Vermicomposting of Organic Waste : Literature Review

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Abstract

Purpose : Adoption of new life style, bad management and low budget in many developing countries resulted in massive accumulation of municipal solid waste (MSW) and agricultural wastes causing several environmental and health problems. Vermicomposting (VC) evolved as one of the promising and economic techniques to process different types of organic waste to a level that is easy to store, handle, and could be applied as a fertilizer to agricultural fields. This paper presents a thorough review on VC of organic waste with concentration on the recent published works. The paper also gives an overview on the new trends in VC research trying to put a structure for the current and new developments.

Results: Study of the various literature show that in order to have an efficient VC system, factors affecting worm health and VC process need to be taken into consideration like pH, moisture content, temperature, soil age and type, substrate and C:N ratio. it has been concluded that vermicompost not only can be used as efficient economic substitute to inorganic fertilizers; but also in land reclamations, removal of heavy metal from different waste, reducing pathogens, adjusting the land biology and structure for better planting and germination.

Conclusions: vermicomposting is a promising technique that required some work of organized research projects in order to reach solid applicable results in the field.

Keywords: vermicomposting, organic waste, heavy metal removal, earthworms, soil reclamation, waste management

1. Introduction

Solid waste accumulation has become a chronic problem in many countries around the world [1]. An estimation of global waste to reach 7 Mega t/d in 2025 if current solid waste strategies are held with no major changes [2]. Many of developing countries cannot cope with this dramatic increase in MSW. In India for example , generation of MSW has increased by 85% in Delhi only from the year 2000 until 2011 [3] out of them 23% only used for landfill. In Brazil, the treated percentage rises to 39% [4] while in Egypt the yearly recorded MSW generation is measured to be 21 million tons with only 9.5% treated [5]. On the other hand agricultural wastes estimates are reaching around 998 million tonnes yearly [6] Both MSW and agricultural waste found to contain high amounts of organic matter reaches 42% in MSW [7] and more than 80% in some agricultural wastes [8] making them an efficient biodegradable matter.

Such massive increase in MSW raises the need for a sufficient eco-friendly method to treat MSW into an environmental friendly product. Various municipal solid waste management and treatment methods were developed to come over the problem of MSW and agricultural waste accumulation. Yet, all of those methods have one or more limitations. One of the famous methods is waste incineration and controlled incineration which have been used widely since the end of 19th century [9], but this method is known for its high carbon emissions [9], [10]. Another waste management method is Landfill, however, recent research points out to some side effect on air and groundwater pollution due to greenhouse gases emissions and groundwater contamination due to leachate releases [11], [12]. Pyrolysis is another treatment process in which organic waste is heated under total absence of air, this method substantially reduces waste volume but requires much complicated plants and use many chemicals making it non-guaranteed solution for clean waste disposal [13]. Above discussion indicates a lack of an optimum solution to treat MSW and green waste accumulation raising the need for an economic and environmental friendly option.

One of the recent trends to solve the waste accumulation problem is vermicomposting. Vermicomposting (VC) involves the combined effect of both microorganisms and earthworms for waste biodegradation [14], [15]. While composting is the biodegradation of organic matter using microorganisms, the vermicomposting is doing the same with earthworms works as accelerator which increase the surface area of decomposition [16], [17].

The word vermicomposting is derived from the Latin word 'Vermis' which mean 'worms' [14]. Vermicomposting can also be defined as a waste management technology that involves decomposition of organic fraction of solid waste in an eco-friendly way to a level that can be easily stored, handled, and applied to agricultural fields without any adverse effects [18].

Historically, the use of earthworms for degradation of organic matter was described by Darwin [19] the first depth research on vermicomposting was made in USA in New

York state and Cornell university [20] however, the regular publication only started on 1980th [19].

Vermicompost (product of vermicomposting) can be considered a potential replacement to agrochemical fertilizers. While agrochemical fertilizers have negative impact on the environment by increasing plant production on the cost of reducing the soil productivity [21]; vermicomposting produces better soil fertilizers richer in nutrients and less in chemical compounds [22], [23]. The short time used for biodegradation of matter in vermicomposting is another advantage. Earthworms can decrease the volume of waste by 50% faster than the microorganisms only as used in natural composting [24].

In spite of the many research work done on vermicomposting, there are only few review papers made for generalization of results. Therefore, this work was prepared to present a review of the latest research on vermicomposting of different types of organic wastes in the last years, with concentration on the research and applications for developing countries. Trying to draw an overall picture on vermicomposting.

