Earthworms as Engineers of Soil and Human Health

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Abstract**—**Fungi are active degrading initiators of organic matter in soils as many substrates are first populated by sugar fungi e.g., Mucorales. Vermicomposting is now well known and is generally a good organic fertilizer majorly populated by bacteria i.e., nitrogen fixers, sulphur bacteria and phosphate solubilizers. The use of vermicompost in introducing these components into the soil leads to improvement of soil health thereby yielding nutritious food which consequently contributes to human health. A number of organic foliar sprays constitute of components similar to plant growth promoter substances. For example, vermiwash is a good liquid fertilizer proven to harbor plant growth promoting substances. Humification may be supported by vermiwash which also, by virtue of its quality may increase microbial actions to produce enzymes and compounds promoting plant growth. The compounds present in vermiwash may not independently foster plant growth but possibly promote plant growth along with beneficial soil microbes. These products are known to improve soil health and in presence of other products i.e., Gunapasela and Panchagavya can offer healthy nutrition from soil to plant. In recent times, insistent use of soil pollutants in forms of chemical fertilizers as against organic practices has negatively impacted surrounding soils, and in extreme cases surface and groundwater reserves. Lately, genetically modified substances (GMS) are used to nurse plants (with consequential impacts on the soil and invariably on human health) in contrast to, organic measures which nurses the soil (improving cluster of biotic elements and nutrients proportionately mixed) for uptake by plants, consequently leading to healthier soils and food produce beneficial for human health. For this reason, the paper highlights the efficacy of earthworms as a sustainable eco-friendly option constructively engineering soil and human health with minimal environmental and ecological impact.

Index Terms**—***Earthworms, Vermicompost, Soil health, Human health, Genetically Modified Substances (GMS)*

I. Introduction

TYPICALLY soil is seen as a formation of natural deposits metamorphosized into weak or solid strata. The presence of organic matter together with actions of micro and macro organisms gives soil its dynamic nature. As such, the rich presence of these microbes in soil is considered to give life to the soil. Numerous soil organisms i.e., earthworms, fungi, bacteria, springtails, mites, millipedes, slugs, beetles, nematodes etc., engineer countless biochemical changes from the decomposition of waste and organic matter. Considering the hosts of organisms present in soil contributing to soil health, it is importantly noted as recorded by [1] that earthworms play the most significant role in soil fertility. Modern day agriculture sees soil fertility through the eyes of genetically modified substances (GMS) and mistakes it for soil behaviours under the influence of chemical fertilizers, disregarding the impact it has on soil and human health in the long run. However, in actual sense, soil fertility in a natural organic setting is the inbuilt ability of soil to deliver proper and proportionate nutrients to plants in sufficient quantities. Therefore, soil health becomes associated with the natural display of soil behaviour in the absence of chemical additives while soil productivity becomes linked to soil capability to yield crops. As defined by [1] soil is a unified body of active and functional structures operating through myriad living organisms in which by virtue of man-based agro-ecosystems, necessitates drastic conservation and management. Soil health as earlier stated is the ability of the soil to naturally operate as an active living system towards supporting plant and animal productivity. Ideally, the abundance, stability and diversity of soil microbes act as key pointers to soil health which in essence, determines the level of soil fertility [2]. On the contrary, in modern agriculture more importance is attributed to soil fertility through GMSs which negatively impacts human and environmental health while little or no attention is given to soil health which inherently possesses the means for soil to maintain its living nature thereby, positively impacting human and environmental health from engineered soil-plant interaction. This paper therefore, posits the efficacy of earthworms in engineering soil health geared towards improved human health as a sustainable eco-friendly option with minimal environmental impact.

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II. BIOTIC COMPONENT OF SOIL

