 100 % capture of organic materials by earthworms and converted into vermicompost. The capital and operating costs are less, and the end products (vermifiltered disinfected and detoxified nutritive water) and byproducts (the nutritive water, vermicompost and earthworms biomass) are of additional economic uses in agriculture and for promoting poultry, fishery and dairy as the worms are highly nutritive feed materials containing about 60 % protein rich in all essential amino acids.

(a) No Sludge Formation: Sludge in Converted into Nutritive Vermicompost : This plagues most municipal councils in world as the sludge is a 'biohazard' and requires safe landfill disposal at high cost. The greatest advantage of vermifiltration system is that there is no formation of 'sewage sludge' (Huges et al 2005). The worms decompose the organics in the wastewater and also devour the solids (which forms the sludge) synchronously. They feed readily upon the sludge components, rapidly convert them into vermicompost, reduce the pathogens to safe levels and ingest the heavy metals.

(b) No Foul Odor : There is no foul odor as the earthworms arrest rotting and decay of all putrescible matters in the wastewater and the sludge. In all developed nations a 'worm farm' has become a necessity in all wastewater and water treatment plants to resolve the sludge problems.

(c) Disinfected and Detoxified Water Fit for Non-Potable Uses: Saving Fresh water : Vermifiltered water is free of pathogens and toxic chemicals (heavy metals and endocrine disrupting chemicals) and suitable for 'reuse' as water for non-potable purposes. The worms devour on all the pathogens (bacteria, fungus, protozoa and nematodes) in the medium in which they inhabit (Bajsa et al 2004). They have the capacity to bio-accumulate high concentrations of toxic chemicals in their tissues and the resulting wastewater becomes almost chemical-free. (Ireland 1983; Hartenstein et al 1980; Haimi et al 1992).

(d) Worms Remove Endocrine Disrupting Chemicals from Sewage : Not Achieved in Any System : Earthworms have also been reported to bio-accumulate 'endocrine disrupting chemicals' (EDCs) from sewage which otherwise is not removed by our conventional sewage treatment plants (STPs). Markman et al (2007) have reported significantly high concentrations of EDCs (dibutylphthalate, dioctylphthalate, bisphenol-A and 17 b - estrdiol) in tissues of earthworms (*E. fetida*) living in sewage percolating filter beds and also in garden soil.

Earthworms can also remove 'arsenic' (As) from contaminated water and make it safe for drinking. Arsenic is one of the 'Endocrine Disrupting Chemicals' in the environment and is widely reported from ground water in the Indo-Gangetic plains of India. We have experimented with vermifiltration of arsenic contaminated groundwater in Patna districts of Bihar in India by earthworms *Eisenia fetida* with excellent results. (Personal Communication: Prof. Ashok Ghosh: ashok.ghosh51@gmail.com)

Commercialization of Vermifiltration Technology (VFT): Simple and Economical and Reuse the Treated Water in Farm Irrigation to Save Fresh Water

Due to its simplicity and cost-effectiveness VFT of both municipal and industrial wastewater is destined to become a global movement. Our new technology has been commercialized in India by Transchem Agritech Ltd. at Gujarat for treatment of 400 KL 'sewage' every day and the end products (clean water, vermicomposted sludge and earthworms biomass) are being supplied to farmers for use in agriculture (mandarp@transpek.com). On average the BOD is being removed by over 95 %, COD over 85 %, TSS and Turbidity over 95 % and fecal coliforms by over 99 %. The dissolved oxygen (DO) values which are nil in raw sewage are increased to 4-5 ppm. The TDS is removed only by 16 %. High TDS is due to anions – nitrates, sulphates, chlorides and carbonates. Nitrates and sulphates are good for water for farm irrigation. Ammonical nitrogen (NH^4-N) from the raw sewage (creating foul odor) is reduced from 25-40 ppm to less than 1 ppm and the total phosphorus (causing eutrophication and algal bloom) from 4-8 ppm to 1-2 ppm. The useful nitrates (NO_3) are increased from 10-20 ppm to over 50 ppm, the useful bio-available phosphates (P_2O_5) from 1-2 ppm to 5-7 ppm and the potassium (K) from 10-15 ppm to 20-25 ppm in the vermifiltered water. The treated water becomes highly nutritive good enough to be used in agriculture with considerable savings on fertilizers. As agriculture uses nearly 80 % of fresh water in world it can save tremendous groundwater water resources.

Our technology is in process of commercialization in Australia, U.S. and Russia. Dr. Maria Soto at University of Chile also worked on the system and commercialized the technology. Hundreds of VFT plants are successfully operating in Chile, Mexico and Venezuela based on her technology (Soto and Toha 1998) (masoto@cec.uchile.cl).

I have suggested Govt. of Bihar to implement the technology for Sewage Treatment in Bihar. Huge volumes of 'untreated sewage' flows into the Ganges every day badly polluting the holy river Ganges.

Vermiremediation Technology to Treat Chemically Polluted Land Onsite Without Earth Cutting and Soil Excavation and Render it Fertile and Productive

Earthworms must have been involved in the formation of soils after the origin of earth and that justify its name. They have been bestowed with a 'grinding machine' called 'gizzard' where they grind rock and sand particles and mix up with their organic secretions (humus) to form the soil. Earthworms have also been used for land recovery, reclamation and rehabilitation of polluted soils, sub-optimal soils such as poor mineral soils, polder soils, open cast mining sites, closed landfill sites and cutover peat. Large tract of arable land is being chemically polluted due to mining activities, heavy use of agro-chemicals in farmlands, landfill disposal of toxic wastes and other developmental activities like oil and gas drilling. No farmland of world especially in the developing nations are free of toxic pesticides, mainly aldrin, chlordane, dieldrin, endrin, heptachlor, mirex and toxaphene.