2. Recent research in Vermicomposting

Besides being used to obtain good fertilizer, It was found that vermicomposting have greater advantages that exceeds the mere decomposition of organic matter into eco-friendly fertilizers. In the above regard; researches on earthworm and vermicomposting can be categorized into four major streams namely: Research on fertilizer production and plant growth, Research on waste management. Research on environmental bioremediation. Researches on fertilizers production and plant growth include the production of fertilizer, its nutrition values, bio-stability and its benefits in growth and total yield of crops compared to other agrochemical alternatives. While research on waste management include studies on the vermicomposting of MSW, agricultural and industrial waste, clean disposal and harm effects mitigation [6], [25], [26]. Research on environmental bioremediation focuses on using earthworm for remediation from different harmful materials for example using the vermicompost as an agent to reduce heavy metal concentration in soil [27], [28], as a bio-sorbent for soil reclamation [29], for the treatment to reduce pathogens and nutrients in wastewater and sludge [30], [31] or even for water treatment to reduce BOD and COD [32]. And finally new researches exposes the use of vermicomposting unconventional uses like using the worms as a biocontrol agent to prevent from some diseases [33] or utilizing the nano-technology [34] or for mitigation of some environmental problems like reducing greenhouse emissions [35] or possibility of the earthworm itself as a replacement food aquatic life [36]. Besides those above there are some studies on the worm biology includes research on the biology of the worms, their fecundity, feeding, and investigations on the best environmental for their living and reproduction.

Fig. 1 shows the current trends in vermicomposting research.

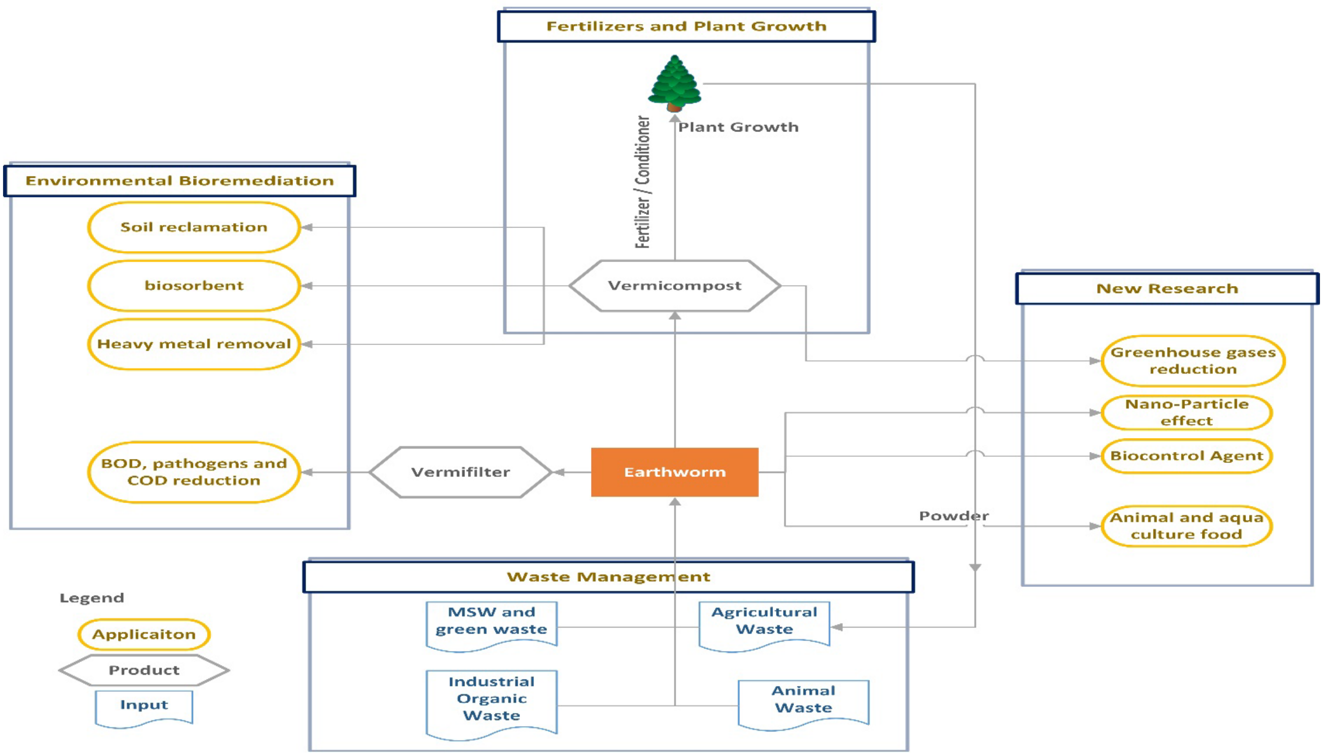

Fig. 1 Recent trends in Vermicomposting research

2.1 Research on a fertilizer and benefits to plants Growth

Earthworms processing of soil improves its characteristics and can be seen in enhancement of soil fertility, adjustment of soil pH, enhancing of soil physical composition, formation of humus, soil nutrient enrichment, higher microbial biodiversity and improving of the soil structure [37]–[40]. The soil from vermicomposting process has higher porosity, aeration, drainage and higher water holding capacity [40]. Generally, vermicompost is a good fertilizer rich in nutrients, humus like product, high in essential plant nutrients like Nitrogen, phosphorous and Potassium (NPK), micronutrients, other beneficial soil microbes, phosphate solubilizing bacteria and growth hormones [38], [41]. Fertilizers produced from vermicomposting process found to have good effects on the growth and germination of plants [42], [43]. It also increases the fungal activity and achieve better growing results than conventional composting and organic fertilizers [44], [45]. Many research shown that some earthworms can increase values of Fe, N, P, K resulting in a more nutrient rich vermicompost [46], [47]. Although vermicomposting have very good effects on plant growth [48], some advised not to use at high concentrations as it may increase the soluble salts in soil impeding plant growth [38]. Different Responses of plants to different vermicomposting was noticed in some studies, which referred by some researchers to the genotype differences between plants [49]. Table 1 presents a summary of some of the recent research on plant growth and effect of fertilizers.