A. Earthworms as a Major Soil Biota

With respect to soil formation, earthworms are a special and one of the most important biotic components of the soil as they maintain the soil structure and improve soil fertility. Earthworms are enormously significant in soil formation as described by [3], primarily by their consumption and fragmentation of organic matter as well as the thorough integration of the fragments with mineral particles to create water stable aggregates. When earthworms feed, they trigger and highly support microbial actions by several orders of magnitude, thereby accelerating the breaking down and stabilization rates of organic matter. Microorganisms are the ultimate decomposers and mineralizers in the waste food-chain and in the degradation of humic fractions. Decomposers are organisms that break down dead or decaying matter and are heterotrophic in that; they utilize organic substrates to get their energy, carbon and nutrients for growth and development. Mineralizers however, are additives that abet solubilization of the nutrient solid and function as catalysts when utilized in small amounts [4]. The dormant microorganisms in soils are stirred to live by earthworms which supplies in their gut organic carbon, moisture, optimum temperature and pH for their duplication. As recorded by [5] microorganisms are excreted in casts and also harbored in the drilospheres; with the fresh casts, urine, mucus and cavity fluid rich in the worm-churned soil and burrows acting as stimulant for the multiplication of dormant microorganisms in the soil. They also become responsible for constant release of nutrients which then supports root growth, healthier and sustainable rhizosphere and ultimately healthier impact on human and environmental health.

B. Microorganisms as Degraders of Organic Matter

Fungi, bacteria and actinomycetes (formerly regarded as fungi) are microorganisms that majorly influence the degradation of organic matter. When microorganisms commence composting through enzymatic decomposition of detritus, they first attack the most abundant substrates i.e., sugars and starch. These attacks cause an increase in temperature and a decrease in pH as a result of their metabolic activities. However, the pH then increases over the next level of protein and nitrogen substrate activities which continue till the thermophase is reached and afterward the pH decreases to a neutral phase [6]. The appearance of microorganisms on substrate is time dependant. This sequential appearance of microorganisms on substrate over time is therefore termed succession as defined by [1]. In the vermicompost- final product, formed either *in-situ* or *ex-situ* as explained by [7], the chief decomposers are bacteria composed of dense population of sulphur bacteria, phosphate solubilizers and nitrogen fixers. The next dense population of earthworm compost is the actinomycetes which adds to the decomposition of humic fractions and are mainly responsible for the binding property of the soil. This binding effect is delivered through threadlike filaments known as hyphae produced by the bacteria. As further explained by [7] the level of soil health is strongly associated with the compound called geosmin produced by many of the actinomycetes. Geosmin is an organic compound with a distinct earthy flavor and aroma produced by a type of actinobacteria and it is known to be responsible for the earthy taste of beetroots as well as a contributor to the petrichor (pleasant smell) that often accompanies the first rain after a long period of warm, dry weather or emanated from the agitation of soil which gives an indication of its rich presence and health of the soil [7]. Many substrates are first populated by sugar fungi e.g., Mucorales as fungi are known to be active degraders of humic fractions in soils. They possess the ability to rapidly sporulate on simple soluble sugars and nitrogen sources. While algae are the oxygenic phototrophic organisms that account for ≥ 40% of the yearly total C fixed. As reported by [1] blue green algae (BGA) are found in vermicompost and when introduced into the soil, beneficially engineer soil health towards yielding nutritious food produce which consequently contributes to human health when consumed as well as have little or no impact on the immediate environment, as against the effects of GMSs when used in food produce and soil improvement. Naturally, most foliar sprays can be harnessed as sustainable eco-friendly technologies as they can be prepared from cheap and local resources. Particularly, the organic ones are known to possess several components similar to substances in plant growth promoters as in the case of vermiwash seen in Table I. Vermiwash for example, is a liquid fertilizer as recorded by [3] formed out of cheap local resources that have found ultimate relevance towards improved soil and human health, as research by [4] have shown the active presence of plant growth inducing substances.

TABLE I
ORGANIC COMPOSITION OF VERMIWASH [1]

No	Compound	**GC Retention Time (min)	Chemical Formula	**Molecular Weight (g/mol)
1	2-(4-methyl phenyl) indolizine	19.3	$C_{15}H_{13}N$	207.3
2	Decanoic acid, ethyl ester	20.0	$C_{12}H_{24}O_2$	200.3
3	1-methyl-2-phenyl-indole	27.1	$C_{15}H_{13}N$	207.3
4	Pentadioic acid, dihydrazide N2,N2'-bis(2-furfurylideno)*	31.2	$C_{15}H_{16}N_4O_4$	316.3
5	Methyl 2-(4-tert- butyl phenoxy) acetate*	33.4	$C_{13}H_{18}O_3$	222.3
6	2-methyl-7-phenyl-1H-indole	29.8	$C_{15}H_{13}N$	207.3