Studies have indicated that the earthworms bio-accumulate or biodegrade 'organochlorine pesticide' and 'polycyclic aromatic hydrocarbons' (PAHs) residues in the medium in which it lives. (Davis 1971; Ireland 1983; Haimi et al 1992; Eijackers et al 2001 and Gevao et al 2001; Contreras-Ramos et al 2006). Bolan and Baskaran (1996) studied the effect of earthworm species *Lumbricus rubellus and Allobophora callignosa* vermicast on the sorption and movement of herbicides C^{14} -metsulforon methyl, C^{14} – atrazine, C^{14} – 2,4 dichlorophenoxyacetic acid (2,4 - D) in soil. Worm vermicasts sorbed higher amount of herbicides from the contaminated soil than the control soil.

We studied the remedial action of earthworms on PAHs contaminated soils obtained from a former gas works site in Brisbane where gas was being produced from coal. The initial concentration of total PAHs compounds in the soil at site was greater than 11,820 mg/kg of soil. Results showed that the worms could remove nearly 80 % of the PAHs (or above 60 % after taking the dilution factors into consideration) as compared to just 47 % and 21 % where worms were not applied and only microbial degradation occurred. This was just in 12 weeks study period. It could have removed by 100 % in another few weeks. More significant was that the worm added soil became odor-free of chemicals in few days and were more soft and porous in texture. (Table 3).

Table 3.
Percent Removal of Some PAH Compounds from Contaminated Soil by Earthworms in 12 Weeks Periods

Extracted PAH Compounds	Treatent-1 Soil + Worms + Cow Dung	Treatent-2 Soil + Worms + Food Wastes	Treatent-3 Soil+Compost (NO WORMS)
1.Benzo (a) anthracene	76% (58%)	71% (56%)	37% (6%)
2.Chrysene	67% (49%)	83% (68%)	41% (12%)
3.Benzo(b) flouranthene	90% (72%)	97% (82%)	65% (47%)
4.Benzo (k) flouranthene	90% (72%)	80% (65%)	40% (10%)
5.Benzo (a) pyrene	89% (71%)	78% (63%)	49% (24%)
6.Dibenzo (a,h) pyrene & Benzo (g,h,i) pyrene	83% (65%)	54% (39%)	54% (30%)
Av.=	**79 % (61%)**	**80% (65%)**	**47.5 % (21 %)**

Source: Sinha et al (2008 b)

(Soil=10 kg; Earthworms=500; Cow Dung and Food Wastes =5 kg).

(Values within bracket are those after taking the dilution factor into consideration due to mixing of feed materials into soil).

Economic and Environmental Advantages of Vermiremediation Technology Over the Mechanical and Chemical Treatment of Contaminated Lands

Traditionally, remediation of chemically contaminated soils involves excavation and subsequent disposal by burial in secured landfills. This is very costly affair and merely shifts the contamination problem elsewhere. The greatest advantage of the vermiremediation technology is that it is 'on-site' treatment and there is no additional problems of 'earth-cutting', 'excavation' and 'transportation' of contaminated soils to the landfills or to the treatment sites incurring additional economic and environmental cost. Vermiremediation would cost about $ 500 - 1000 per hectare of land as compared to $ 10,000 - 15,000 per hectare by mechanical excavation of contaminated soil and its landfill disposal.

Significantly, vermiremediation leads to total improvement in the quality of soil and land where the worms inhabit. They swallow large amount of soil every day, grind them in their gizzard and digest them in their intestine with aid of enzymes. Only 5-10 percent of the digested and ingested material is absorbed into the body and the rest is excreted out in soil in the form of fine mucus coated granular aggregates called 'vermicastings' which are rich in NKP (nitrates, phosphates and potash), micronutrients and beneficial soil microbes including the 'nitrogen fixers' and 'mycorrhizal fungus'. The polluted land is not only 'cleaned-up' but also 'improved in physical (soft and porous), chemical (rich in humus, micro and macronutrients) and biological (beneficial soil microbes) quality'. A 'wasteland' is truly transformed into 'wonderland'. (Sinha et al 2008 b ;Sinha et al 2011 b).

Vermi- Agriculture Production Technology to Improve Soil Fertility and Boost Farm Productivity to Produce Nutritive and Health Protective Organic Foods

Use of chemical fertilizers over the years after the 'Green Revolution' have destroyed the natural properties of soil everywhere in world and made it more 'compact' and 'biologically dry' (depleted in beneficial soil microbes). Earthworms and its vermicompost make the soil 'soft and porous' (by burrowing actions) and restore its physical, chemical and biological properties to improve its natural fertility and productivity. Earthworms vermicompost work as an excellent biofertilizers at least 5-7 times more nutritive than all other composts and gives 30-40 % higher crops yields over chemical fertilizers. It also contains 'plant growth hormones' (auxins, gibberlins and cytokinins). Earthworms and its vermicast also engineers 'biological resistance' in plants against pests and diseases due to 'actinomycetes', repels insect pests and suppress plant diseases' in crops and 'inhibit the soil-born fungal diseases' due to 'chitinases'. Vermicompost consistently improve seed germination, enhance seedling growth and development. The biggest advantage of great social significance is that the food produced is completely 'organic and chemical-free'.