Table 1 Summary of selected VC research on planting growth

Se	Plant	Substrate + Amendment	Result	Reference
1	Wheat, pea, gram and mustard	Buffalo Dung + gram bran	Noticeable increase in plant growth and germination , Flowering of wheat at 75.75 days	[42]
2	Linseed (Linum usitassimum)	Cattle Dung	When added at 40-60% to soil increased performance of seeds, root morphology stem growth, and the total yield.	[49]
3	Maize	Fungi + vermicompost	Increased plant P uptake and shooting.	[50]
4	Maize	Cattle manure using Eisenia Fetida applied at 30 t / ha	Increase in plant biomass by 7.7 % Increase in grain yield by 18.3 %	[51]
5	Wheat	Vermicompost and chemical fertilizers	Increased growth in sodic soil	[52]
6	Wheat	-	Increased growth by 39% Increased grain yield by 35 % Increased protein value by 12 %	[41]
7	Pea (Pisum Sativum)	Fungi + vermicompost	Increased plant total height by 34%, 50.61% fresh weight, 33.23 % dry weight	[53]
8	Tomato (Lycopersicum esculentum L)	MSW vermicompost 25:25:50 (MSW compost: vermicompost: perlite)	Increased the tomato red fruits in the harvest period and total yield significantly Total yield increased from 449.05 g to 2037.5 g/ plant Shoot dry weight increased from: 26.42g to 35.69 g	[54]
9	Tomato (Lycopersicum esculentum L)	Cattle dung vermicompost 15% : 85 Soil	All VC samples increased total yield and quality parameters while best growth was in 15% VC: 85% soil Germination increase : 86% Height increase : 25 cm total yield increase from 0.36 to 0.61 kg	[48]

In most cases NPK values were increased after vermicomposting. However, the increase of total Nitrogen TN was related in some cases with a reduction of Potassium K [24], [57] and in other cases with a little increase in K [16]. Results of Cao *et al.* shows differences from lab to field experiments with higher C:N reduction in lab [58] indicating the non-negligible effect on actual environmental conditions on the worm.When compared with traditional compost, vermicompost showed higher nutrient values than natural composting. However, some research pointed out the persistence of some harmful microbes and referred that to the lack of the thermophilic phase in traditional composting [59], [60]. Table 2 gives a summary of the research done on different earthworms showing the effect of most significant nutrients before and after the experiment.

In order to achieve a good vermicompost, some consideration for the worm environment and feeding behaviour needs attention; for example feeding worms with high biodegradable waste may result in an anaerobic zone which creates a very hazardous environment on worms [66].

2.2 Research on waste management

Within the limits of the information available to authors, there is no devoted projects to study and evaluate the treatment of different waste types using vermitechnology. While the European waste catalogue list specifies 839 waste entries – including 405 entries classified as hazard [55], only few of them were studied.

Table 2- Changes of nutrient parameters before and after vermicomposting as reported from different research.

Se	Earthworm	Substrate + Amendment (ratio)	C:N ratio initial	C:N ratio Final	K,P,N Initial g/kg or %	K,P,N Final g/kg or %	pH initial	Moisture content %	Temp Initial ºC	Effect (reference)
1	Eudrilus eugeniae	Cow dung + sewage sludge (1:4)	6.8 ± 0.2	-	3.7±0.1 % 1.5±0.1 % 1.2±0.1 %	2.4±0.1 % 1.4±0.1 % 2.1±0.1 %	5.5	81.3	30.1±0.4	Best media for increasing earthworm quantity biomass [56]
2	Eisenia Fetida	Paper cup waste + Cow dung (1:1)	46.6	15.02	- 1.8% 0.61%	- 3.8% 1.39%	6.21	60-80%	20-25	[23] Ability of E.Fetida to convert paper cup waste into useful fertilizers
3	Eisenia Fetida	Buffalo Excreta 100%	73	16	7.26 ± 0.36 5.55 ± 0.50 7.02 ± 0.17	15.30 ± 0.97 11.56 ± 0.99 15.43 ± 0.29	7.49.± 0.03	70.±10	23±3	[61] achieved highest worm biomass gain and highest fecundity for E. Fetida.
4	Eisenia Fetida	Water Lettuce + CD (1:4)	39.37 ± 1.86	27.02± 1.13	4.83 ±0.06 3.73 ± 0.05 11.35 ± 0.39	5.96 ±0.08 5.78 ± 0.09 15.13 ± 0.65	7.70 ± 0.02	65-70%	26.5 - 28.1	[62] achieved highest worm biomass gain and considerable C:N ratio
5	Eisenia Fetida	Household Waste 100%	32	16.5	- 0.54 ± 0.1 1.7 ± 0.2	- 0.72 ± 0.3 2.2±0.4 %	8.2 ± 0.4	60-80%	18-20	[63]
6	Eisenia Fetida	Food Waste	27.9	12.1	0.86% 0.29%	1.2% 0.28%	6.4-7.6	78.5%	22 ± 2	[58]
7	Eisenia Fetida	Cattle manure	-	-	0.523±0.007 % 0.240±0.005% 1.87±0.01%	0.503±0.018% 0.248±0.003% 1.63±0.04%	8.63± 0.02	8.03±0.06	13.2	[51] vermicomposting increase the total grain yield of maize.
8	Eisenia Fetida	cattle manure + biogas additives	30	-	1.18%2 1.02%3 1.13%	Increased with no values in ref.	7.3 – 7.6	60-70%	28-30	[64] suitability of combining VC with biogas production.
9	Eisenia Fetida	Cow dung + gram bran	51.3±.38	11.6±1.1	7.3±.12 g/kg 6.9±.04 g/kg	8.0±.13 g/kg 7.4±.06 g/kg	8.6±.02	7.0±.06	-	[42]
10	Eisenia Fetida	Rice Straw / Paper waste and cow dung (80:10:10)	97.00 ± 3.29	22.17 ± 0.94ab	- - 5.19 ± 0.17 g/kg	- - 11.04 ± 0.39 g/kg		60-70%	20-23	[65]