*Presumed; **Approximate values

According to [8] indone compounds separated in vermiwash have about 3 isomers namely; 2-(4-methylphenyl) indolizine- which is an alkaloid plays a vital role as plant growth promoter. Fatty acid from earthworm cavity known as capric acid was separated at an approximate retention time of 20 min and was reported that in minute concentrations plays a crucial role in promoting plant growth. Methyl 2-4(-tert-butylphenoxy) acetate belongs to the ring-substituted phenoxy aliphatic acids known to generally exhibit strong retarding effects on abscission (the natural detachment of parts of a plant, typically dead leaves and ripe fruit) thereby, promoting plant growth. Also as reported by [4] the innate features of vermiwash triggers increased microbial action and humification as such, produces enzymes and compounds that induce plant growth. Furthermore, Maleic acid according to [9] is also a vital promoter of plant growth. These active ingredients found in vermiwash may not trigger plant growth individually however; in unison with favorable soil microbes found in vermiwash can act positively. These products engineer soil health and in combination with other ingredients as noted by [1] i.e., Panchagavya, Gunapasela or fish-amino etc., can supply healthy nutrition to the plant via the healthy soil which consequently impacts human health. Hence, as rightly expressed by [1] "*in organic farming practice we do not nurse the plant, we nurse the soil*" by so doing, the soil in turn triggers its group of biotic components to mix and supply the appropriate nutrients desired for food produce which eventually becomes beneficial to human health when consumed. More to this, phytonutrients (a substance found in certain plants believed to be beneficial to human health and help prevent various diseases), e.g., polyphenols and antioxidants, protect both people and plants [1]. However, chemical based pesticides among other negative effects on soil and the environment have been recorded to hinder the ability of plants to manufacture these important plant compounds necessary for soil health. Nevertheless as reported by [10] NCBT01 (*Jeysai*), a mixture of ginger garlic asafoetida (a smelly resinous gum obtained from the roots of a herbaceous plant, used in herbal medicine) and cow's urine has proven effective in the control of root grubs saving ≥ 25% of chemical cost as well as lowering the detrimental effects on human and environmental health.

III. VERMICOMPOST AS ORGANIC FERTILIZER

A. Earthworms as engineers of vermicomposting

Out of the myriad species of earthworms the world over, ≥ 6000 species have been successful identified. These can be broadly divided into two main groups: -

1. Those that live in humus on top soils (mainly called compost worms); and
2. Those that live in the soil at different depths (called tunneling worms).

It is noted that neither of this two groups can survive for long in the other's environment. In India where vermitech using local species of earthworms (vermes=earthworms; tech=technology) is widely practiced, ≥ 509 earthworms have so far been identified and the epigeics from garden soils becomes visible after the monsoon season. For example, *Perionyx excavatus* and *Lampito mauritii* are common local earthworm species used in vermicomposting. These soil and human health engineers as specified by [3] can be cultured or used in composting by applying simple practices i.e., in tanks, pits, concrete rings or crates. In South Africa however, ≥ 320 of these two groups have been successfully identified, including one of the longest species on the planet, up to 7m in length in some specimens [11]. All earthworms produce vermicast- "*worm poop*" (also called worm castings or manure, the end-product of broken-down organic matter by earthworm as seen in Fig. 1. These castings have been shown to contain reduced levels of contaminants and a higher saturation of nutrients than do organic materials before vermicomposting) and vermitea- "*worm pee*" (also referred to as worm tea, is a liquid product made by steeping or brewing the compost in water as shown in Fig. 2, but it is sometimes erroneously referred to as worm leachate) both of which improve soil structure, soil fertility, soil health and invariably human health [12].

