Environmental Influence of Soil toward Effective Vermicomposting

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Abstract

Vermicomposting is a process by which the organic waste is converted into manure with the help of earthworms. Growth rate, onset of maturity (clitellum development), rate of reproduction (cocoon production) and population buildup of earthworm during vermicomposting have been depend upon the conditions like temperature, moisture and physico-chemical properties of the feed mixtures. *Eisenia fetida* was superior to other epigeic species and tolerate wide range of temperature, moisture and pH. Endogeic species produced lesser cocoon than epigeic species and cocoon production decreased at low temperature. Maintenance of temperature and moisture content is the critical step for vermicomposting. Growth and maturation of earthworms was best at 20–25°C temperature with 80–85% moisture content. Increase temperature upto 30°C accelerated growth rate of earthworms and lessened the time to sexual maturity. Earthworms can survive in the soil contaminated with heavy metals by accumulating heavy metals in their tissues.

Keywords: earthworm, growth rate, physico-chemical properties, heavy metals, vermicomposting

1. Introduction

Over the past few years disposal and management of organic solid wastes has become more problematic and rigorous due to rapidly increasing population, intensive agriculture and industrialization. Aristotle, the Greek philosopher, documented very early the importance of earthworm in the ecosystem, and called them "intestines of the earth". After that, Darwin [1] highlighted the role of earthworm in breakdown of animal matter as well as dead plant. Transformation of organic waste through vermicomposting is of multifold interest as along with checking pollution of the environment, it results in production of a rich, more stable and homogenous product as compared to composting [2, 3]. Vermicompost acts as a buffer, has a significantly lower volatile solid content and high N, P, K content in the plant available form [4, 5].

Out of the 3200 species of earthworm reported from the world over, 509 species belonging to 67 genera are known to occur in the Indian subcontinent and about 374 species have been reported from different habitats of India alone [6, 7]. Certain epigeic earthworms, which have natural ability to colonize organic waste; show tolerance to wide range of environmental factors; short life cycle; high reproductive rates; high rates of feedstock consumption, digest and assimilate organic matter shows good potential for vermicomposting [8]. Few surface feeders earthworms species which contain all these characteristics and widely used in vermicomposting of a wide variety of organic wastes are *Eisenia fetida* (Savigny), *Eudrilus eugeniae* (Kinberg), *Eisenia andrei* (Bouche), *Dendrobaena veneta* (Rosa) and *Perionyx excavatus* (Perrier). Other species like *Dichogaster modigilani, Drawida nepalensis, Lampito mauritii, Lumbricus rubellus* and *Dendrobaena rubida* have also been used to some extent [9, 10]. Growth rate, onset of maturity (clitellum development), rate of reproduction (cocoon production) and population buildup were recorded as the indices of suitability of a particular mixture for the worms.

2. Suitable species of earthworm used for vermicomposting

Epigeics species are useful for biosolid waste management as these worms can hasten the composting process to a significant extent and produce better quality of vermicomposts, compared with those prepared through traditional methods [11]. *Eisenia. fetida* is used throughout the world for this purpose as it is ubiquitous, can tolerate a wide range of temperature and can live in wastes with good moisture content [8, 12]. *Eudrilus eugeniae* and *Perionyx excavatus* is the other commonly used worm. *Eudrilus eugeniae* is large in size, grows rapidly but has poor temperature tolerance, hence, may be suitably used in the areas with less fluctuation of temperature (tropical areas).

Lampito mauritii, Drawida willsi, Dichogaster bolani and *Pheretima elongata* are some others useful species used in the vermicomposting [13–16]. There is a species specific variation in food preference and accordingly the time taken for bioremediation also varies. Kaviraj and Sharma [16] compared the efficiency of exotic *Eisenia fetida* and local *Lampito mauritii* in vermicomposting of municipality solid waste and showed that *Eisenia fetida* was much better in vermicomposting as compare to *Lampito mauritii* in terms of C:N ratio reduction, TOC reduction, increase in EC and TK but *Lampito mauritii* was able to modify the soil characteristics. Tripathi and Bhardwaj [11] also observed that both the species of earthworms increased the N, P, K content while decreased the C:N and C/P ratios after 150 days. Moreover, the average number of hatchlings and cocoons produced by *Eisenia fetida* were also much more than *Lampito mauritii*. Thus, they concluded that *Eisenia fetida* was a better adapted species for vermicomposting of kitchen waste mixed with cow dung under tropical conditions. Dominguez et al. [17] found that *Eudrilus eugeniae* is also be a suitable species for vermicomposting. Out of the Indian species *Perionyx excavatus*, *Dichogaster modigilani, Drawida nepalensis* and *Lampito mauritii* could be exploited for vermicomposting because of their continuous breeding, high rate of cocoon production, short development time and high hatching success [18].