Earthworms swallow large amount of soil every day, grind them in their gizzard and digest them in their intestine with aid of enzymes and excrete out in the form of fine mucus coated 'vermicastings' which are rich in humus, NKP, micronutrients and beneficial soil microbes including the 'nitrogen fixers' and 'mycorrhizal fungus'. Humus is generally lacking in soils devoid of earthworms as it takes very long time for soil or any organic matter to decompose to form humus while earthworms secrete them in their excreta. Without humus plants cannot grow and survive. It is essential for root formation. (Sinha et al 2011 b and 2012 b).

Earthworms act as an aerator, grinder, crusher, chemical degrader and a biological stimulator in soil. In soil they inevitably work as 'soil conditioner' to improve its nutritive value and productivity. This they do by soil fragmentation and aeration, breakdown of organic matter in soil and release of nutrients, secretion of plant growth hormones and, proliferation of nitrogen-fixing bacteria. Worms swallow large amount of soil with .organics everyday and digest them by enzymes. This is excreted out in the form of fine mucus coated granular aggregates called 'vermicastings' which are rich in NKP, micronutrients and beneficial soil microbes. One square meter of healthy soil contains 1,000 earthworms. One acre of land can contain up to 3 million earthworms, the activities of which can bring 8 - 10 tonnes of topsoil to the surface (in the form of nutrient rich vermicasts) every year. Earthworms loosen the soil as they move through it. Their activity creates channels in the soil for movement of air and water. Earthworms climb up to the surface of soil to grab remnants of plants and feed in tunnels and thus fertilize all strata of soil. Presence of worms improves water penetration in compacted soils and can increase cumulative rainfall intake by up to 50%. Soils with a large healthy worm population drain 4 - 5 times faster than soils with very few worms. Worm activity can increase air-soil volume from 8 - 30% and increases the bioavailability of nutrients and trace elements which are present in the soil. Earthworms population of 0.2 to 1.0 million per hectare of land can be established within 3 months. In general a land inhabited and ploughed by earthworms for 3 years will become high yielding farmland (Bhawalkar 1995). According to the estimate of an American researcher, 1,000,000 (one million) earthworms in a garden plot provide the same benefit as three gardeners working 8 hours in shifts all year round, and moreover having 10 tons of manure applied in the plot (Xu Kuiwu and Dai Xingting 1998).

Nitrogen Contribution in Soil

Barley and Jennings (1959) reported that worms significantly contribute nitrogen (N) contents to soil by over 85%. Earthworms can contribute between 20 to 40 kg nitrogen/ha/year in soil, in addition to other mineral nutrients and plant growth regulators and increase soil fertility and plant growth by 30-200%. (Darwin 1881). Earthworms recycle nitrogen in the soil in very short time and the quantity recycled is significant ranging from 20 to 200 kg N/ha/year. After 28 weeks soil with living worms contained 75 ppm of nitrate nitrogen compared to the control soil without worms which contained 45 ppm. Worms increase nitrogen levels in soil by adding their metabolic and excretory products (vermicast), mucus, body fluid, enzymes and decaying tissues of dead worms. They also contribute nitrogen indirectly through fragmentation of organic materials and grazing on soil microorganisms. Earthworm tissues contains about 7.9 % N on a dry weight basis. Living worms release nitrogen from their bodies and after death it is rapidly decomposed in about 4 days releasing all nitrogen into the soil. In a study with potted ryegrass, over 70 % of the N^{15} added was incorporated into plant shoots after 16 days. Study found that 50% of the N in dead worm tissues was mineralized in 7 days while 70% in 10-20 days and the N was converted to 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 ranging from 10-74 kg N/ha/year. In corn field mortality and decomposition of dead earthworms could contribute 23.5 kg N /ha/year. In case of inorganic fertilizer-treated farm soil it is only 15 .9 kg/ha/year.

The Biotechnological Actions of Earthworms and its Vermicompost in Protection of Crops from Pests and Diseases: Killing Pests Without Pesticides

(a) Induce Biological Resistance in Plants: Vermicompost contains some antibiotics and actinomycetes which help in increasing the 'power of biological resistance' among the crop plants against pest and diseases. Pesticide spray was significantly reduced where earthworms and vermicompost were used in agriculture.(Sinha and Valani 2011). Vermicomposts are consistently capable of conferring or inducing plant resistance in economically important plants. It has been shown to increase 'resistance' in host plants against pests, pathogens, plant parasitic nematodes and a large number of arthropods including jassids (*Empoasca kerri*), aphids (*Myzus persicae* and *Aphis craccivora*), spider mites (*Tetranychus urticae*), mealy bugs (*Planococcus citri*) and caterpillars (*Pieris rapae*). (Chaoui et al 2003; Arancon et al 2002, 2005 and 2007).

Vermicompost amendments as low as 20% have been shown to decrease leaf consumption by caterpillars and population growth of aphids on cabbage (Arancon et al 2005). Yasmin (2011) found that vermicompost was very effective in causing *Arabidopsis* plants to become resistant to the generalist herbivore *Helicoverpa zea*. Vermicompost causes plants to have non-preference and toxic effects on insects. This resistance adversely affects insect development and survival on plants grown in vermicompost-amended soil. This resistance is possibly due to the interactions between the diverse microbial communities in vermicompost with plant roots, as is evident from the sterilization assays of vermicompost.

(b) Repel Crop Pests : There seems to be strong evidence that worms varmicastings sometimes repel hard-bodied pests. Edwards and Arancon (2004) and Edwards et al. (2007) 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.