Fig. 1. Earthworm broken-down organic matter to *worm poop*

Fig. 2. Product of steeping compost in water as *worm pee*

Earthworms are one of the few if not the only creatures known to man on earth that takes in rubbish and passes out healthy material. Nevertheless, how well have these natural resources been harnessed? Let us see: - for instance, in Montelimar, France, 35000kgs of organic waste is collected daily by the Sovadec Institute for Organic Technology. This is converted by earthworms to 25000kgs of vermicasts daily, used to produce soil conditioners, germination media, potting soil and other worm-based products. These products are used to grow large quantities of organic vegetables and cut flowers for the open market which helps to keep waste management costs at bearest minimum for the township. In India, the M.R. Morarko Research Foundation have in recent years enabled ≥ 300 000 subsistence farmers reduce their overall production costs by ≥ 20% under 5 years by teaching them how to practice vermiculture. These has also led to a substantial increase in crop production, while improving soil health, quality and shelf life of crops and ultimately, improve human health. Earthworms, dried and powdered, are a source of protein-rich food for livestock and pets, while all anglers know that fresh worms are a delicacy for most fish species. Again, in India, the Bahawalkar Earthworm Research Institute in Pune State has designed and built many thousands of waterless toilets in which earthworms convert human waste to fertile worm castings. The same Institute also operates vermifilters which as recorded by [11] (they claim) converts raw liquid sewage into water fit for human consumption with the processes occurring in a very hot and dry region. Furthermore, in Israel, several kibbutzim (collective farms and settlements) have over the years used earthworms to improve soil health, soil structure water retention and aeration. In Russia also, vermiculture is practiced on a massive scale, even more than in U. S. A. In a special case, it was reported that earthworms were used to engineer the clearing of toxic waste after the Chernobyl disaster. Scientists in Wales have also successfully used earthworms to remove contaminant heavy metals from old abandoned mines which helped improve the health of inhabitant's in areas of such activities. More to this, in Australia, significant research has been done on utilizing earthworms as engineered converters of organic "wet waste" into vermicompost [11]. The University of New South Wales is a leader in this research niche. They set up a unit called the Recycled Organics Unit (ROU) to establish how to run large scale waste recycling efficiently. ROU has produced a booklet "Best Practice Guidelines to Managing Vermiculture Technologies," which is an excellent blueprint for large-scale organic waste management. In Southern Africa however, despite the abundance of this natural resource, little has been achieved with respect to this eco-friendly practice. In fact, since late 2007 as indicated by [11] vermiculture practices have grown at such a tremendous rate that earthworms cannot be produced fast enough to keep up with the demand.

Therefore in Southern Africa and other countries lacking in this area, a lot more research into "native" worm species indigenous to respective regions is dire for the conservation of this natural resource and the environment, and towards improved soil and human health.

B. Earthworm Species and Succession in Vermicomposting

On the internationally scale, three species of earthworms are recognized for vermicomposting namely; *Eisenia fetida*, *Eudrilus eugeniae* and *Lumricus rubellus*. The process of composting as recorded by [1], although shows the occurrence of different microorganisms i.e., bacteria, phosphate solubilizers, fungi, actinomycetes and the microorganisms involved in the Nitrogen cycle; succession is shown in the quantity of microbes reliant on the nature of the substrate, the age of the compost, the ambience created by the existing microbes to its successors and also the physical and chemical characteristics. The majority of the microorganisms in the initial stages of composting are the heterotrophic bacteria, which depend on oxidation of the large amount of organic C which reduces during the thermophilic phase till the biodung compost formed. At this point, vermicompost increases as a result of the passage of the material through the earthworm and the presence of the assimilable C, in the cavity and the cast of the earthworm [13]. Also, the role of microorganisms in the Nitrogen cycle is very pertinent such that, there is heightened presence of ammonifiers in the primary stage of composting which relates with the high amount of protein break-down and microbial actions to lower C: N. However, nitrifiers are increased from commencement of the processes to finish with the products of ammonifiers creating environment for multiplication of nitrifiers which utilizes ammonia and transforms it to nitrite and nitrate. To substantiate this as per [14], extra-cellular ammonia-nitrogen decreases progressively from the early higher values during the entire composting process while the ammonification process is reported to increase due to high temperature. Nitrification potential as indicated by NO_2-N decreases with composting time as observed by [15], while the NO_2 production decreases to stable low levels during the later stages of composting till no further decomposition occurs as C: N ratio stabilizes. The NO_3 production has been reported to increase till $\geq$ 14 days of composting after which it decreases till $\geq$ 35 days; which is plausibly accounted for by the high temperature as nitrification is inhibited by high temperature and also gives a clear indication of microbial immobilization [16]. The dominance of the extra-cellular production of NO_3 on the worm churned vermicompost could be proof for enhanced nitrifier activity. Generally, the amount of phosphate in compost samples till formation of vermicompost progressively increases from start to finish which could be reasonably accounted for by the increased phosphatase (an enzyme that catalyzes hydrolysis of organic phosphates in specified acidic or alkaline conditions) action in vermicompost as earthworm (vermicast and vermitea) displays higher phosphatase activity [17]. As recorded by [1] it is also noted that PO_4 production shows a reduction $\geq$ 21 days into composting which relates that high NH_4^+ concentration impedes the P fixed [18]. With respect to succession, ammonifiers which are the main organic N colonizers are replaced by the nitrifiers and phosphate solubilizers such that, phosphate solubilizers progressively increase throughout the process. Oxidation of sulfur and sulfate compounds as indicated by [1] are elaborated by aerobic autotrophic organisms i.e., *Thiobacillus thiooxidans* and *Thiobacillus thioparus,* found in vermicompost and considered to be responsible for the amelioration ability of vermicompost on saline soils. Also, population density of actinomycetes increases from the process start to finish with an exception in the thermophilic stage where a level of reduction occurs. Furthermore, actinomycetes occur after available substrate dissolves at the initial stages and is colonized in the decomposition stage towards compost maturity. In addition, as observed by [1] the optimum temperature of actinomycetes is 40-50ºC which correlates to lignin degradation temperature in compost. However, the fungal density is reported to drop as composting progresses. The Mucoraceous group of fungi normally called sugar fungi in conformance with nutritional theory is present at the start and early stages of composting whereas, the dominant *Aspergillus* species are chief to the degradation of initial organic C as they are known to enhance cellullases and hemicellulases. Lignolytic fungi *Coprinus* sps mainly colonizes compost at the later biodegradation stages of complex organic matter. The thermophilic fungi however, show increase in density and diversity across the thermophilic phase thus, causing a faster degradation rate of lignin, pectin and cellulose with respect to high temperature. Potential biocontrol agents i.e., *Trichoderma viridae* and *Trichoderma harzianum* are found during composting and also highly present in the vermicompost. The density and diversity of algae is noted to steadily increase till the vermicompost is formed. Finally, the pertinent presence of algae e.g., *Nostoc* sp *Oscillatoria* sp and *Anabaena* sp cannot be overemphasized in that, they are known to enhance soil fertility towards nutritious crop yield for improved human health [19].