Earthworm species *Eudrilus eugeniae, Eisenia fetida, Perionyx sansibaricus, Pontoscolex corethrurus* and *Megascolex chinensis* were compared for their efficiencies in biodegrading organic wastes and *Eudrilus eugeniae* was found to be superb of all these [10]. *Eudrilus eugeniae* inoculated in waste also diminish the toxic heavy metals and might be helpful in obtaining a clean environment [19]. Some scientists recommend that vermicomposting with polyculture gives faster results over monoculture [13, 20]. When three earthworm species, i.e. *Eisenia fetida*, *Perionyx excavatus* (epigeic) and *Lampito mauritii* (anecic) were used, the reactor with polyculture performed better than the traditional monoculture vermireactors [21]. On the other hand Elvira et al. [22] found that mixed cultures of epigeics species viz. *L. rubellus, E. fetida* and *D. rubida* did not show any advantage over pure cultures. They reported that *E. andrei* showed higher growth rates in mixed cultures while the growth rate of *L. rubellus* and *D. rubida* decreased slightly in mixed cultures as compared to pure cultures.

3. Effect of temperature and moisture on earthworm

Reinecke and Kried [23] and Reinecke and Venter [24] concluded that *E. fetida* could survive well even in harsh environmental conditions, especially temperature (5–43°C) and fluctuating moisture conditions. However, growth and maturation of earthworms was best at 20°C and 85% moisture content under laboratory conditions [11, 25]. Dominguez and Edwards [26] found that 80% moisture was optimum for vermicomposting of pig manure and hostel kitchen waste by *Eisenia anderi*. Lalander et al. [27] observed that if the temperature of the vermibed or unit was more than threshold temperature, then earthworm moves to the edges and top levels, leaving unprocessed material in the center.

Edwards et al. [28] studied the life cycle of *Perionyx excavatus* in a variety of organic wastes under various population density pressures and temperatures between 15 and 30°C. They observed that an increase in temperatures up to 30°C accelerated the growth of earthworms but decreased the time to sexual maturity. However, the highest rates of reproduction occurred at 25°C both in cattle solids and sewage sludge. Earthworms grew at similar rates in cattle solids, pig solids and aerobically digested sewage sludge, but the earthworms did not grow well in horse solids and grew poorly in turkey wastes. Edward [29] in another study evaluated the optimal conditions for breeding of *E. fetida* with different range of animal and vegetable waste under aerobic condition with temperature ranged from 15–20°C, moisture 80–90%, ammonia content <0.5 mg/g, salt content <0.5% and pH in the range of 5–9. He found that the population density of earthworms per unit volume or weight of a waste was very important in affecting rate of growth and reproduction.

Dominguez et al. [17] made an observation on the biology and population dynamics of *Eudrilus eugeniae* in cattle waste solids by growing them in groups of 1, 2, 4, 8 or 16 hatchlings in 100 g of waste in incubators at 15, 20, 25 and 30°C. They found that earthworm biomass production was temperature dependent, maximum production being attained at the two highest population densities and highest temperature (30°C). The highest organic waste to earthworm ratio of 10:1 (10%) was recorded at the most dense earthworm population.

Bhattacharjee and Chaudhuri [9] studied the reproductive biology of seven Indian species of earthworm, viz. *Lampito mauritii* Kinberg, *Polypheretima elongata* (Perrier), *Perionyx excavatus* Perrier, *Pontoscolex corethrurus* (Muller), *Dichogaster modiglianii* (Rosa), *Eutyphoeus gammiei* (Beddard), and *Drawida nepalensis* Michaelsen in different seasons (natural variation in temperature). The peregrine earthworms such as *Dichogaster modiglianii, Perionyx excavatus, Polypheretima elongata* and *Pontoscolex corethrurus* were continuous breeders with high fecundity. Native *Lampito mauritii* and *Drawida nepalensis* were found to be semi-continuous, whereas, *Eutyphoeus gammiei* was a discrete breeder. There was a dramatic increase in cocoon in the summer and monsoon months with peaks during April and July while cocoon production decreased during winter. Temperature also affected the incubation period of cocoons. With increase in temperature within a temperature range of 28–32°C under laboratory conditions, incubation period increased in the endogeic worms (*Pontoscolex corethrurus, Polypheretima elongata and Drawida nepalensis*) and decreased in the epigeic worms (*Perionyx excavatus* and *Dichogaster modiglianii)*. There was a significant ($P < 0.05$) positive correlation between number of hatchlings per cocoon and incubation period in *Lampito mauritii* only. Edwards and Arancon [30] reported that an increase in temperatures up to 30°C accelerated the growth of *Perionyx excavatus* and reduced the time for attaining sexual maturity. However, the highest rates of reproduction occurred at 25°C both in cattle solids and sewage sludge.