Many successful studies were carried on different types of MSW and almost all of them were successful to produce soil conditioner with satisfactory C:N ratio and suitable amount of nutrients even if the raw material had some deficiency [47], [56]. Similarly, other researches made on the biomass including coffee bulb resulted in a similar increase in N, Ca, Mn, P but a decrease in K [67]. Also on rice straw paper waste [65].

2.3 Researches on Environmental Bioremediation

Pathogen Removal

Many research have been made to validate the effect of earthworms and vermicomposting on the pathogen removal. However, the results are quite diverse and is difficult to drive solid conclusion. In some research, earthworms were able to reduce the pathogens (faecal coliforms, salmonella spp. and helminth ova) in a septic tank to permissible authority levels, and noted that pathogen reduction efficiency was associated with an increase in earthworm population [30]. This comes in parallel with study on MSW mixed with cow manure and municipal sludge in equal proportion, in the later ; Eisenia Fetida were able to achieve a reduction of faecal coliforms from 350,000 MPN to 800 MPN and the complete removal of parasite eggs. [31]. When vermicomposting made with dewatered sludge only; some pathogens were totally removed and a change in bacterial community was reported [70].

On the other hand some researches showed that E. Coli and some microbial contaminations are persistent in vermicomposting systems [58], [68]. Aira *et al.* concluded that Eisenia Andrei were not able to reduce E.coli [69]. while Hénault-Ethier *et al.* concluded that the main reason for removal of the E.coli is the microbial community and abundance of the earthworm will have no effect [57].

It might be that the method of vermicomposting affects the results, Mengistu *et al.* reported that vermicomposting combined with windrow composting method had better pathogen removal effect [71]. Selected number of research are shown in Table 3 to present an idea on the ability of earthworm to reduce pathogens and the effect of different substrate.

Table 3 Summary of selected research on pathogen and microbial removal

	Earthworm	Substrate + amendment	Pathogen / microbe	Reading Before	Reading After	Reference
1	Eisenia Fetida	Municipal pelletized sludge	Bacterial count	7.41±0.46 x 10^9/g	2.79±0.07 x 10^9/g	[70]
2	Eisenia Fetida	Raw Sludge from Septic tank	Faecal coliform Salmonella spp. Helminth ova	1600 MPN/g dry wt 2400 MPN/g dry wt 10 viable ova/g dry wt	60 MPN/g dry wt <3.0 MPN/g dry wt 0	[30] at worm density 2.5 kg/m^2
3	Eisenia Fetida	Cow manure waste Cow manure sewage	Faecal coliforms Faecal coliform	350,000 MPN/g 6,500,000 MPN/g	800 MPN/g 2400 MPN/g	[31]
4	Eisenia Fetida	MSW + dry faecal sludge 2:1	Faecal coliform Helminth egg	4.63±0.04 cfu/g (log_{10}) 38.88±1.6 /g	<1000 cfu/g 2.5 /g	[71] windrow composting followed by VC
5	Eisenia Andrei	Cow manure	Faecal coliform	3.8 ± 1.8 x 10^3 cfu/g dry wt	13.5 ± 2.2 x 10^3 cfu/g dry wt	[69]

Heavy metal accumulation and removal

Heavy metal removal by vermicomposting can be divided into two main research trends one is the removal using the vermicomposting process i.e. earthworm becomes the fate of heavy metal and the other is using the vermicompost as an adsorbent or a means of removal i.e. vermicompost is the fate of heavy metal. Table 4 below shows a selective summary of some research on heavy metal removal.

Old and new research mostly agreed on effectiveness of vermicomposting in the reduction of total and bioavailable metal content [72]. When vermicomposting process is used for the heavy metal removal, the earthworm is doing this either by transforming part of the mobile fraction of heavy metal into residual fractions that are not suitable for plant uptake [73], [74] or by storing into the earthworm tissue [72], [75].

