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Review

Impact of Vermicomposting on Greenhouse Gas Emission: A Short Review

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Abstract: The implementation of cutting-edge agricultural practices provides tools and techniques to drive climate-smart agriculture, reduce carbon emissions, and lower the carbon footprint. The alteration of climate conditions due to human activities poses a serious threat to the global agricultural systems. Greenhouse gas emissions (GHG) from organic waste management need urgent attention to optimize conventional composting strategies for organic wastes. The addition of various inorganic materials such as sawdust and fly ash mitigate GHG during the vermicomposting process. This paper critically investigates the factors responsible for GHG emissions during vermicomposting so that possible threats can be managed.

Keywords: vermicomposting; greenhouse gas emissions; carbon sequestration

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1. Introduction

The changing temperature conditions, precipitation variability, and the incidence of extreme weather events are increasing day by day throughout the world, including the Indian subcontinent [1]. The Paris Climate Conference (COP21) created the goal of limiting the amount of heat-trapping gases, i.e., carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases (F-gases) emitted globally. The largest climatic impacts will be greatest in those regions where agricultural production is vital for securing livelihoods and promoting economic growth [2]. Soil is a major source and sink of greenhouse gases, producing approximately one-fifth of global CO_2 emissions [3], roughly one-third of global CH_4 emissions, and two-thirds of N_2O emissions [4]. The green revolution has increased global food production which indirectly increased the dependence of farmers on synthetic chemical fertilizers, pesticides, and insecticides. The repetitive use of chemical fertilizers causes severe environmental and land degradation. Vermicomposting is an integrated biological process of converting organic waste into vermicast by employing earthworms and naturally occurring microbes under a mesophilic environment. Vermicomposting has been reported as a sustainable technique for the treatment and management of different organic wastes [5]. Earthworms increase the bacterial abundance in the soil as their gut conditions are favorable for the multiplication of bacteria and the suppression of fungi [6].

The burrowing action of earthworms efficiently maintains anaerobic conditions in vermibeds and thereby lowers greenhouse gas emissions [7]. The emission of greenhouse gases during vermicomposting has only been documented recently [8–10]. The effects of the presence of earthworms during vermicomposting on greenhouse gas emissions have not been analyzed specifically, but a study reported that the vermicomposting of household waste emitted more CO_2 and CH_4, but less N_2O than traditional composting [11]; however, Yang et al. reported the positive role of earthworms in reducing gaseous emissions in vermicompost [12], resulting in fewer emissions of NH_3 and total greenhouse gases (8.1 kg CO_2-eq/t DM) than those from thermophilic compost. The earthworm addition during composting showed less gas emission from animal manure [13,14], however, another study [15] reported more greenhouse gas emissions compared to conventional composting. Thus, the aim of the present review is to provide an inclusive outline of the factors and conditions accountable for greenhouse gas emissions during the vermicomposting process so that this environment-friendly process can be optimized with comparatively less emission.

2. Vermicomposting

Vermicomposting is an eco-friendly technique that utilizes earthworms, soil microbial flora, and a few endemic gut flora of earthworms to convert solid and other agri-waste into vermicast. The earthworm gut is anoxic and has an elevated amount of water, sugars, organic and amino acids, thus providing the best environment for various microbial flora such as cellulitic, denitrifying bacteria, chitin degraders, ammonia oxidizers, and nitrogen fixers, etc. The decomposition of organic waste into nutrient-rich vermicast is mediated by the burrowing, gut digestion, casting, and mucus secretion of earthworms during the vermicomposting process [16]. Several studies have reported that vermicompost is a rich source of P, N, K, Mg, Ca, and S that, in turn, improves soil health and that plants can easily uptake these nutrients [17]. Vermicompost also acts as a biocontrol agent as it contains antagonistic microorganisms to control phytopathogens [18]. The tremulous urbanization thrust toward worldwide economic development leads to the huge production of both municipal and industrial waste per capita and creates an uncomfortable situation for waste management. Waste management in landfills releases huge greenhouse gases around 3640 mg CO_2-e/m^2/hour, whereas vermicomposting emits only 463 mg CO_2-e/m^2/hour [19]. The Australian Bureau of Statistics in 2005 reported that 17 million tons of greenhouse gases were emitted in Australia due to landfills in the year 2005. Waste management practices were next to agriculture in enhanced greenhouse gas emissions (GHG) that need urgent attention [7]. Vermicomposting of various organic wastes emits unpredictable amounts of CO_2, CH_4, and N_2O based on their C and N content. Though vermicomposting is an environmentally friendly and sustainable approach on a large scale, it is still associated with the high emission of greenhouse gases. There are reports that vermicomposting lessen methane emissions in comparison to composting [20,21] and it was reported that the emission of CH_4 and N_2O reduced to 32% and 40%, respectively, with high moisture content, whereas the emission reduced to 16% and 23% at low moisture condition [13]. A recent study by [22] explained that earthworms played a positive role in soil carbon mineralization by employing a statistical model and revealed a 24% increase in carbon mineralization in the presence of earthworms with 1.95 mg/g soil dry mass earthworm density. Two important factors that affect soil carbon mineralization are earthworm density and time from their inoculation [22]. Greenhouse gas emissions could be mitigated by maintaining aeration, moisture content, and temperature in the vermicomposting peats. The greatest advantage of vermicomposting over conventional thermophilic composting is that it can be used immediately after its production.