Hahn (2012), practicing vermiculture agriculture in U.S., claims that his products (vermicompost) repels many different insect pests and suppress pathogenic bacteria, fungi and soil nematodes causing crop diseases. His scientific explanation is that this is due to production of enzymes 'chitinase' by 'chitin degraders' bacteria and fungi in the vermicompost which breaks down the chitin in the insect's exoskeleton. Chitin degraders can also digest bacteria and all other chitin based fungi. There are also 'cellulose degraders' enzymes in vermicompost that are able to digest bacteria and cellulosic fungi e.g. *Pythium* and *Phytopthora* which causes wide range of crop diseases. He asserts direct relationship between efficacy of repellency and the number of chitin degraders and the concentration of chitinase enzymes. All indications are that a threshold of 10 million chitin degraders cfu/dwg are required for repellency. The higher the concentration at root zone, greater and faster is the repellency. At 26 million cfu/dwg of chitin degraders aphids were driven from roses in 90 days; at 54 million cfu/dwg in 4 weeks and at 220 million cfu/dwg aphids were chased off in just 4 days. Parasitic nematodes were also suppressed. A 20 acre cauliflower infested with 'centipedes' saw elimination in 3 months. Some 30,000 pine trees in the forest of San Bernardino, U.S. were being decimated by the 'bark beetles'. Upon treatment with chitin degraders and chitinase rich vermicompost the mortality was reduced to less than 1%. The neighboring untreated pines are being lost at 80 + % every year. In a Pecan research project in U.S., application of chitinase rich vermicompost produced a 400 % increase in yield while also eliminating the 'pecan scab' and 'pecan weevil'.

The level of 'chitin degraders' in vermicompost prepared from feeding normal cattle dung and food wastes to the earthworms is generally 2-3 millions cfu/dwg which is below the 10 million cfu/dwg threshold for effective action. If about 30 % chitin is added to the feed material the level of chitin degraders can be significantly increased to 200 million cfu/dwg in the vermicompost. This can be achieved by adding shrimp or crab shells, melted cow horns or even dead bugs to the worm beds. Number of cellulose degraders in the vermicompost can be increased by adding paper or saw dust in the feed materials. (George Hahn; Personal Communication, 2012). (geohahn@gmail.com)

(c) Create and Restore Disease Suppressive Soils : Earthworms act as 'vector' for dispersal of 'disease-suppressive' useful microbes in soils (Compant et al, 2005). Earthworms gut act as a 'microbial factory' and it proliferates the microbial community and diversity in millions and trillions in soils in short time. (Binet et al, 1998). Increasing the population of mixed species of earthworms in soil can proliferate the population and distribution of these 'bio-control microbial agents' in farm soil in billions and trillions. For example *A. trapezoids* spread the bio-control bacterium *Pseudomonas corrugata* (which is highly effective against *G. graminis* var. *tritici* on wheat) to a depth of 9 cm in soil after surface inoculation in pots compared to a depth of only 3 cm in soil without earthworms (controls).

Earthworms have also been found to be directly involved in suppression of soil-borne plant diseases Genus *Aporrectodea* have been found to reduce the symptoms of several soil-borne plant diseases. Presence of *A. rosea* and *A. trapezoids* in soils were correlated with a reduction in the symptoms of diseases caused by *Rhizoctonia solani* in wheat crops in an Australian farm soil. These earthworm species were also associated with suppression of crop diseases caused by *Gaeumannomyces graminis* var. *tritici* on wheat (Elmer 2009). Elmer (2009) also reported that when the population of earthworms *Lumbricus terrestris* was augmented in soils infested with soil-borne pathogens it significantly reduced the diseases of susceptible cultivars of asparagus (*Asparagus officinalis*), eggplant (*Solanum melongena*) and tomato (*Solanum lycopersicum*). Earthworms activity was also associated with increase in plant growth and plant weights were increased by 60-80%.

Chaoui et al. (2002), Edwards and Arancon (2004 a and b) and Arancon et al (2007) have found that use of vermicompost in crops inhibited the soil-born fungal diseases and suppressed the insect pest populations such as the two-spotted spider mite (*Tetranychus urticae*), mealy bug

(*Pseudococcus* sp.) and aphid (*Myzus persicae*). They also found statistically significant suppression of plant-parasitic nematodes in field trials with pepper, tomatoes, strawberries and grapes. Yardim et al (2006) found that vermicompost suppressed tomato hornworm (*Manduca quinquemaculata*) and cucumber beetles (*Acalymma vittatum* and *Diabrotica undecimpunctata*). The scientific explanation behind this concept is that high levels of agronomically beneficial microbial population in vermicompost protects plants by out-competing plant pathogens for available food resources i.e. by starving them and also by blocking their access to plant roots by occupying all the available sites. This concept is based on 'soil-foodweb' studies pioneered by Dr. Elaine Ingham of Corvallis, Oregon, U.S. (http://www.soilfoodweb.com). Edwards and Arancon (2004 a and b) also studied the agronomic effects of small applications of 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.

Several authors have also reported that the aqueous extracts of vermicomposts depress soil-borne pathogens and pests. They found in their field experiment that only half as many plants of tomatoes sprayed with aqueous extract of vermicompost were infected with *Phytopthora infestans* (that cause 'late-blight' disease) as those of control ones (Sinha and Valani 2011).

Earthworms and Vermicompost Produce Nutritive and Health Protective Organic Foods

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

Studies made at CSIRO (Council of Scientific and Industrial Research Organization), Australia found that the presence of earthworms (*Aporrectodea trapezoids*) in soil lifted protein value of the grain of wheat crops (*Triticum aestivum*) by 12 % (Baker and Barrett 1994). Shankar and Sumathi (2008) studied tomato grown on vermicompost and reported that it had significantly higher total antioxidants, total carotene, iron (Fe), zinc (Zn), crude fibre and lycopene content than the other organically grown tomatoes. Also tomato, spinach and amaranthus grown on vermicompost had significantly higher vitamin C. Vermicompost applied tomato also registered significantly higher 'shelf-life' when stored at room temperature.