In the first case total content of the residual fraction of heavy metal increases accompanied by a decrease in mobile fraction through chemical speciation into less available forms [73]. However, the reduction of heavy metals should be related to the bio concentration factors in the worm tissues [72], [76].

When relating efficiency of heavy metal removal to the bio concentration factor (BCF) it would be possible to estimate the removal of metal by doing pre-studies to measure the BCF in each worm species. When done, a scientific approximation of the heavy metal reduction and transformation into residual fractions could be calculated in advance [76].

Beside bioavailability of metal in worm tissues, Controlling the pH also affects the amount of metal transfer. As the increase in pH increases the tendency of earthworm to absorb heavy metals [77]. Omouri *et al.*[75] suggests earthworms can be used as environmental monitoring tool since they can store considerable high concentration of bismuth in their tissues [75]. In all cases care must be taken when exposing worms to excessive metals as they may cause higher worms mortality rates [78],

Table 4 – Summary of research results on removal of heavy metals using vermicomposting

Se	Earthworm	Substrate	Objective	Starting value of experiment	End value after experiment	Study Result	Ref.
1	Eisenia Fetida	vermicompost product	Using vermicompost as an adsorbent in paper mill effluent and its effect to remove different water pollutants.	BOD 440 mg/L TDS 780 mg/L Mn 0.12 mg/L	BOD 260 mg/L TDS 210 mg/L Mn 0.09 mg/L	Vermicompost is a good adsorbent for heavy metal and is effective to reduce BOD and COD in wastewater.	[28]
2	Eisenia Fetida	Mix of (saw dust , fly ash, soil and straw)	Using earthworm for heavy metal reduction in vermicompost	As 43.5 mg/L Cr 187.5 mg/L	As 40 mg/L Cr 125 mg/L	VC caused increase of the residual fraction in vermicompost to a value that not suitable for plant uptake.	[79]
3	Eudrilus eugeniae	Different types of MSW	Comparison between composting and VC in heavy metal removal	Cd 3.2 ± 2.2 mg/kg Cr 45.3 ± 4.9 mg/kg	Cd 1.1 ± 0.0 mg/kg Cr 21.3 ± 17.2 mg/kg	VC is very efficient in heavy metal removal	[76]
4	Metaphire posthuma	MSW and Cow dung (2:1)	comparison between Metaphire Posthuma and E. Fetida in removal of heavy metal	Pb 25.0 ± 2.5 mg/kg	Pb 6.5 ± 0.05 mg/kg	Removal fraction depends on the worm bio-availability.	[46]
5	Eisenia Fetida	House hold waste	Comparison between VC from sewage sludge and municipal house hold	Cd 0.2 ± 0.1 mg/kg Pb 0.8 ± 0.4 mg/kg Cr 6.4 ± 0.6 mg/kg	Cd 0.05 ± 0.03 mg/kg Pb 0 mg/kg Cr 0 mg/kg	E. Fetida is very efficient in removing heavy metals .	[63]
6	Eisenia Fetida	Water hyacinth 100%	Effect of E. Fetida in vermicomposting of water hyacinth	Pb 894 ±9 mg/kg Cr 17.6 ±4 mg/kg	905 ±30 mg/kg 38.8 ±3.8 mg/kg	Increase in residual fraction which has no or little bioavailability	[74]

As a bioremediation or bio-sorbent agent

The main hinder to phytoremediation is the low bioavailability in plants. The higher bioavailability of earthworms to some pollutants including heavy metals suggests the use of both the earthworm and plants together in a phyto–bioremediation process [80]. Phytoremediation only can also be enhanced using certain amounts of vermicompost or vermicompost with certain additives. For example adding fungi with P rich vermicompost at 20 mg P/kg equivalent enhanced the phytoremediation of plant C. Ensiformis in copper contaminated soil [81]. While using 25% of vermicompost without any additives increased the ability of Oat grain to bio-extract Cr and Pb [82].

One of the methods to remove heavy metals from wastewater is using the vermicompost as an adsorbent [27], [28]. It's thought that the dead microbial biomass in the dried vermicompost are effective in concentrating metals. Moreover, the humic and vulvic substances in the vermicompost possess high capacity to interact with metal in water and organic substances [83]. When used as an adsorbent, the vermicompost was able to adsorb efficiently Cu, Mn, Fe and Zn and reduce the effluent biochemical oxygen demand (BOD) , chemical oxygen demand (COD), and total dissolved solids (TDS) to a very reasonable limits. It also worked as a buffer to neutralize pH in industrial waste [28].

Land reclamation

Beside improving soil organic content by increasing the N value and decreasing some pathogens [18], [57], [68]; Earthworms usually increases stability of soil structure, improves structure of the soil and reduces runoff [84]. It was found that the addition of vermicompost enhances the bauxite residue properties and increases aggregate stability in soil reclamation [85]. Some studies show that vermicompost can also enhance soil properties in terms of increase in air permeability and reducing penetration resistance [29].