3. Greenhouse Gas Emissions by Organic Waste Management

Greenhouse gas emission is one of the foremost problems connected with waste management; CO_2 is generated under strictly aerobic conditions, whereas CH_4 and N_2O are produced from the anaerobic mineralization of organic waste [23]. The COP21 Paris climate change conference established the desire to reduce GHG in all sectors [24]. China had the highest CO_2 emissions from agriculture, forestry, and other land use in 2014, followed by the United States, the European Union, India, the Russian Federation, and

Japan (Figure 1). Greenhouse gas emissions have many detrimental ecosystem impacts such as the melting of glaciers, rise in sea level, global warming, acidification of the ocean, etc. Many studies reported that the Earth's temperature increased by 1 °C in the last 100 years and the "Intergovernmental Panel on Climate Change" (IPCC) predicted that the global average temperature would increase by 5.8 °C by the end of 2100. There are reports that by maintaining aerobic conditions during the composting process, GHG emissions can be mitigated up to a certain extent [25,26]. The mixing of waste material in vermicomposting beds at regular intervals, size reduction, and mandatory aeration reduce CH_4 emission to a substantial extent.

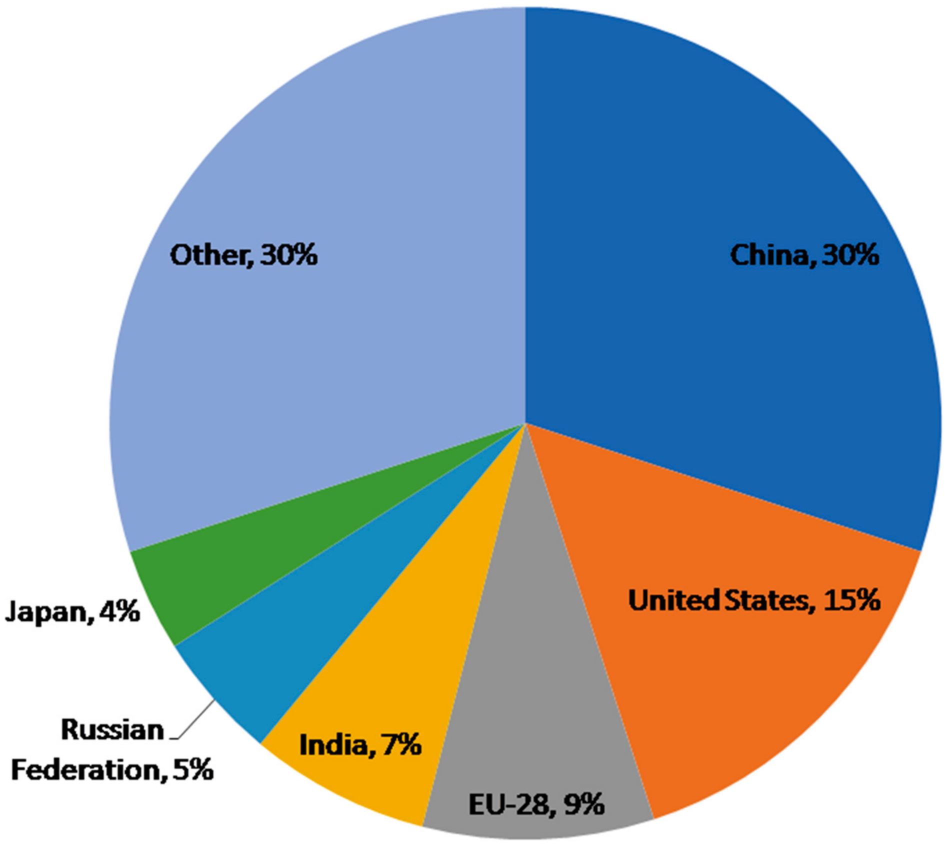

Figure 1. Various carbon dioxide (CO_2) emissions from countries in 2014 (Source: [27]).