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

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

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

Some Studies Proving the Scientific Validity of Earthworms and Vermicompost in Promoting Higher Crop Growth Over Chemical Fertilizers

(1) Kale and Bano (1986) studied the grain yield of rice crops (*Oryza sativa*) on vermicompost and chemical fertilizers and found that rice crops receiving vermicompost @ 10,000 kg / ha were statistically at par with those receiving chemicals @ 200 kg / ha. There were greater population of nitrogen fixers, actinomycetes and mycorrhizal fungi inducing better nutrient uptake by crops and better growth in all vermicompost applied soils. The cost of production is still cheaper as the vermicompost is produced from wastes and chemical fertilizers are several times more costly.

(2) Studies at CSIRO Australia found that the earthworms can engineer growth of wheat crops by 39 %, grain yield by 35 %, lift protein value of the grain by 12 % and fight crop diseases. More significantly, it reduced the demand for water irrigation by nearly 30-40 %.(Baker and Barrett, 1994; Baker et al 1997).

(3) Buckerfield and Webster (1998) found that vermicompost boosted grape yield by two-fold as

compared to chemical fertilizers. Treated vines with vermicompost produced 23 % more grapes due to 18% increase in bunch numbers. The yield in grapes was worth additional value of AU $ 3,400 / ha. Significantly, the yield was greater by 55 % when vermicompost applied soil was covered under mulch of straw and paper. Still more significant was that 'single application' of vermicompost had positive effects on yields of grapes for long 5 years.

(4) Arancon et al (2004 and 2006) studied the agronomic impacts of vermicompost and chemical fertilizers on strawberries. Vermicompost was applied @ 10 tons / ha while the inorganic fertilizers (nitrogen, phosphorus, potassium) @ 85 (N)- 155 (P) – 125 (K) kg / ha. 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.

(5) Webster (2005) studied the agronomic impact of vermicompost on cherries and found that it increased yield of 'cherries' for three (3) years after 'single application' inferring that the use of vermicompost in soil builds up fertility and restore its vitality for long time and its further use can be reduced to a minimum after some years of application in farms. At the first harvest, trees with vermicompost yielded an additional $ 63.92 and $ 70.42 per tree respectively. After three harvests profits per tree were $ 110.73 and $ 142.21 respectively.

We also studied the growth impacts of vermicompost on farm wheat crops in Bihar, India. Vermicompost supported yield better than chemical fertilizers and had other agronomic benefits. It significantly reduced the demand for irrigation by nearly 30-40 %. Soil tests indicated better availability of essential micronutrients and useful microbes. There was significantly 'less incidence of pests and disease attacks' in vermicompost applied crops which reduced use of chemical pesticides by over 75 %

Table 4.
Growth & Yield of Farmed Wheat Crops Promoted by Vermicompost, Cattle Dung Compost and Chemical Fertilizers

Treatments	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	100 Quintal CDC / ha	33.2 Q / ha
4). Chemical Fertilizers	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 +100Q CDC / ha	41.3 Q / ha

Keys:N=Urea; P=Single Super Phosphate; K=Murete of Potash (In Kg/ha)
Source: Sinha et al (2009 a and 2010 a)

Advantages of Vermiculture Agriculture Over Chemical Agriculture

The biggest advantage of great social significance is that the food produced is completely organic 'safe and chemical-free'. Studies indicate that vermicompost is at least 4 times more nutritive than the conventional composts and gives 30-40% higher yield of crops over chemical fertilizers. In Argentina, farmers consider it to be seven (7) times richer than conventional composts in nutrients and growth promoting values (Pajon - Undated). Vermicompost retains nutrients for long time. Of greater agronomic significance is that the minerals in the vermicompost are 'readily and immediately bio-available' to the plants. Chemical fertilizers (and also manures) have to be broken down in the soil before the plants can absorb. The humus in vermicompost also helps chemical fertilizers become more effective (Kangmin 2010).

Vermicompost also has very 'high porosity', 'aeration', 'drainage' and 'water holding capacity' than the conventional compost. This is mainly due to the 'humus content' present in the vermicompost. Thus vermicompost use reduces the requirement of water for irrigation by 30-40 %. Another big advantage of great economic and environmental significance is that production of vermicompost (locally from community wastes) is at least 75 % cheaper than the chemical fertilizers (produced in factories from vanishing petroleum products generating waste and pollution). And over successive years of application, vermicompost 'build-up the soils natural fertility' improving its total physical, chemical and biological properties. On the contrary, with the continued application of chemical fertilizers over the years the 'natural fertility of soil is destroyed' and it becomes 'addict'. Subsequently greater amount of chemicals are required to maintain the same yield and productivity of previous years.

Another advantage of great environmental significance is that vermicompost 'suppress plant disease' in crops and inhibit the soil-born fungal diseases. Vermicompost has a diversity of 30,000 useful bacteria and fungi plus chitin and cellulose degraders which are not present in conventional composts. If vermicompost is dissolved in water and brewed aerobically into 'Vermicompost Tea' (VCT) the useful microbes multiply to 9 billion in 24 hours. This makes VCT more economical for farmers. In field trials with pepper, tomatoes, strawberries and grapes significant suppression of plant-parasitic nematodes has been found. There is also significant decrease in arthropods (aphids, buds, mealy bug, spider mite) populations with 20 % and 40 % vermicompost additions. **(**Edwards and Arancon 2004). Humus in vermicast extracts 'toxins', 'harmful fungi and bacteria' from soil and protects plants. Actinomycetes in vermicast induces 'biological resistance' in plants against pests and diseases. As such use of vermicompost significantly reduces the need for 'chemical pesticides'.