In terms of enhancing supressing soil problems like extra salt and metal; vermicompost was used to mitigate the effect of salty soil by enhancing grow of some crops [86]. It was also used to reduce effect of lead contaminated soil [87]. In sodic soil , the use of vermicomposting works to improve TOC, alkaline phosphatase, β-glucosidase, dehydrogenase and cellulose activities that were increased [52].

Vermicompost combined with addition of fungi enhances the soil microbial diversity, reduces the pH and increases the calcium phosphate uptake accordingly [50], [88], [89]. The existence of earthworms on the other side increased the soil carrying capacity of microbial biomass and facilitated the flow of N from litter to stable soil organic matter [90]. Bidabadi *et al.* found that using the leachate of vermicompost has a significant effect on the reducing the salt stress in soil which helped in growth and production of pomegranate [86].

Table 5 presents a summary of the research done on land reclamation using vermicomposting.

Table 5 Summary of Research on land reclamation using vermicomposting

Soil Type	Substrate + Amendment	Result	Reference
Sodic Soil	Vermicompost pre-enriched with plant growth promoting fungi combined with chemical fertilizers.	Increased bulk density by 234%, TOC by 181%, alkaline phosphatase by 234%, β-glucosidase 176%	[52]
Clay soil with pH 5.1 agro-ecological	Vermicompost mixed with soil at rate 2.5 g C/kg Soil.	4.65 mg C/kg Soil , low CO_2 emissions compared with natural soil at same temperature	[91]
Salty soil	Vermicomposting leachate used to reduce salt stress in pomegranate	Vermicompost leachate reduced the accumulation of Na+ ions in the seedling, it also improved activity of enzymes.	[86]

2.4 New Research

Water Treatment

By the beginning of the 90th earthworm found a way to the treatment of wastewater and proved their efficiency and economic use. The idea was based on utilizing the microorganisms in worm guts for biochemical degradation of waste while using the earthworm to host the microbes in a process known as vermifiltration. Activities for a combined system of plants and earthworms was found to be the best effective in chemical oxygen demand COD removal providing the least emissions of greenhouse gases [32], [92]

Jiang *et al.* summarized the different factors affecting the vermifiltration system for wastewater treatment as : Earthworm species type (anecic, endogeic, and epigeic), Filter media, chemical factors like (pH, Ammonia, chemical components), temperature, operating and design features like (hydraulic load, C:N ratio, and bed height) [92]. Arora and Kazmi [93] show high correlation factor between temperature and treatment parameters like COD and BOD. They also reported that highest removal rates are gained in spring and autumn while the optimum temperature for the earthworm is ranging between 25-27 ºC. Vermifiltration was also used in sludge treatment and dewatering with good results and is considered as a new technology that results in treated sludge with smaller particle size and higher surface area [94].

Greenhouse gases

Some research have been done to investigate the effect of vermicomposting on CO_2 emissions. Results that when vermicompost is added to soil it results in relatively low C mineralization and CO_2 emissions. Thus, works to increase the carbon content of soil and enhances soil health [91]. In wastewater treatment using the earthworm combined with plants (eco-filter), It was found that C:N = 5:1 is giving the optimum removal efficiency and least greenhouse gases emissions [32].

3. Parameters affecting vermicomposting

In order to construct an optimum vermireactor, a study of the different parameters affecting the worm and vermicomposting process is required. Some parameters were found to have high effect on the function of earthworms and the quality of vermicompost. Temperature, pH, feedstock, and Carbon to nitrogen C: N ratio are important factors directly affecting the life of worm and final result of the vermicompost [18]. Other factors include moisture content, soil age, and substrate type and soil age are affecting the worms growth and production rate [54], [95], [96]. An optimum maturation time was found to be 75 days for most composts using Eisenia Fetida [24].

Kiyasudeen *et al.* [97] summarized the optimum conditions for earthworm breeding from different literature to be 5-9 pH, 15-20 ºC optimum temperature (limits 4-30 ºC), dark environment, max ammonia limit 500 mg/kg and few others. Those results found different from some recent research and even some new factors were involved recently like the effect of soil density, soil age, and toxic materials on the abundance and life of earthworms [95].

Since composting and vermicomposting work to decrease the carbon value largely resulting in higher N content [16], both Carbon and Nitrogen should be present in the substrate to allow worms to grow [17]. Because some earthworm feeds like MSW may lack some organic components [98], adding organic matter to the original substrate might be necessary in order to get the worm functioning. Substrates may include, biomass from municipal solid waste, coffee bulb, vegetable waste or others [56], [67], [99], [100] while organic matter can be added as sludge, animal waste or any carbon rich material [100], [101].

Having a low starting Carbon to Nitrogen C:N ratio may result in faster carbon decomposition and possible dangerous anaerobic zone which is very harmful to worms [102].

3.1 pH, moisture and temperature

Soil pH values directly affect the earthworm reproduction and function in many ways. It was found that higher pH values increases tendency of nano toxin particles to transfer into worm reducing their reproduction rate [103] and to absorb heavy metals as well [77]. While some studies reported an increase in the vermicompost pH referring that to the increase in salts due to the vermicomposting process[16], other reported a reduction in pH [46]. An increase in pH value was associated with an increase of the rate of Zinc removal from a combination of sewage sludge and cow dung [77]. While a decrease of pH reduces the effect of the toxic material (mercury) on the earthworm, possibly because of the solubility of toxins [104]. This indicates a significant effect of pH on the lethal reception of worms.