3.1. Mitigating GHGs Emission during the Vermicomposting of Waste

The mitigation policies to lessen the GHG emission during vermicomposting comprise the following: use of C-rich amendment material such as sawdust [28], red mud and fly ash [29], inorganic material [30], and an aeration system. The selection of a bulking agent is based on locally available agricultural residues such as wood chips [31], corn stalks [8], and spent mushrooms and cotton gins [32]. The role of biochar in mitigating greenhouse gas (GHG) emissions has been documented in many pieces of literature [29,33]. Greenhouse gas emission during composting and vermicomposting is controlled by various factors such as aeration, the addition of a bulking agent, pH, temperature, and C/N ratio [34]. Many studies suggest that the incorporation of sewage sludge and cow dung significantly reduces greenhouse gas emissions [35]. Wang et al. found that a reed straw addition to duck dung reduces N_2O generation. However, manure cannot be used in vermicomposting as it enhances GHG production [34]. Greenhouse gas emission is linked with the carbon content of the waste used. Vermicomposting can be used for reducing the methane emission from the sewage sludge with an additive of pelletized wheat straw [36]. There are reports that worm composting reduces CH_4 emissions in comparison to controlled conditions due to the aerobic environment maintained in the pile by the earthworms. The increased aeration period and suitable maintenance reduce CH_4 emissions during the vermicomposting process. Moisture is also an important factor that regulates greenhouse gas emissions during vermicomposting. Excess moisture in worm composting bins causes the death of worms, increases N_2O emission by enhancing the process of nitrification and denitrification, and induces CH_4 emissions by supporting the growth of methanogenic bacteria in vermibeds.

The center of the anoxic earthworm gut contains the highest concentration of N_2O [37,38]. An increase in the radius of the earthworm might increase the probability that the N_2O is further reduced to N_2 before it leaves the alimentary canal [39]. There are reports that gut passage time and competing redox processes may be important factors for the in vivo emission of N_2O and N_2 by earthworms [40]. The passage through the earthworm gut accelerates the decomposition of organic matter due to mineralization, fragmentation, and the consequent increase in microbial activity (Figure 2) thus, higher C storage occurs with the physical protection of soil organic matter inside cast aggregates [41]. The feeding ratio is also an important parameter for the determination of GHG emissions during vermicomposting (Table 1).