(6) Vermi-Industrial Production Technology : Huge earthworms BIOMASS results in all VERMICULTURE PRACTICES as worms double their population every 60 – 70 days. All species earthworms are potential source of 'BIOLOGICAL RAW MATERIALS' for production of useful 'biodegradable' industrial products and also as valuable source of 'proteins' for production of 'nutritive feeds' for promoting allied 'food industries' like fishery, dairy, poultry and piggery for meat and milk production.

Production of Nutritive Feeds for Fishery, Dairy and Poultry

Earthworms are rich in high quality protein (65 %) and is 'complete protein' with all essential amino acids. There is 70-80 % high quality 'lysine' and 'methionine'. Glumatic acid, leucine, lysine and arginine are higher than in fish meals. Tryptophan is 4 times higher than in blood powder and 7 times higher than in cow liver. Worms are also rich in Vitamins A and B. There is 0.25 mg of Vitamin B_1 and 2.3 mg of Vitamin B_2 in each 100 gm of earthworms. Vitamin D accounts for 0.04 – 0.073 % of earthworms wet weight.

Thus worms are wonderful pro-biotic feed (vermimeal) for fish, cattle and poultry industry (Dynes 2003). Pigs fed with fresh worms at 150 gm per head per day increased in weight gain by 34.6 % compared with pigs that were not fed. Gain in weight of broiler chickens given 14 % vermimeal (of *E. euginae*) in diet was comparable with that of birds fed on commercially produced feeds. Growth of fish was significantly greater with a diet of 15 % vermimeal (of *P. excavatus*) and 10 % fish meal compared to that with 25 % fish meal only. (Guerrero 2005). Earthworms are being used as 'additives' to produce 'pellet feeds' in the USA, Canada and Japan (Kangmin 1998). Since earthworms have a dry matter content of about 18 %, it will take about 5.5 kg of fresh worms to produce 1 kg of vermimeal.

Promotion of Lubricant, Cosmetics, Soaps and Detergent Industries

Some biological compounds especially the fatty acids from earthworms are also finding industrial applications. Being 'biodegradable' they are environmentally friendly and sustainable. 'Stearic acid found in earthworms is a long chain saturated fatty acid and are widely used as 'lubricant' and as an 'additive' in industrial preparations. It is used in the manufacture of metallic stearates, pharmaceuticals soaps, cosmetics and food packaging. It is also used as a 'softner', 'accelerator activator' and 'dispersing agents' in rubbers. Lauric acid and its derivatives have industrial applications as 'alkyd resins', 'wetting agents', a 'rubber accelerator' and 'softner' and in the manufacture of 'detergents' and 'insecticides' (Ang-Lopez and Alis 2005). Worms are also finding new uses as a source of 'collagen' for pharmaceutical industries.

(7) Vermi- Health Protection Technology : Earthworms have been used in traditional medicine for thousands of years in several parts of world. Traditional medicinemen in China, India and Philippines used earthworms in forkloric healings of many human illness. Earthworms have also been used internally and externally as powerful aphrodisiacs. The earthworm protein accelerates growth, develops muscles, puts on weights, covers protein and amino acid deficiency, improves sexual performance, stimulates the appetite and makes feed more attractive. (Vohora and Khan 1978). They also reported that earthworms have healing effects on wounds, chronic folds, piles and soar throat. Balamurugan et al (2007) reported use earthworms in treatment of 'neural disorders', 'bronchitis' and 'tuberculosis'. Scientist have isolated 'bronchial dilating' substance from earthworms. Earthworm extract can also combat 'asthma' (Prakash 2010).

Earthworms can calm down the liver and purge the internal fire in body, with wonderful effect on the stasis in veins. Modern medical science indicates earthworm contains three types of enzymes that can dissolve blood clots. These are, fibrinolytic enzyme, plasminogen activator and collagenase. Oral administration of earthworms powder and enzymes were found to be effective in treating 'thrombotic diseases', 'rheumatism', 'arthritis', 'diabetes mellitus', 'pulmonary heart disease', 'lowering blood pressure', 'epilepsy', 'schizophrenia', 'mumps', 'eczema', 'chronic lumbago', 'anemia', 'vertigo' and 'digestive ulcer' (Mihara et al 1990; Wenling and Sun 2000). Earthworm powder has been used to 'improve blood circulation' and to treat 'apoplectic stroke' from 10th Cent. A.D. They can also heal the damage done to liver and kidney due to alcohol intoxication. (Prakash 2010).

Several of the above medicinal properties of earthworms have now been scientifically verified. Researchers at Quinghua University, China has extracted 4 valuable medicinal compounds from earthworms – a large molecular compound which has 'anti-carcinogenic' effects; medium molecular compound which has 'anti – thrombosis' and 'thrombus dissolution' effects; a small molecular compounds which contain 17 kinds of amino acids, polymers, trace elements and vitamins; and a 4th product which can cure burns and scalds (Kangmin 1998).