While Kiyasudeen *et al.* concluded that 80-90% moisture is best for earthworm breeding, some claimed that proper vermicomposting process requires a moisture content of approx. 70% [105] and many research done around 70% content with good results [62], [63].

It has been identified that both moisture and temperature have combined effects on earthworm survival and biomass gain [106]. As for temperature, it was found that burrow depth created by the worm is getting deeper with increasing of temperature from 5 to 20 ºC [107]. Burrow depth is an important factor as it indicates the ability of the worm to ingest and process enough soils height. As temperature increases within the limit range (5-30 ºC) [97], the reduction of BOD and COD increases in wastewater treatment systems [93], possibly due to the higher decomposition rate of the bacteria. Cocoon production was also found to increase with increase in temperature [108].

In eco-filter, the increase in temperature found to have a high effect on the removal efficiency of chemical oxygen demand COD from wastewater treatment [32], [93].

3.2 Substrate

Substrate has a major effect on the earthworm function and the bacterial community included. This is due to the fact that earthworm is co-composting its food using the bacteria in their guts [109]. It has been found that adding a worked substrate of previous vermicompost greatly affect the resulting vermicompost [110] indicating the effect of the worm food on their products. In spite of that, earthworms also has a core microbiome in their guts which could be the reason that a worm can survive in nutrient poor substrate [111]. On the other hand, the bacterial community of the cast strongly dependant on the substrate [112]. This explains the different results of nutrients with different substrates.

Adding organic substrate to MSW enhances the biodegradation process. However, the amount of organic substrate should be carefully selected as adding high nutrient content that is fast biodegradable to the worms may cause anaerobic environment that is harmful to worms [113].

Substrates included biomass from palm oil , coffee bulb, cow manure, or poultry [14], [67], [98], [114]. Generally, Sewage sludge and cow dung appeared to be the most effective substrate to enhance the vermicomposting process[22]. This is possibility due to the high carbon content in their components. Buffalo excreta achieved a biomass gain from 11.52 ± 1.28 to 42.8 ± 2.17 with an increase of approx. 271% [61]. This advantage of buffalo was in parallel with the results from [100], [115].

3.3 Worms type , Stocking density, soil age and feeding rate

Earthworm itself can be classified into three categories (epigeic, endogeic and anecic) each have different response to environmental conditions and different behaviour [92], [97], [108]. Temperature was found to increase the incubation period of the endogeic earthworms while reducing the same with epigeic worms proving that earthworm species behave differently under same environmental conditions [108]. Earthworm is also a food in itself to different types of vertebrates and invertebrates [116]. Therefore, the existence of threating creatures to the earthworm will affects the abundance of earthworms into specific media and hence the results of the process.

A stocking density of approx. 1.6 kg worms/m^2 resulted in the highest substrate biodegradation [17]. In a research for pathogens removal, it was found that the increase of stocking density results in higher removal efficiency [30] to an max at 2.5 kg worms/ m^2.

There is a lack of research on the stocking density and the measuring parameters are different between different research making it difficult to reach a generic figure. An optimum value of stocking density for the treatment of water treatment sludge effluent was found to be 16-32 earthworm/kg waste [117]. The value changes to 27-53 worm/kg waste of cow dung [118] while with paper bulk used as substrate x reached that an optimum 1.6 kg/ worms / m2 results in the highest rate with a feeding rate of 1.25 kg feed/kg worm/ day. One research relates the density as well to the soil age as younger soils resulted in lower worm densities [95]. Garg *et al.* found that higher stocking densities results in higher growth rate while lower stocking densities results in higher biomass gain per worm [118].

Johnston *et al.* developed a model for the earthworm distribution and abundance for the worm Aporrectodea caliginosa, though needs a verification on other earthworms; it shows that the abundance of earthworms is greatly affected by the amount of food, soil temperature and water content [116].

3.4 C:N ratio

Carbon to Nitrogen or C:N is a well-known method for determination of the maturity of compost [73]. It is probably the most widely known indicator to decide about Composting and vermicomposting works to decrease the carbon value largely resulting in higher N content [16]. In order to achieve this both Carbon and Nitrogen should be present in the substrate to allow worms to grow [17]. Having a low starting C:N ratio might result in faster carbon decomposition and possible dangerous anaerobic zone which is very harmful to worm [102]. In Table 2 Starting C:N and final C:N ratio are shown for various earthworms and substrates. The studies shown in table are confirming the results of [95], [119] that the higher the different C:N starting ratios affect the performance and speed of vermicomposting. However, it can be concluded from Table 2 that the around 60% reduction is the maximum value that can be attained. It shows that the lower starting values of C:N ratio the lower C:N ratio gained, this is possibly confirming to Abbasi *et al.* in terms of suffocation of the worms by the higher amount of Nitrogen [102]. On the other hand the table also indicates an optimum C:N ratio can be estimated as 25-40. This also comes in parallel with the results of Ravindran *et al.* [101] who had C:N ratio of 40 which achieved the best vermicompost quality. In addition to the aforementioned, the results also comes in parallel of Some research report that C:N ratio is strongly related the organic matter content of the vermicompost which concludes a decrease in organic matter leads to lower C:N ratio [23], [61], [120]. When biochar added to the Eisenia Fetida in vermicomposting of sewage sludge; it increased the no of cocoons by 213%, but affected the bioavailability of Cd and Zn [121].