Elvira et al. [22] studied the growth rate and reproduction of the epigeic species *Lumbricus rubellus* and *D. rubida* in cow dung and their possible interactions with *E. andrei*. The mean growth rate of *D. rubida* was 3.84 mg/day, reaching sexual maturity at 54 days and producing an average of 1.45 cocoons per week. After collection, 85% of the cocoons of this species were viable, incubation took an average of 21.7 days and an average of 1.67 worms emerged from each cocoon. On the other hand, the mean growth rate of *L. rubellus* was 8.02 mg/day, maturity at 74 days, with a mean weekly production of 0.54 cocoons. After an incubation period of 36.5 days, 64% of the cocoons hatched and one worm emerged from each. The mixed cultures tested did not present any advantage over pure cultures; *E. andrei* showed higher growth rates in mixed cultures, while the growth rate of *L. rubellus* and *D. rubida* decreased slightly in mixed cultures as compared to pure cultures. On the other hand, maximum biomass gain by *P. excavatus* was 292 mg per gram cattle waste at 25°C. Increasing temperatures up to 30°C accelerated the growth of earthworms and lessened the time to sexual maturity [29].

Soobhany et al. [19] resulted that moisture content within the feed mixture decreased with an increase in temperature by employing *E. eugeniae* in municipal solid waste. Initially they set the starting temperature of municipal solid waste in the range of 28–30°C and moisture content within the range of 81.8–83%. During vermicomposting of municipal solid waste, a sharp increase in temperature was recorded by them which mainly due to heat evolution resulting from rapid breakdown of organic matter and nitrogenous compounds by microbial activities which cause the water evaporation from the feed mixture and moisture content was decreased upto 50–55%. So thus maintenance of temperature and moisture content is the critical step for vermicomposting.

4. Growth rate of earthworm

The earthworms grow best in easily metabolizable organic matter and non-assimilated carbohydrates; these also favor their reproduction [31]. There was a positive correlation between Growth and reproduction with volatilable solid content of the waste [29]. Earthworm growth slows down when C: N ratio and temperature is high [32, 33]. The biomass gain by *E. fetida* during vermicomposting was found to depends on the population density and food type [34]. Viljoen and Reinecke [35] observed that single raised worm began to gain biomass at a higher rate than those raised in batches. While Dominguez et al. [36] reported a decrease in worm biomass even when additional feed was provided to worms every week. So the physico-chemical or the nutrient characteristics of the waste might be related to the growth of earthworm along with temperature, pH and moisture content. The interaction of these physico-chemical organic waste palatability and strength of feeding by earthworm is directly related to the interaction of these parameters and consequently it affects growth and reproduction of earthworm [37]. Hartenstein et al. [38] reported the regression equations for *Eisenia fetida* with respect to its age and observed that 50% of the earthworm population became clitellate at 25°C in relation to population density in activated sludge and in horse manure. A mean particle size of 0.3 mm of horse manure proved superior in supporting a weight gain (+45%) than a particle size of 0.5 or 1 mm. Pure cellulose, newspaper or wood shavings as substrate were ingested by *E. fetida* but failed to result in weight gain. Neuhauser et al. [39] and Neuhauser et al. [40] also reported a weight loss in *E. fetida* for a longer duration in the waste. This might be due to the transformation of most of the substrate to vermicompost, which could not further support their growth. Gunadi et al. [41] reported that *E. fetida* and *E. anderi* grew much faster in tea leaf wastes pre-composted for 1 week as compare to fresh waste because of the high protein content. However in fresh cattle solids, death of *E. fetida* was observed after 2 weeks by Gunadi and Edward [42]. They attributed death of earthworms to the anaerobic conditions which developed after 2 weeks in fresh cattle solids. Mature worms were not able to adapt to the medium as compared to 20 day old worms. Rates of growth and cocoon production were slightly less in a defined medium (7% organic content) than in a cow manure control medium (70% organic content) [43].