IV. CONCLUSIONS

This paper indicated the importance of earthworms as engineers of soil and human health. It has been noted that in the absence of GMS and soil enhancing chemicals (that contributes to crop, soil, surface and groundwater contamination) healthy-fertile soils promote healthy crop produce which invariably, promotes healthy living for humans and the environment. As such, harnessing earthworms particularly in Africa with wide biodiversity is pertinent for improved human and environmental health, carbon footprint reduction and conservation of the eco-system. Hence, the following conclusions were reached:

- That earthworms are abundant natural resources that can be harnessed through vermiculture towards engineered revitalization of soil for improved agri-practices particularly in African countries.
- That the recognition and utilization of botanical resources for pest control and composting can improve the economic conditions of local farmers while promoting soil and human health through cheap and eco-friendly technology.

- Also, in unison with soil biotic conditions, organic input can tremendously augment the quantity and quality of crop produce towards improved health and sustainability.
- Additionally, the involvement of government parastatals and agro-industries can influence decisions and policies towards eco-system conservatory needs through vermiculture.

Finally, the aforesaid large worm species found near King William's Town are not quit known by most South Africans as such, more research and sensitization is required on the value of vermiculture. Also, since almost all plants require soil to survive and produce, it is imperative we take proper care of the soil. This becomes a way of ensuring that plants needed by humans and animals survive and are conserved. The on-going degradation of soil by injudicious chemical agri-practices is a thing of concern as it destructs soil biota and causes contamination of ground resources. Among the most consequential impacts of these practices, is the decline in earthworm population that possesses the natural ability to rebuild the soil. Therefore, regardless of how little a garden or how vast a farm, owners are charged with the responsibility of enhancing soil quality or maintaining high level of soil health. Since it is true that "*earthworms are the pulse of the soil- the healthier the pulse, the healthier the soil*". This is achievable by simply incorporating earthworms into the humus layer above the soil or ensuring the right conditions for them to flourish. In this light, the Earthworm Interest Group of South Africa stand to educate, promote healthy soil –use techniques and foster interest, knowledge and further research into vermiculture and its benefits to mankind. Thereby, help growing numbers of people produce more and better food while reducing their individual carbon footprints.

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