4. Evaluation of vermicomposting in Egypt (as a sample developing country).

Egypt is producing approximately 10 million tons of MSW every year [122]. With some estimations goes to 23 million tons. Out of which the recycled amount is only 9.2 % [5]. However, studies shows that the major percentage of solid waste generated from developing countries is organic[122], [123]. Reaches up to 60% in Egypt - not considering biomass- raising it as a potential hungry country for energy.

MSW found to have highly organic waste in developing countries in general [19], [124]. Vermicomposting technology can be used for economical recycling of solid organic waste in developing countries because of the possibility to use on existing landfills and for gas production as well [18]. Vermicomposting – as per some studies – can be used as a complete sustainable system for small communities [125].

However, One of the most difficulties to use composting in developing countries is the waste separation process which might be needed to ensure only organic waste is available for the earthworms [126]. Most developing countries do not recycle their majority of MSW and mostly thrown in dump areas creating severe health and environmental problem [25]. This might be due the lack of education, corruption or the funds needed to build a landfill plant. An overlook on the solids waste management researches in the last 20 years shows that developing countries lack the advanced research on solid waste management [127] [18]. Which may be related to the lack of technological tools. Vermicomposting can reduce the volume of the MSW largely as well as achieving a reduction in greenhouse gas emissions [35], [91]. Comparison between composting and vermicomposting shown almost in all results a higher nutrient values in the vermicompost then compost.[47], [124], [128]. This could be a good indicator for developing countries to move from composting into vermicomposting strategy. In a similar study on CO2 emissions, it was concluded that CO2 emissions are much less than other treatment process [59]

4.1 Home composting

[129] investigated that home composting and vermicomposting could be a potential means of MSW treatment as it provides the least greenhouse gases emissions among other treatment processes. Using of aeration , bulking agents and earthworm abundance will enhance them [59]

Some research shown that home composting is used with good results good results [130].

4.2 Economic assessment

Few economic studies done to investigate the save of composting in general and vermicomposting in particular, some of those reached a figure of 84% of saving compared to landfill if proper sorting of MSW is made [131] and the figure reduces with reduction of sorting quality. It was found that both composting and vermicomposting are viable options [59]. In some experiment the above ground biomass and mass yield of maize grain has been increased by 7.7% and 18.3% respectively [51]. In the same experiment the cost of vermicomposting to conventional composting was less than 5% while the total gain was higher than composting by approximately 4 doubles.

4.3 Challenges

The selection of food and ingestion by earthworms is still not fully understood [132] raises a high risk problem against vermicomposting of MSW in developing countries due to poor or lack of MSW sorting and lack of products standards [131]. on another perspective in case of choosing to use home vermicomposting as a different treatment process, a challenge of social awareness with the benefits and methods to do. On the other hand the extensive use of pesticides in developing countries causes a great danger on the earthworms life and maturation that should be taken into account [21]. Due to the limited temperature ranges of vermicomposting, some pathogens are yet existing in the matured vermicomposting [18], [68].

In spite of the good properties of vermicomposting, yet it needs further research and development to come over the different drawbacks like the requirement to maintain of the mesophilic temperature and humidity [21]. Some of the drawbacks the persistence of harmful bacteria. This is because vermicomposting does not undergo a thermophilic state while the temperature of the compost is increased up 60 ºC causing death of harmful bacteria [57], [68].

Nevertheless, some earthworm techniques have been used in developing countries with some success like the earthworm eco-filtration for wastewater treatment [92]

Vermicomposting requires also high humidity and worms function better in special environment which is not easy to avail in many cases [21]. pH level also plays a great role as it has a high effect on the solubility of harmful material into soil [103]

5. Conclusion

Vermicomposting can be a viable economic and feasible option to solve the problem of MSW and green waste accumulation. The various research done on the conversion proves the feasibility of the process to produce a good fertilizers rich in nutrients and have various good results on plant growth. However, it worth noting that almost all the vermicomposting research on plant growth and nutrient recovery were made on limited number of crops pointing the need for the study of more plants especially over longer periods on the same land.

It’s suggested that the earthworm and its application would better be studied in separate devoted research project. This may help to devote exclusive research projects to the many benefits of those valuable creatures and reach solid results for direct applications.

It was noticed – up to the knowledge of the authors - that most of the research on the worm biology are quite old, this triggers some worries regarding the validity of the information especially with the dramatic changes in environment during the last 30 years.

The majority of research done on vermicomposting was made on the worm Eisenia Fetida. Therefore other studied are needed to investigate the behaviour of the local worms in each developing country, as such local worms might have been developed to cope with its environmental and weather surroundings.

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