Current researches made in U.S., Canada, China and Japan on the identification, isolation and synthesis of some 'bioactive compounds' from earthworms (*Lumbricus rubellus* and *Eisenia fetida*) with potential medicinal values have brought revolution in the vermiculture studies (Wang 2000). Some of these compounds have been found to be enzymes exhibiting 'blood clot dissolving' and 'anti-blood clotting' effects. The coelomic fluid in earthworms is reported to have wide variety of biological actions on human beings including cytolytic, haemolytic, agglutinatic, proteolytic, mitogenic, anti-pyretic, tumorostatic, bacteriostatic and anti-microbial activities. (Stein and Cooper 1988). The earthworm's 'anti-oxidant', 'anti-microbial', 'anti-cancerous', 'immune-boosting' and 'clot dissolving' MEDICINE CHEST is so powerful as that of any plant and even many pharmaceuticals.

Cure for Heart Diseases

Earthworms makes very big promise for cure of 'heart diseases' by acting as an 'anti-coagulating agent' and 'dissolving fibrin' in blood that forms 'blood clots' in arteries. They have been suspected to contain the enzyme 'proteases' which specifically dissolve the fibrin clots or anti-coagulants which selectively interfere with the intrinsic pathway of the bood coagulation cascade. Study indicated that the DNA (with around 72 base pairs) of the earthworm *Lumbricus rubellus* is responsible for the anti-coagulatory effects. It is an excellent source of 'proteases' with very high fibrinolytic activities. (Seung et al 1997). Lumbrokinase (LK) derived from earthworms *Lumbricus rubellus* has potent fibrin-dissolving properties, 'lower blood viscosity' and markedly reduce 'platelet aggregation'. It also 'inhibits the coagulation pathway' and activates fibrinolysis by increasing t-PA activity. (Cooper 2009). Charles Darwin (1881) also described in his book that earthworm digestive fluid can dissolve 'fibrin' in blood.

Recent researches suggest that it may be effective in treatment and prevention of 'ischemic heart disease' as well as 'myocardial infarction', 'embolism' of peripheral veins, and 'pulmonary embolism'. In a study at Harbin Medical University, China (2006) heart attack was induced in rats by permanently clamping shut the 'left anterior descending coronary artery'. A dose-dependent administration of LK decreased the size of infarction. (Qingsui 2003; Cooper 2009)

Cure for Cancers

Cooper (2009) reported that he was never been able to 'induce cancer' in earthworms despite irritating them. That was very remarkable observation and inspired him to probe further. He found that earthworms 'leukocytes' can recognize human cancer cells as 'foreign' and can kill them. Electron microscopy showed an astonishing cinematography of 'earthworms cells' becoming incredibly active, throwing out 'pseudopodia', and literally tearing apart 'cancer cell membranes' from a human cell cancer line named K 562. A peptide 'Lombricine' isolated from *Lumbricus terrestris* by Japanese scientists in 1991 has been shown to 'inhibit growth of spontaneous mammary tumors' in mice. Daily subcutaneous injections of lombricine (0.3 mg/0.05 ml olive oil) markedly slowed down the growth of tumors. Lombricine given orally (120 mg/kg) as a part of the diet also slowed the growth of tumors though to a lesser degree. Injection was most effective and prompt in action. (Nagasawa, et al 1991). One killer 'glycolipoprotein' extract called G-90 retards tumor growth in mice. Chen et al (2007) have studied and confirmed that earthworm 'fibrinolytic enzymes' showed significant anti-tumor activity in hepatoma cells both *in-vitro* and *in-vivo*, due to apoptosis of hepatoma cells and inhibit the expression of MMP-2 gene.

Commercialization of Vermi-medicines from Earthworms

In 1997, a 'Fibrinolytic Product' made from earthworms, named PLASMIN, was approved by the Chinese government as a new medicine. In 1999, the China Medical Society made Plasmin a key product to be promoted all over China. In 2000 it was included in the Chinese National Pharmacopoeia. Canada has also produced this medicine. The commercial name of this product is BOLOUAKE in Canada. (Titov et al 2007).

Shanxi Zhong Yuan Wei Pharmaceutical Co. Ltd. in China has produced 'THROMBOLYTIC CAPSULES'. The Drug Approval Number is 'National Yaozhun Zi Z10960063'. The drug is used for the treatment of fever, sedatives for the treatment of convulsions, stimulating the flow of meridians and collaterals, for stroke, hemiplegia, numbness and hypertension. The drug is to be taken orally 2-3 capsules three times a day before meals. (Kangmin 1998).

This product contains enzymes that can dissolve blood clots. Animal thrombosis test proved that rabbits after treatment can recanalize the blood embolization in 5 hours. The results of the human body test show that the dissolution time of plasma euglobulin after oral intake was significantly shorter, indicating the product has significant thrombolytic effect.

VERMIVIT is an alcoholic extract from the earthworms tissues (*E. fetida*). It is rich in protein concentration with 17 microelements, vitamins and essential amino acids. This preparation is being used to treat 'shotty breast' for which there is no modern medicine to cure the afflictions except surgically.

Earthworms Help Reduce Emissions of Greenhouse Gases, Mitigate Global Warming and Climate Change

(1) Reduce GHG Emissions in Solid Waste Management Programs : Waste landfills are proving to be an economic and environmental burden on society. Waste management by vermicomposting can divert huge amount of wastes from landfills. Landfills emit huge and more powerful greenhouse gases methane (CH_4) and nitrous oxides (N_2O) which are molecule to molecule 22 times and 312 times more powerful in absorbing solar radiations than carbon dioxides (CO_2). Every 1 kg of waste diverted from landfills prevents 1 kg of greenhouse gas emission equivalent to CO_2. In 2005, landfill disposal of MSW contributed 17 million tons CO_2-e (equivalent) of GHG in Australia, equivalent to the emissions from 4 million cars or 2.6 % of the national GHG emissions. (Australian Greenhouse Office 2007).