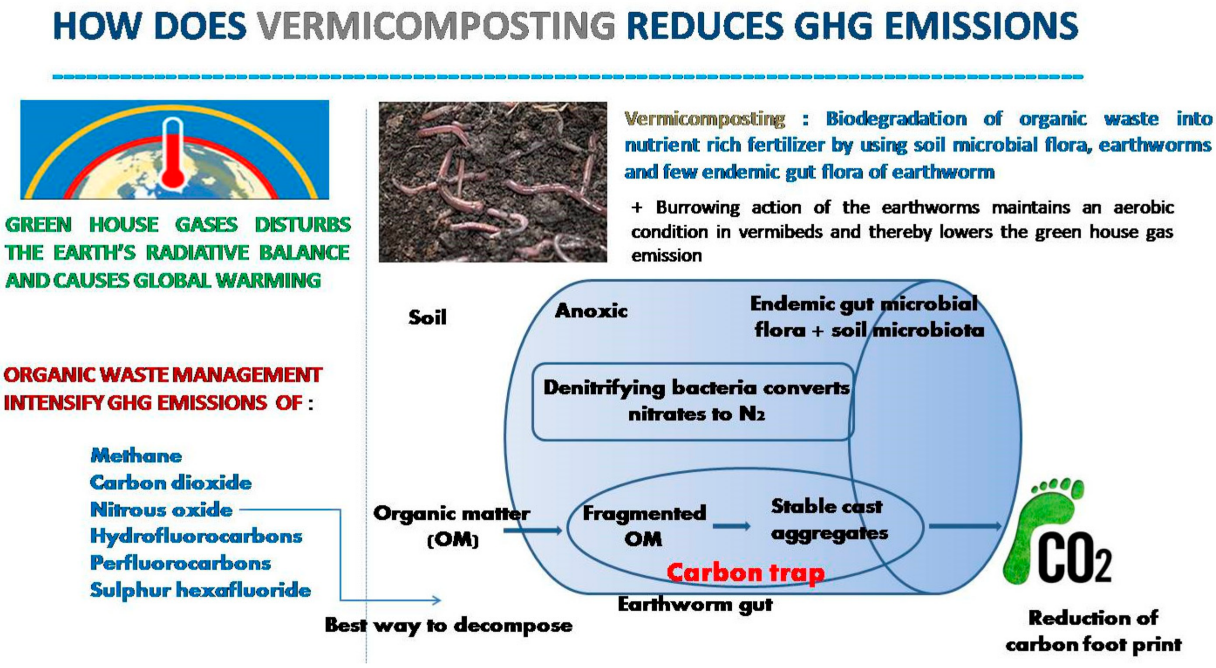

Figure 2. Vermicomposting in climate-smart agriculture.

Table 1. Parameters mitigating GHGs emissions during vermicomposting.

S. No	**Parameters**	**Vermicomposting Reactor**				**Composting Reactor**				**Reference**
		Methane [CH_4]	**NitrousOxide [N_2O]**	**Carbon Dioxide [CO_2]**	**Duration Days**	**Methane [CH_4]**	**Nitrous Oxide [N_2O]**	**Carbon Dioxide [CO_2]**	**Duration Days**	
1	Earthworm species (i) Eisenia fetida, Perionyx excavatus, Eudriluseuginaeand Lumbricusrebellus (ii) Eisenia andrei and Eisenia foetida(Red mud addition) (iii) Eisenia fetida	4.76 kg mg^{-1} 0.033 (μg g^{-1} h^{-1}) 2.28 (kg CO_2-eq t¡1 DM)	1.17 kg mg^{-1} 0.012 (μg g^{-1} h^{-1}) 5.76 (kg CO_2-eq t¡1 DM)	1675 kg mg^{-1} 16.5 % decrease in CO_2 emission N.M	30–60 56 50	2.2 kg mg^{-1} 0.024 (μg g^{-1} h^{-1}) 10.52 (kg CO_2-eq t¡1 DM)	1.5 kg mg^{-1} 0.007 (μg g^{-1} h^{-1}) 12.29 (kg CO_2-eq t¡1 DM)	882 kg mg^{-1} 519–730 (mg g^{-1}) N.M	30–60 56 50	[11] [29] [12]
2	Waste characteristics (i) Municipal solid waste (ii) Home waste (iii) Source segregated Household waste	2.2×10^{-3} kg mg^{-1} 4.76 kg mg^{-1} 0.02–0.38 kg mg^{-1}	N.D 1.17 kg mg^{-1} 0.12–1.5 kg mg^{-1}	N.M 1675 kg mg^{-1} N.M.	240 30–60 84	1.4 kg mg^{-1} 2.2 kg mg^{-1} 0.05–6.6 kg mg^{-1}	1.2 ppm kg mg^{-1} 1.5 kg mg^{-1} 0.005–0.37 kg mg^{-1}	N.M 882 kg mg^{-1} N.M.	240 120 84	[42] [11] [15]

