Earthworms for Eco-friendly Resource Efficient Agriculture

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Abstract

Waste production became the main concern in the era of the increasing world population. Millions of tons of waste are being generated everyday worldwide, and now, it is a big challenge for managing the financial and ecological expense of these wastes. An additional significant problem is arising from the disposal of municipal solid wastes, which cause emission of greenhouse gases. For sustainable development, a chief part of municipal wastes has biological garbage which can be converted into eco-friendly material like vermicompost (VCM) by using earthworm. Earthworm's activities increase the soil fertility by improving soil formation, soil porosity, water infiltration, decomposition of organic material, humus formation, suppression of soil-borne diseases & pests, and by promoting nutrient cycles which ultimately help in plant growth. Due to their beneficial activities, they cause the main change in soil properties; therefore, they are known as "Ecological engineer." Earthworms also act as a bioindicator. Earthworm forms a significant portion of soil invertebrate's biomass about 40–90% in different soil condition. The earthworm species have great diversity across the globe, which is the deciding factor to earthworm's potent towards soil improvement. Indian earthworms are dominant by indigenous species that contribute approximately 89% of total earthworm diversity and are represented by nine families, 67–69 genera, and 418–509 species of earthworms out of them, approximately 51 are exotic species. The present chapter highlights in depth the role of earthworm in efficient and sustainable agriculture.

Keywords

Earthworms · Ecological engineer · Efficient agriculture · Municipal wastes · Soil fertility · Sustainable development · Vermicompost

Abbreviations

Ca	Calcium
Cd	Cadmium
cm	Centimeter
CM	Compost
DNA	Deoxyribonucleic acid
GA	Gibberellic acid
ha	Hectare
HMs	Heavy metals
IAA	Indole-3-acetic acid
K	Potassium
kg	Kilograms
kPa	Kilo Pascal
m	Meter
mg	Milligrams
mm	Millimeter
Mn	Manganese
MOs	Microorganisms
N	Nitrogen
P	Phosphorus
t	Tonnes
VCM	Vermicompost
μm	Micrometer

2.1 Introduction

During the green revolution, agricultural production was increased due to the heavy use of chemical fertilizer, bringing more area under irrigation and by using improved genotypes (Meena et al. 2020a). Nevertheless, excess use of chemical fertilizers disturbs soil macro- and micro-fauna leading to the degradation of soil quality. Another problem arising from this is increasing of organic wastes, and decreasing of better quality of food. Earthworms have immense potential to effectively utilize these wastes to produce vermicompost. Therefore, the vermicompost is a biological fertilizer formed by the action of different earthworm species. This vermicomposting greatly contributes to the soil health improvement, product quality, efficient agriculture and thereafter overall sustainable development (Fadaee 2012; Jangir et al. 2016; Jakhar et al. 2017). Vermicompost not only decreases the volume of organic wastes but also has beneficial effect on soil fertility and plant growth. Therefore, it is suggested that we must use organic fertilizer (i.e., VCM) for good health practice (Sinha et al. 2010; Meena et al. 2018, 2020b).

Earthworms are an important member of soil invertebrate contributing about 40–90% of soil macro-faunal biomass except in some ecosystem (Fragoso et al. 1999b; Tondoh et al. 2007). Aristotle was the first who draw the attention towards the importance of earthworm and called them "Intestine of Earth" (Edwards and Bohlen 1992). In 1881, Darwin wrote the scientific book—"*The formation of vegetable mould through the action of worms with observation on their habits*" (Feller et al. 2003) in which he mentions, how worms help in soil formation and contribute to the nutrient cycle (Clark et al. 2009). Due to their vital benefit, he called earthworm as "Friend of Farmer" (Ismail 1997). Most of the people especially during Darwin time think earthworms were only unpleasant slimy, blind, ugly, senseless, and deep animals and only used as fish bait (Feller et al. 2003), but Darwin work creates interest in earthworm (Ismail 1997).

On the basis of size and habitat, Oligochaeta class of the phylum Annelida is distinguished into two groups: Microdrili (small, mainly aquatic worms including the terrestrial family Enchytraeidae) and Megadrili (larger, mostly terrestrial worms and their aquatic representatives) (Julka 1993). Earthworm belongs to phylum Annelida, class Oligochaeta with bilateral symmetry. These soil invertebrates are long, narrow, cylindrical, segmented, brownish-black tinge to purple. The dorsal side of the earthworm is darker than the ventral side. These biological agents live for almost 3–7 years depending on the environmental condition and earthworm species. They are cold-blooded animal breath through moist skin. They do not have an eye but are sensitive to light through photoreceptors present at their head region (Ismail 1997; Canti 2003; Sinha et al. 2010). They are hermaphrodite, but cross-fertilization takes place. During fertilization, two earthworms adhere to each other by their ventral surface. In mature earthworm, the anterior region generally from 13 to 17 segmented becomes swollen with glandular thickening which produces cocoon, this segment is known as clitellum. Cocoon passed from this anterior region and deposited into moist soil. Two to three juveniles are hatched out from each cocoon (Edwards and Bohlen 1996). Earthworm's body has 65, 14, 14, and 3% protein, carbohydrates, fat, and ash, respectively (Sinha et al. 2010). Due to highly richen in protein content, they are used as fish bait (Feller et al. 2003). Under the optimum condition of temperature, moisture, and feeding material, earthworm can multiple up to 256 earthworms in every 6 months from single earthworm (Sinha et al. 2010).

Bouche (1977) classified earthworm into epigeics, anecics, and endogeics on the basis of their feeding habits and position in the soil layer (Fig. 2.1).