Reinecke and Viljoen [44] observed that cocoon production by *Eudrilus eugeniae* was much more at 25°C in different types of substrates. Evans and Guild [45] however, observed a peak production of 3.8 cocoons per week per individual of *Eisenia fetida* at 13°C. On the other hand Venter and Reinecke [46] observed clitellum for the first time in *Eisenia fetida* after 60 days. A positive correlation was observed by Satchell [47] between number of cocoons and the zone of soil inhabited by worms. The species of the deeper soil layer produced less cocoons as compare to species living near the surface due to adverse environmental condition. Olive and Clark [48] reported that temperature more than optimum level decreased cocoon production in earthworms. Lavelle [49] found a positive relationship between the size of the adult and cocoons produced by the earthworms but Senapati and Sahu [50] reported that the size of worms bore a negative relationship with the number of cocoons. They asserted that greater rate of cocoon production by small to medium sized epigeic earthworm *Dichogaster modiglianii* and *Perionyx excavatus* and top soil endogeic worms *Pontoscolex corethrurus* and

Lampito mauritii was due to exposure to the high mortality risk environment. Lee [51] and Edwards and Bohlen [52] proposed that size of cocoon was not always correlated with size of worms as cocoon production and time for maturation varied with species, population density and external factors such as temperature, moisture and energy content of the available food. Barne and Striganova [53] noticed higher mortality rate with increase in density of worms but Jager et al. [54] reported that growth curves were hardly affected by changing the density of earthworm *Eisenia veneta* but had an unexpected effect on reproduction. At higher density, the earthworm produced cocoons at larger body size and the maximum reproduction rate was lower. Reinecke and Viljoen [44] found no significant correlation between cocoon size and number of hatchlings produced. Hatching success of cocoon produced by worms younger than 60 days was low, the rate of hatching increased as the worms grew. Gunadi et al. [55] reported that the numbers of cocoons were less with increasing time of pre-composting but there was no clear pattern of effect of pre-composting on the number of hatchlings produced in cattle solids. Weight of hatchlings varied from 2.5 to 2.6 mg/cocoon.

5. Changes in physico-chemical quality of the feed wastes during vermicomposting

The physio-chemical composition of the vermicompost is known to be influenced by the different kind of feed given to the animal, bedding material used and the way the waste is collected, stored and handled before utilization [56]. A detailed review of various changes in physico-chemical parameters of feed material during vermicomposting is given in the following section.

5.1. pH and electrical conductivity (EC)

The differences in the pH of vermicompost are directly dependent on the type of raw materials used for vermicomposting. Different substrates used for vermicomposting resulted in different types of intermediates products which shows a different behavior in pH shift. The neutral pH throughout the vermicomposting is ideal for the growth of earthworm [57]. The occurrence of acidic environment may be attributed to the bioconversion of organic acids or higher mineralization of the nitrogen and Phosphorus into nitrites /nitrates and orthophosphate, respectively [42, 58–60]. The pH of cow dung and sheep manure vermicompost came out to be 8.48 and 8.6 [60], cattle manure had a pH of 6.0–6.7 [61, 62], pig manure had a pH of 5.3–5.7 [63, 64] and the one derived from sewage sludge had a pH of 7.2 [65]. The lower pH of the final vermicomposts might be due to production of CO_2 and organic acids by microbes during the process of bioconversion of different substrates in the feed given to earthworms [66, 67]. The decline in pH might be due to reduction in quantity of different types of volatile solids and to the growth of earthworm's biomass. The larger the increase in biomass growth, there was greater the reduction in volatile solids and hence the more shift toward the acidic condition [68, 69]. A decrease in pH might be an key factor in nitrogen retention as this element is lost as volatile ammonia at higher pH value. The lower pH was due to production of fulvic acid and humic acid during decomposition [70].

The change of mesophilic to thermophilic condition changes pH from acidic to alkaline due to conversion of organic –N- to NH_4^+ [71–74]. Rynk et al. [75] suggested that the excess of organic nitrogen not required by microbes was released as ammonia which got dissolved in water and increased the pH of the vermicompost. Datar et al. [76], Singh et al. [77], Goswami et al. [78], Huang et al. [79] and Lleo et al. [80] also reported an increase in pH during vermicomposting of solid waste, beverage biosludge, tea factory coal ash, fruit & vegetable waste and home waste respectively. They asserted that an increase in pH during composting and vermicomposting process was due to progressive utilization of organic acids and an increase in mineral constituents of the waste. On the other hand Song et al. [67] and Ravindran et al. [81] observed decrease in pH during vermicomposting of fermented tannery waste and animal manure spiked with mushroom residue respectively. They attributed that production of CO_2, organic acids and joint action of earthworms and microbes lead to low pH of the vermicompost.