3.2. Effect of Feeding Ratio on Greenhouse Gas Emission (GHG)

The feeding ratio is the ratio of substrate added over earthworm biomass [43]. The optimum feeding ratio helps in decreasing GHGE by 23–48% as compared to non-earthworm-treated composting. A low amount of GHGE during vermicomposting is because of many factors such as (i) earthworms help to increase aeration due to the continuous turning of the substrates [11,16] and (ii) stabilization of the substrate after passing through the gut of the earthworm [44]. In case of a high feeding ratio, the conditions are reversed and GHGE increases. The findings for GHGE during vermicomposting are contradictory; for example, [15,45] had a different view than that of [8,11,16]. This difference in result can be well explained in terms of the feeding and burrowing behavior of earthworms [45], carbon quality and nitrogen content [16,44], temperature, and scale of the experiment [11,44]. The denitrification process that takes place inside the earthworm gut is the main physiological process for N_2O emission in anecic earthworms [45]. A high feeding ratio decreases the conversion rate of fresh materials into vermicompost. Previous studies revealed that more food supply decreases the biomass and reproduction of earthworms [44]. However, a low feeding ratio increases the mineralization of nitrogen compared with a high feeding ratio [43]. A high feeding ratio increases temperature and obstructs air circulation in the pile [45], both of which influence GHG emissions. At a supra-optimal feeding ratio per unit of earthworm biomass, increased temperature in piles also causes earthworm mortality and larger GHG emissions. There are reports that the high moisture content reduces CH_4 and N_2O emission in vermibeds by 32% and 40% but low moisture reduces the emission only by 16% and 23% [44]. The analysis of various factors affecting the rate of emission of greenhouse gases will enhance our understanding to develop experimental models to lessen GHG emissions.

3.3. Role of Earthworms in Soil Carbon Sequestration

Carbon sequestration is a process to fix and store atmospheric carbon dioxide and results in the mitigation of global warming. Soil organic matter (SOM) is formed due to litter decomposition and plays an indispensable role in soil carbon (C) sequestration [39]. In the comparison of systems without earthworms and with earthworms, a sequence of events takes place that actually deals with carbon cycling and carbon sequestration. From Figures 3 and 4 it is well understood that the earthworms decrease the potentially mineralizable carbon and increase the readily mineralizable carbon and stabilized carbon. A study reported that earthworms increased the carbon mineralization in straw by employing C^{13} labeling [46] and creates a priming effect by inducing organic matter mineralization [47]. There is a report that soil organic C stock and carbon sequestration increased to a small extent due to the addition of vermicompost at a 5 t ha^{-1} rate [48]. This little augmentation in the soil organic C stock may generate large impacts in reducing the concentration of atmospheric C. The presence of earthworms adds vermicast to soil and enhances the soil's physicochemical and biological properties which favor the growth of plant roots in the deeper layer of soil and gather more C in the soil [48]. The increase in organic C in soil maintains a sustainable agriculture system and behaves as a potent sink of atmospheric CO_2 [49]. Reduced tillage, improving soil biodiversity, managing wastes/vermicompost, micro-aggregation, and mulching can play a significant role in decreasing CO_2 emissions and enhancing soil C sequestration [50]. The net carbon sequestration mainly depends on the pool size of the activated carbon and its utilization in the formation of stabilized carbon and mineralized carbon [51]. Earthworms have various impacts on the C cycle, based on soil organic carbon content, and do not play a significant role in CO_2 emission but increase net C sequestration as huge amounts of C, i.e., earthworm-activated C, are present and stabilized by earthworms [51].

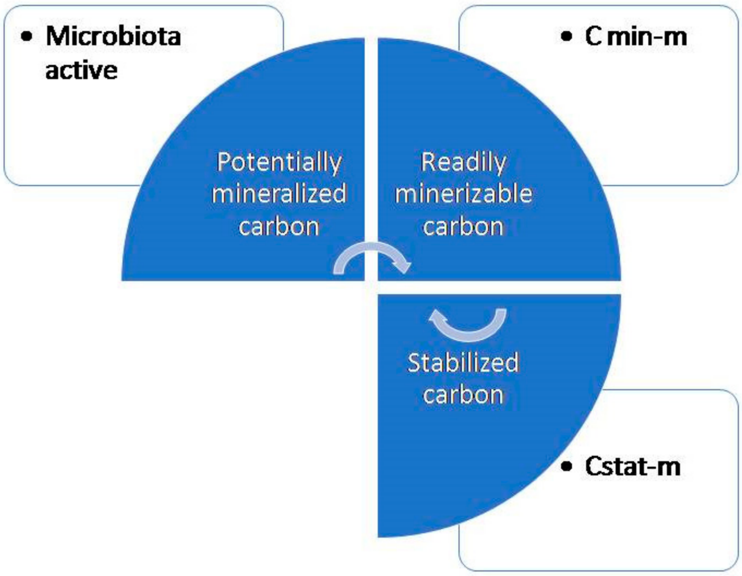

Figure 3. Carbon sequestration in a system without earthworms.