Studies have established that vermicomposting of wastes by earthworms significantly reduce the total emissions of greenhouse gases in terms of CO_2 equivalent, especially nitrous oxide (N_2O) which is 296-310 times more powerful GHG than CO_2. Our studies showed that on average, vermicomposting systems emitted 463 CO_2-e / m^2 / hour respectively. This is significantly much less than the landfills emission which is 3640 CO_2-e /m^2/hour. Vermicomposting emitted minimum of N_2O – 1.17 mg / m^2/ hour, as compared to Aerobic Composting (1.48 mg / m^2/ hour) and Anaerobic Composting (1.59 mg / m^2/ hour). Hence, earthworms can play a good part in the strategy of greenhouse gas reduction and mitigation in the disposal of global MSW.(Sinha et al 2009 b; Chan et al 2010; Sinha et. al 2012 b).

(2) Reduce GHG Emissions in Wastewater Treatment Programs : All conventional wastewater treatment systems such as the 'Activated Sludge', 'Aerated Lagoons' and 'Rotating Biological Contactors' etc. are high energy (electricity) requiring processes emitting proportional GHGs. The degradation of 'organics' in the wastewater and slurry emits huge amounts of powerful greenhouse gases methane (CH_4) and nitrous oxides (N_2O) and also ammonia (NH_3) which creates foul odor.

Studies done at Rennes University, France on effects of earthworms on gaseous emissions during vermifiltration of animal wastewater indicates that earthworms decrease the emissions of methane and nitrous oxides and also ammonia. More the population of earthworms in the vermifilter bed lesser is the emissions of those gases. (Luth et al 2011).

(3) Sequester Carbon Back into Soil in Agriculture Development Programs : Much of the world's carbon is held in the soils, including the farm soils as 'soil organic carbon' (SOC). The global pool of SOC is about 1,550 Pg C (1 Pg= 1,000 million metric tons or MMT) i.e. 41 %. The loss of SOC as CO_2 due to aggressive 'ploughing and tillage' in the wake of modern chemical agriculture and mechanized farming practices has augmented the atmospheric carbon pool as greenhouse gas further inducing the global warming and climate change. Of the increase of atmospheric carbon over the last 150 years, about a third (33.3 %) is thought to have come from agriculture (Robbins 2004). Australia has 473 million hectares of agricultural land and emitted 537 million tones of CO_2 in 2009. (Leu 2011).

All over the world agricultural and environmental scientists are trying to reverse the trend by putting more carbon back into the soil – a process called 'carbon sequestration' through the use of all composts including earthworms vermicompost. Earthworms secrete 'humus' and hence the vermicompost contains more 'stable forms of carbon' as 'humates' which remains in the soil for long periods of time. Compost use in farms would 'sequester' huge amounts of atmospheric carbon (CO_2) and bury them back into the soil, mitigate greenhouse gases and global warming. Composts are in fact disintegrated products of 'plant biomass' which are formed from atmospheric CO_2 fixed during photosynthesis by green plants. Plants absorb atmospheric CO_2 and converts them into 'plant material' (biomass) in sunlight. The Intergovernmental Panel on Climate Change (2000) recognized that carbon (C) sequestration in soils as one of the possible measures through which the greenhouse gas (GHG) emissions and global warming can be mitigated. Applying composts to agricultural lands could increase the amount of carbon (C) stored in these soils and contribute significantly to the reduction of GHG. Application of composts to the soil can lead either to a build-up of soil organic carbon (SOC) over time, or a reduction in the rate at which soil organic matter (SOM) is being depleted from soils – thus benefiting the soil and the environment in every way (Bolan 2011).

Conclusion:

All vermiculture technologies – vermicomposting (for solid waste management), vermifiltration (for wastewater treatment), vermiremediation (for land and soil decontamination) and vermiagroproduction (use of vermicompost for farm production) can be used as most economical and sustainable alternatives to some of the 'environmentally unfriendly' civil engineering methods to achieve those objectives of development while also significantly reducing waste and pollution and the emission of green house gases (GHG). Accounting for the emission of GHG which induce 'global warming' has become essential in all modern developmental programs.

Vermiculture is a growing industry all over the world and a 'waste-less' enterprise as all by-products (earthworms biomass) and end products (nutritive vermicompost, treated clean and nutritive water and remediated fertile land and soil – all disinfected and detoxified) are economically 'useful'.

Earthworms are truly justifying the beliefs and fulfilling the dreams of Sir Charles Darwin who called them as '*unheralded soldiers' of mankind*' and '*friends of farmers*' and said that '*there may not be any other creature in world that has played so important a role in the history of life on earth'*. They are also justifying the beliefs of great Russian scientist Dr. Anatoly Igonin who said '*Nobody and nothing can be compared with earthworms and their positive influence on the whole living Nature*. *They create soil and improve soil's fertility and provides critical biosphere's functions: disinfecting, neutralizing, protective and productive'*.

World knew about the traditional roles of earthworms in farm waste management and farm production, but the 'new discoveries' about their role in vermicomposting of hazardous wastes (sludge and fly-ash), treatment of 'wastewaters' (even toxic industrial wastewater), 'chemically polluted soils', and more recently about their uses in lubricant, detergent, feed and pharmaceutical industries for developing 'life-saving medicines' have brought a revolution in the vermiculture studies. The earthworms truly combines the attributes of both 'environmental and civil engineers' and a 'producer and protector' for human civilization.

If the researches into their 'bioactive compounds' is successful in 'waging a war on cancer', it will be the biggest scientific achievement of the new millenium for mankind, much bigger than the moon landing of 1969 and a great tribute to the 'father of modern biology' Sir Charles Darwin.

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