Electric conductivity (EC) is a good indicator of the suitability and safety of vermicompost [82]. The reports regarding electrical conductivity during vermicomposting process are contradictory, some workers reported decrease in electrical conductivity [77, 83–85] and others an increase in electrical conductivity [67, 69, 86, 87]. The decrease in pH might be due to decrease in ions after forming a complex, whereas the increase in pH might be due to the degradation of organic matter to release various types of cations of different mineral salts in available forms such as phosphate, ammonium and potassium [88, 89] or may be due to loss of organic matter [16].

5.2. Nitrogen

Earthworms may influence microbial N transformation such as mineralization, nitrification and denitrification through their interaction with soil biota and increase concentration of ammonia in the fresh vermicasts [90]. Nitrogen generally declines during aerobic composting due to use of nitrogen by the rapidly multiplying heterotrophic bacteria but it increases during vermicomposting [69, 77, 91]. Chaudhuri et al. [66] reported the decrease in potassium and nitrogen content during the vermicomposting of kitchen waste with the help of *P. excavatus*. This might be due to NH_3 volatilization, incorporation into earthworm tissue and leaching into bedding material with as well as without earthworms or due to release of ammonia [92]. Although, nitrogen content increased during the process of vermicomposting of various materials [93–97] but final TKN content in vermicompost was always dependent on the initial nitrogen present in the feed material and the degree of decomposition [98–100]. Decrease in pH may also have an important effect in nitrogen retention as nitrogen is lost as volatile ammonia at high pH [89]. There is also might be good relation between nitrogen and C/N ration of the initial feed mixture because less the C/N ratio the greater will be the decomposition rate of the organic waste and hence the greater the increase in nitrogen [101]. Casting and burrowing behavior of earthworms increase C and N mineralization due to nitrogen fixing bacteria [102]. According to Needham [103], Tillinghast [104] and Viel et al. [105] loss in organic carbon may be the critical factor for nitrogen addition. Mucoproteins in the mucus secreted by epidermal glands, urea excreted through nephridia and ammonia through the gut with cast materials also helped in enhancing the nitrogen content in the vermicompost. Dead worms and their decaying tissues also adds a significant amount of nitrogen to the vermicomposting system.

Whalen et al. [106] found that microbial biomass was responsible for maximum of nitrogen released from decomposing earthworm tissue. Whalen et al. [107] observed that juvenile of *L. terrestris* excreted significantly more nitrogen as compare to adults at 10°C but in *Aporrectodea tuberculata* nitrogen excretion was significantly greater for adults as compare to pre-clitellate individual at 18°C. There is a high concentration of NH_4-N, NO_3-N in soils incubated with earthworms than soil incubated without earthworms for 48 h. Amador et al. [108] reported that organic nitrogen released by dead earthworms reached to 21.1–38.6 t/h/year. Kumar et al. [109] revealed that the content of nitrogen was decreased during vermicomposting which may be due to denitrification, NH_3 volatilization and ammonification. The decrease in content of nitrogen was also supported by Benitez et al. [110] with 36% loss of total nitrogen during vermicomposting of sewage sludge.

5.3. Organic carbon and C:N ratio

The C:N ratio is one of the most common indicator used for estimating compost maturity [111]. A decline in C: N ratio <20 indicates an advanced degree of organic matter stabilization and reflects a satisfactory degree of maturity of organic wastes but a C:N ratio ≤15 is preferred for agronomic application [10, 112]. According to Song et al. [67], C:N ration <12 indicated that vermicompost had the preferable properties for field application. Speratti and Whalen [113] observed that mean N_2O and CO_2 fluxes during the study period tended to be greater from enclosures with added earthworms than the control (no earthworms added), but were non-significantly different due to the low survival rate of introduced earthworms. Better control of earthworm populations in the field is required to fully assess the impact of earthworms on CO_2 and N_2O fluxes from temperate agro-ecosystems. Similar results was also reported by Tognetti et al. [114] and observed that the rate of CO_2 production from vermicompost was much higher as compare to traditional compost. Cabrera et al. [115] reported faster decline in C:N ratio during vermicomposting as compared to compost without earthworm.. However, Atiyeh et al. [116] reported that the C:N ratio of the manure with or without earthworms decreased progressively.