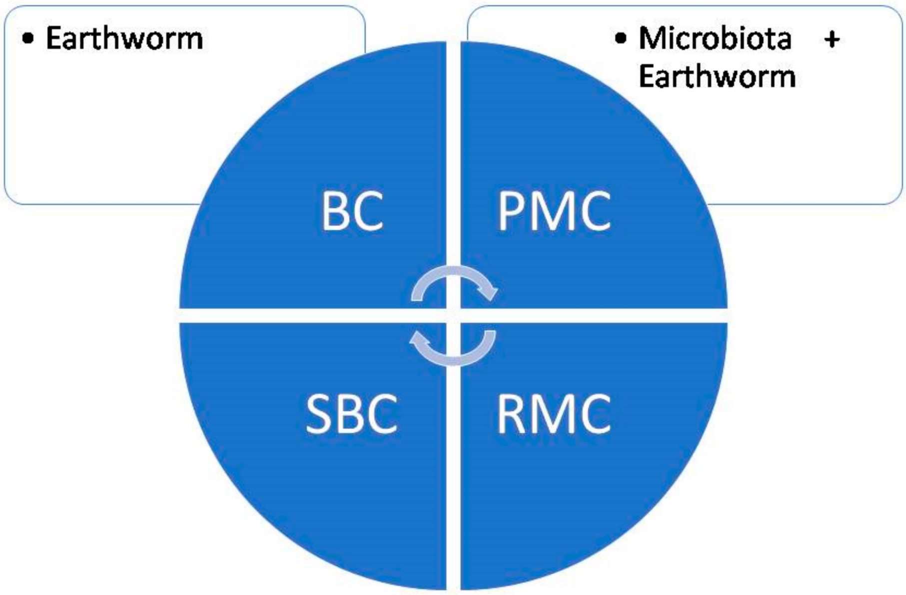

Figure 4. Carbon sequestration in a system with earthworms; BC: basal activated carbon; PMC: potentially mineralizable carbon; SBC: stabilized carbon; and RMC: readily mineralizable carbon.

An earthworm affects net C sequestration due to unequal amplification of carbon stabilization in comparison to C mineralization and generates an earthworm-mediated carbon trap (Figure 5). The changes in the chemical composition of soil organic matter over a longer period of time in earthworm treatments lower C loss and creates greater C sequestration. Earthworms enhance C stabilization in macro and micro-aggregates formed in their casts. A similar kind of observation was made by [52] that 35% of new C is augmented in biogenic aggregates, compared to a conventional system. The scale and method of C dynamics in an agroecosystem are greatly influenced by the earthworms [53]. The feeding manner of earthworms can differentially change the integration of fresh organic material (OM) into biogenic aggregates. This might have significant consequences for C protection and extended soil organic carbon (SOC) storage [54].

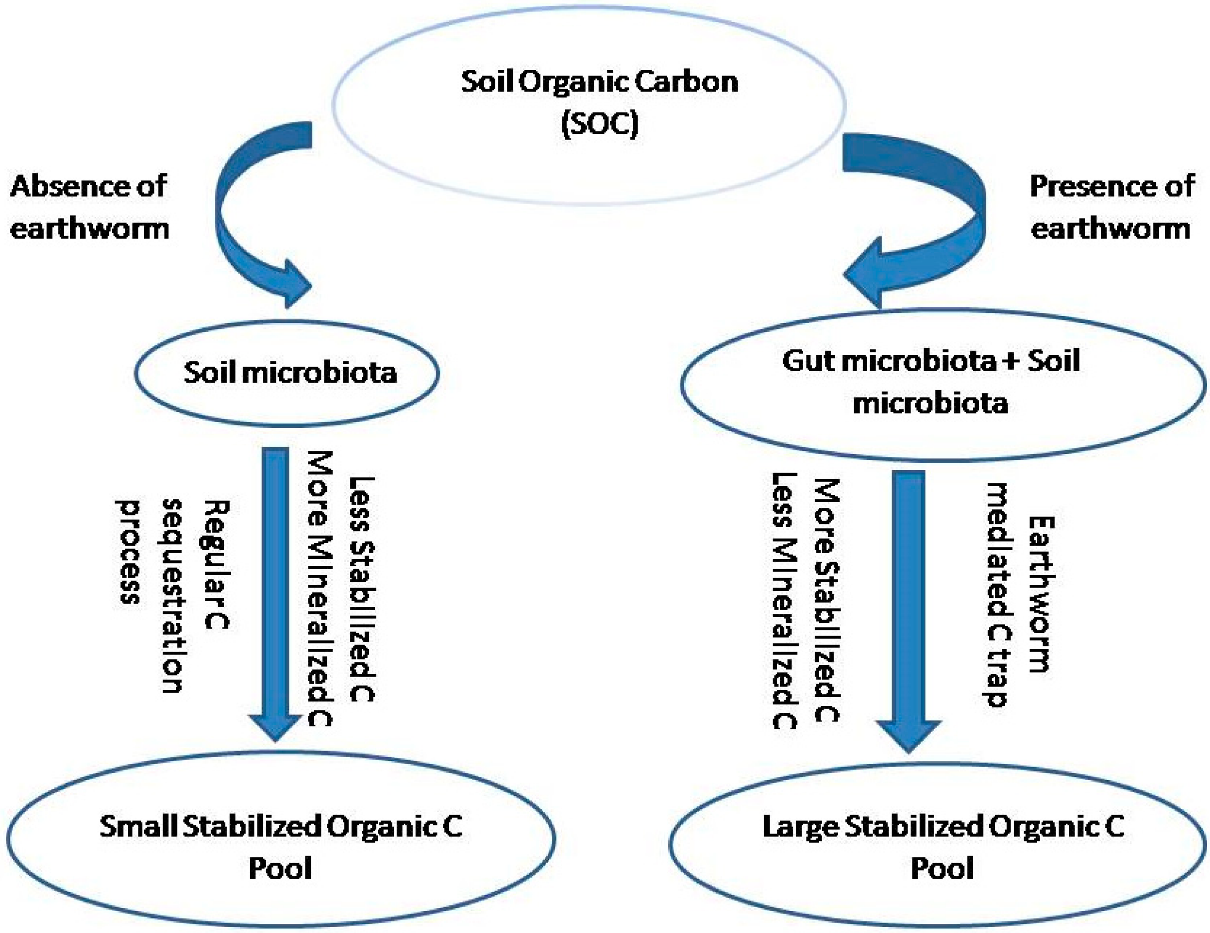

Figure 5. The earthworm-mediated carbon trap (modified from [51]) conceptualized interpretation of the effect of earthworms.

4. Conclusions and Future Perspective

Earthworms, while burrowing, ingest soil, add various biodegradable compounds such as proteins, sugars, etc., and egest this mixed mineral soil as a nutrient-rich cast. The vermicast is a good source of phosphorous and nitrogen due to the higher activity of microorganisms in it. The presence of bioavailable compounds in the cast increases the carbon use efficiency of microorganisms and developed microbial necromass which becomes stabilized inside vermicast aggregates. The presence of earthworms influences the soil structure, porosity, nutrient dynamics, and microbial activity which increases plant growth, yield, and percentage of photosynthesized carbon. In sustainable agricultural practices, vermicasts can be used as a natural amendment to improve soil conditions and increase nutrient content in the soil; it also helps to meet the nutritional requirements of plant species [55]. An experiment performed with a greenhouse pot revealed that the application of vermicast alone (100%) or 75% vermicast with added Mycorrhizal fungi was toxic to plants, due to high chemical nutrient concentrations, compared to the addition of 25% or 50% vermicast [56]. Vermicast is rich in beneficial microorganisms, essential nutrients, humic and non-humic substances, and growth-promoting hormones with desirable physical properties [57–59]. The large surface area of vermicast granules provides more microsites for microbial activity and nutrient retention [60,61]. This leads to slow nutrient release for an extensive time period. The availability of scientific literature regarding nutrient mineralization and pattern of release is limited [62]. Despite many studies on the effect of earthworms on the soil microbial community, it is still not clear whether the earthworm has its own microbiota or if it originates from the soil. Further research is needed to understand the shift of microorganisms and the activation of microbial genes induced by earthworm activity. This mini-review indicates that there is a research gap in determining the exact GHG emissions during the vermicomposting process. Worm composting with different additives and earthworm species should be investigated, along with the impact of seasons on GHG emissions during vermicomposting. Large-scale research on vermicomposting is scant due to various challenges in accurate GHG measurement methods. The measurement, mitigation, and perspectives on the emission of commonly known GHGs during composting and vermicomposting have been reviewed in detail by [34]. Further research is essential to find out the most accurate method for large-scale GHG measurement.

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