The loss of organic carbon may be mainly due to high CO_2 emission via strengthened carbon mineralization due to respiratory activity of earthworms and microorganism [117] which cause faster reduction in carbon and lowering of C:N ratio during vermicomposting. The total organic carbon reduction ranged from 10 to 45% during vermicomposting of organic waste [118] while Singh et al. [82] observed increased in organic carbon content from soil to vermicast. The C:N ratio of vermicompost reduced to 12–17:1 from 21–69:1 [11, 16, 55, 119, 120]. Saha et al. [121] and Pramanik [122] observed that decrease in C:N ratio attributed to an increase in earthworm abundance which leads to rapid decrease in organic carbon due to enhancement in organic matter oxidation. Aira and Dominguez [123] reported that rise in microbial biomass during vermicomposting increase carbon losses. Briones et al. [124] suggested that calciferous organs of worms provided a mechanism of CO_2 regulation and both environmental and metabolic CO_2 could be fixed by this organ.

5.4. Phosphorus

Phosphorus is an important nutrient for growth of plants and is used for protein formation, metabolism, photosynthesis, seed germination and flower and fruit formation [125]. However,

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phosphorus in soil is in mineral form which was readily available for plants but the potential activity of earthworm and phosphate solublising microorganisms increases phosphorus availability for plants [120, 126].

Gomez et al. [85]; Pramanik [122]; Lim et al. [127]; Singh et al. [128]; Hanc and Chadimova [129] asserted that the rise in total Phosphorus during vermicomposting was probably due to mineralization and mobilization of phosphorus as a result of bacterial and fecal phosphatase activity of earthworms. When organic matter passed through the earthworm gut, some amount of phosphorus is converted into more available form due to enzyme phosphatase and further release of might be attributed to the phosphorus solublizing microorganisms present in the cast [20]. In 1999, Patron et al. [130] noted that earthworm activity accelerated transformation of organic Phosphorus to plant available phosphorus form. Lim et al. [127] and Bayon and Binet [131] observed an increase of phosphorus by 25% and 2.4–49.5% by employing E. fetida and *E. eugeniae* for vermicomposting of paper waste sludge and rice husk respectively. Ghosh et al. [132] observed that vermicomposting of different waste materials resulted into 12–20.9% increase in easily extractable phosphorus.

According to Kaviraj and Sharma [16], organic matter decomposition by microbes resulted into acid production which is the major mechanism for solubilization of insoluble phosphorus and potassium. Therefore, presence of a huge number of gut microbes in earthworm might play an important role in increasing phosphorus content in the vermicompost. Mba [133] and Wan and Wong [134] studied the effects of *Bacillus megaterium* (phosphate solubilizing bacteria) and earthworm *E. fetida* and *Pheretima guillelmi* on Phosphorus turn over and transformation in soil. They found that the number of *B. megaterium* was increased in all the treatments with earthworm. The activity of acid phosphatase increased in the treatments having earthworm *Pheretima guillelmi* along with a significant increase in both inorganic and water soluble phosphorus. Acid phosphatase promoted the hydrolysis rate of organic phosphorus into inorganic phosphorus and the *B. megaterium* found in the worm casts of *E. euginae*. According to Pramanik [122], the higher phosphorus content might pertain to the higher adsorption rate of NO_3^- anions and replacement of PO_4^- ions from humic colloids. Hanc and Chandimova [129] resulted that total phosphorus content in the final vermicompost was 11% higher than control. They also observed that enhanced number of microflora in the earthworm gut might have played an important role in release of available phosphorus.

5.5. Potassium

There are contradictory reports regarding the total potassium content in vermicomposts obtained from different substrates due to the differences in the chemical nature of the initial raw materials [135]. Song et al., [67], Gomez et al. [85], Benitez et al. [110], Lim et al. [127] and Bhat et al. [136] have reported higher potassium concentrations during vermicomposting process. Increase in potassium content in vermicompost suggested that earthworms have symbiotic gut microflora with secreted mucus and water to degrade the ingested substrate which cause release of easily assailable metabolites [89]. Garg et al. [83], Singh et al. [128] and Elvira et al. [137] reported that total potassium concentration decrease in vermicompost. This decrease in concentration of potassium may attributed to the variation in chemical composition of initial feed mixture or due to leaching of potassium because of low water holding capacity of the vermicompost [128].

Guerra-Rodriguez et al. [72], Delgado et al. [138] and Suthar [139] revealed that mineralization process significantly enhanced the concentration of exchangeable potassium during vermicomposting. Suthar [20] and Nahrul Hayawin et al. [96] also reported higher potassium content in the vermicompost produced from distillery sludge, oil farm waste and food industrial sludge respectively. Lim et al. [127] observed 15–121.4% increase in potassium content by using *E. eugeniae* for vermicomposting of rice husk. Huang et al. [84] cultured hatchlings, juveniles and adults *E. fetida* into three different culture tubs to study the changes in bacterial and fungal community composition. They observed that potassium concentration in vermicompost cultured with juveniles was more as compare to vermicompost cultured with adults earthworms. Vermicompost cultured with juveniles has 33.3% more potassium as compare to vermicompost cultured with adults.

5.6. Bioaccumulation of heavy metals and its effect on earthworms

The increasing exploitation of natural resources by human beings during the past few centuries has adversely affected the global balance of heavy metals causing a gradual increase in the concentration of metals in the soil ecosystem [140]. In order to maintain the environmentally sound soil quality, investigators are seeking methods to reduce the mobility of heavy metals from wastes to soil ecosystem. Metal mobility and availability can be reduced by raising the soil pH [141]. Phyto-remediation is known as the most viable and environment friendly technology. But, a limited number of plants have been found to have phyto-accumulation ability and a very less number can be used for field phyto-remediation because of low biomass production. Therefore, earthworms appears to be a valuable substitute for control of metals in contaminated soils [142]. According to Hopkin [143], the earthworms have capacity to control metals, particularly trace metals, such as Cu and Zn, in their bodies. Earthworms can also be used as bioindicators for assessing the level of soil contamination with agricultural runoff, heavy metals, acid rain, pesticides etc. [144].

The capability of earthworms to mitigate the heavy metal toxicity and to increase the nutrient profile of organic wastes might be useful in sustainable land restoration practices [20]. Heavy metals have the capability to bind with ligands of the tissues and thus leads to their bioaccumulation in the food chain [145]. A positive correlation between metal concentrations in the earthworms and those in the soils were observed with differences in bioaccumulation factors for different metals, this could be due to a variable metabolic requirement of earthworms for metals [146]. The effects of sub lethal concentrations of lead nitrate on reproduction and growth of *P. excavatus* was studied by Maboeta et al. [147]. The growth was affected negatively by the presence of lead while maturation rate and cocoon production was not affected.

Earthworms are have the capability to inhabit and survive in sites contaminated with metals [148] and have the ability to accumulate heavy metals in the cells of yellow tissue [149]. Earthworm populations may develop mechanism by which they can tolerate or resist the effect of metal induced stress. Such tolerance or resistance acquired by earthworms either through a variation in their genetic structure or reversible changes in an earthworm's physiology.

Toxicity tests done by various authors have shown that heavy metal pollution negatively affects life-history of earthworms such as growth, reproduction and survival [150]. Beyer et al. [151] studied the bioaccumulation of methyl-mercury in the *E. fetida* and its effect on regeneration after excision of the caudal end. They found that earthworms treated with 25 ppm or more methyl-mercury did not survive while the survival rates in other concentrations were 97% in control, 92% in 1 ppm and 79% in 5 ppm after 12 weeks. All surviving earthworms in the control regenerated but 29% of earthworms in 5 ppm group only healed without regenerating their tail end. An opposite results were reported by Boudou and Ribeyre [152] and Burton et al. [153] that the absolute concentration of total mercury and monomethyl-mercury bioaccumulated in *E. fetida* were higher in the earthworm exposed to the higher mercury soils and lower in the less mercury contaminated soils. The bioaccumulation factors for total mercury and monomethyl-mercury were larger in earthworms exposed to less contaminated soils and smaller in more mercury contaminated soils. Zhang et al. [154] reported that Bioaccumulation factors of methyl-mercury from soil to earthworms were much higher than those of total mercury, which suggested that methyl-mercury might be more easily absorbed by and accumulated in earthworms because of its lipid solubility.

Maenpaa et al. [155] showed that the treatment of high Phosphorus significantly reduced lead, zinc and cadmium bioavailability to the earthworm which was due to formation of metal–phosphate complex in the soils. This amendment reduce ecological risk to soil-inhabiting invertebrates exposed to heavy metal contaminated soils. Malley et al. [156] reported that earthworm act as an indicator for heavy metals toxicity that are present in the materials and are bioconverted, giving an indication of potential environmental hazard. The capacity of earthworm to uptake and redistribute heavy metals in their body lead to a balance between uptake and excretion which helps them to survive in metal contaminated soil. Kızılkaya [157] observed that the earthworm *L. terrestris* had the capacity to accumulate significant levels of zinc, and thus earthworm ingestion may result in zinc transfer to higher trophic levels. He observed that the cast and earthworm bodies receiving the highest Zn dose showed significantly higher Zn content than the non-treated soil. The effect of earthworm (*L. mauritii*) activity on mobility of Pb^{2+} and Zn^{2+} in the soil (DTPA-extractable) and its composting potential in the presence of these metals was investigated by Maity et al. [158] and suggested that the use of *L. mauritii* in amelioration of metal contaminated soil. Liua et al. [159] noticed that earthworm treatment increased the biomass of cabbage and decreased the bioaccumulation of Cd and Cu in the cabbage plants.

Udovic and Lestan [160] reported that bioavailability of Pb and Zn before and after soil leaching with EDTA with two earthworm species, *L. rubellus* and *E. fetida,* actively regulated soil pH, but did not significantly change Pb and Zn fractionation in remediated soil. Sivakumar and Subbhuraam [161] reported the effects of Cr (III) and Cr (VI) on the survival, behavior, and morphology of the earthworm, *E. fetida,* in water at pH 6, 7 and 8 and their toxicity in 10 different soils and an organic substrate. A decrease in the pH of water resulted in increased toxicity of Cr to the earthworm. In water, both Cr species produced behavioral changes and morphological symptoms. Wei-bao and Hong-qiang [162] elucidated role of earthworms and microbes in improving soil structure and controlling bioavailability of soil nutrients including heavy metals through bio-absorption, enrichment, precipitation, dissolution, and oxidation–reduction.

The influence of salinity on partitioning of, uptake in and toxicity of zinc to earthworms was studied by Owojori et al. [163] by exposing *E. fetida* in the laboratory for 28 days in OECD artificial soil spiked with either NaCl (experiment 1) or a combination of Zn and NaCl (experiment 2) and observed that the cocoon production was significantly affected by increased NaCl and Zn administered as individual substances, and the effects were more severe when both substances were present together. It was concluded that an increase in salinity had an additive to synergistic effect on influencing the toxicity of Zn to these earthworms. Frank et al. [164] noted slight increase in the metal contents in worm castings except for Cr and Zn over the worm feed mixture. This could be explained by the fact that organic matter was being reduced on passage through the gut of worms but actually worms did not appear to bioaccumulate metals within their tissue. Singh et al. [77], Kaur et al. [91] and Deolalikar et al. [165] reported an increase in heavy metal content in the vermicompost of paper mill sludge. The increase was more appreciable for Fe and Cu. The weight and volume reduction due to breakdown of organic matter during vermicomposting might have been the reason for increase in heavy metal concentrations in vermicompost. A 2% increase in Cu and a decline in the concentration of Mn, Zn and Pb in vermicompost were reported by Khwairakpam and Bhargava [166].

Song et al. [67] conducted a pilot scale trial to investigate the response of heavy metals and nutrients changes to composting animal manure spiked with mushroom residues with and without earthworms. They resulted that composting without earthworm have high concentration of heavy metals, that is, As, Pb, Cu, Zn, while that in vermicompost concentration of heavy metals decreased significantly relative to the compost. The decrease of metals concentrations in the vermicompost occurred for at least two reasons. First, vermicompost processed by earthworms had high level of humic acid which posed a stronger sorption effect on formation of stable metal humus complex especially for Cu and Zn [167]. Second, bioaccumulation of heavy metals by earthworms tissues with the help of epithelial layer and body fluids [168]. Singh et al. [82] and Kharrazi et al. [120] also observed decrease in concentration of heavy metals in the final vermicompost material. Soobhany et al [19] concluded that the reduction in toxic heavy metals by inoculating earthworm in the organic waste might be helpful in gaining clean environment.

6. Conclusion

Growth rate of earthworm, clitellum development, cocoon production and population buildup of earthworm were depend upon the physico-chemical composition of the feeding materials, types of feed mixture and environmental conditions like temperature, moisture and pH determine the sexual maturation in earthworms. Out of the various species of earthworms, *Eisenia fetida* is the most preferred species as it is hardy, prolific breeder and accepts a wide variety of food. Thus vermicast egested by the earthworm is a good source of N and P which is easily available to the plants and it has many advantages as compared to fertilizer and compost. The bioaccumulation of heavy metals by earthworms may be helpful to reduce the metal from organic waste. The feeding and casting activity of earthworm can stabilized the soil structure and change its physico-chemical properties and thus played an important role in sustainable agriculture.

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