There is a complex interaction between earthworm and their surrounding environment that make a challenging task for their study that we now called earthworm ecology (Bartlett et al. 2010). There are no doubt earthworms have beneficial roles for crops, but a few earthworm species may harm crops like *Polypheretima elongata* in central Taiwan (Gates 1959; Shih et al. 1999). The earthworm has a major role in ecosystem services that is why they are also called as ecological engineers. They play an essential role in the soil formation, improved soil structure, prompted nutrient cycling, water regulation, climate regulation, and pollution remediation. Earthworms ingest surrounding organic material and breakdown them into smaller particles (Blouin et al. 2013; Bajiya et al. 2017; Lakhran et al. 2017). They can engulf waste material almost equivalent to their own body weight daily (Sinha et al. 2010) and makes macroaggregates through their borrowing, consumption and egestion activities, thus, help in pedogenesis and soil development (Bartlett et al. 2010). The more carbon

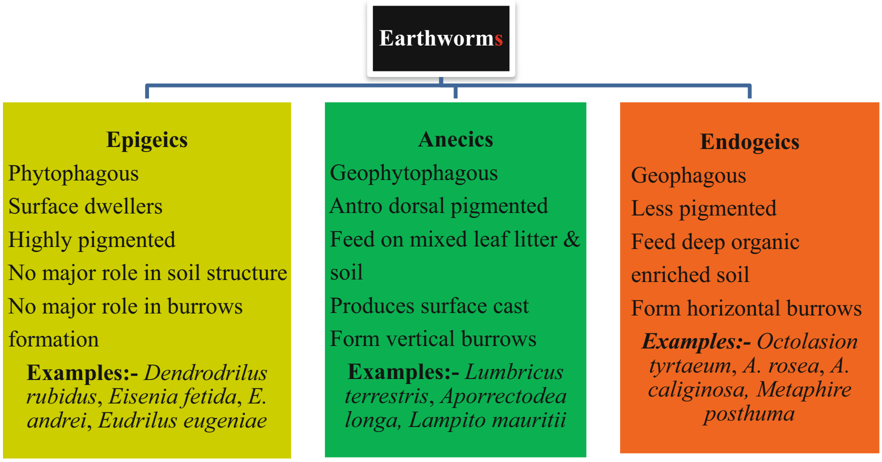

Fig. 2.1 Classification of earthworms

gets stored in these stable aggregates which improve the carbon sequestration and prevent its rapid release as greenhouse gas (Lavelle et al. 2006; Kumar et al. 2018; Meena et al. 2019). They were found to increase soil air volume 8–30%, thus refining water infiltration rate and water holding capacity (Wollny 1890; Ismail 1997).

Bioindicator has the main function of in-situ soil pollution if there is a link between deleterious change to an organism and the surrounding environment. Choice of an organism as bioindicator play a crucial part in an ecosystem, and it must be representative of almost all species inhabitant that area and the surrounding environment. The earthworm is a candidate for good bioindicator of soil pollution (Scott-Fordsmand and Weeks 2000). They have chemoreceptor which helps in searching for food. They are sensitive to the surrounding soil environment condition. They can tolerate 5–29 °C soil temperature (Sinha et al. 2010). Earthworms are susceptible to rehabilitation, biological disturbance, ecosystem perturbations (Fragoso et al. 1999a; Tondoh et al. 2007), soil humidity, soil pH, humus quality, metal contamination, pesticides, agricultural practices, and acid rain (Muys and Granval 1997). The change in number, biomass, or species richness in the natural population can be used as bioindicator. They can accumulate heavy metals (HMs) in their body tissue (Scott-Fordsmand and Weeks 2000), and particular species can accumulate specific metal contaminant. Therefore, also act as a biological indicator of metal pollution in soil (Suthar et al. 2008).

A large amount of animal and plant residues are being produced as the global human population continued to increase, which become a significant cause of pollution. Nowadays waste management becomes a serious problem. The landfill is not a solution to all problems because it may cause underground water pollution (Fadaee 2012). For efficient management, waste material must be converted into useful products. Earthworm converts biodegradable material into a different product which can be directly used by plants, thus helps in nutrient cycling. Crop residue can be converted into smaller particles about 2–3 microns by gizzard and passed from the intestine for enzymatic action. Bioreactor (gizzard + intestine) releases various enzymes like amylase, protease, lipase, cellulases, and chitinase, which bring biochemical conversion of waste material (Sinha et al. 2010). The earthworm has the efficiency to engulf a vast amount of organic material and release cast (earthworm excreta). Earthworm's cast is organic fertilizer because of rich in humus, exchangeable nitrogen (N), phosphorus (P), potassium (K), manganese (Mn), calcium (Ca) and other beneficial microorganisms (MOs) (phosphate solubilizing bacteria, N-fixing bacteria, *Pseudomonas,* actinomycetes), and plant growth hormone (gibberellins, auxin, cytokinin) (Ismail 1997; Adhikary 2012). During the passing of organic waste through earthworm's gut, MOs get incorporated in this ingested waste and released with the cast. These MOs further help in the breakdown of organic material. Finally, this waste is converted to VCM, which is also known as "organic gold" (Sinha et al. 2010).

2.2 Diversity of Soil Earthworms

Most of the ecosystems are highly rich in soil fauna which is distinguished by their body size. Soil macro-fauna have body size larger than 2 mm (millimeter) and mesofauna having a size between 100 μm (micrometer) and 2 mm; whereas microfauna has a size less than 100 μm (Barrios 2007; Wissuwa et al. 2012; Wu and Wang 2019). Among them, soil macro-fauna (invertebrates) like earthworms, root herbivorous insects, ants, and termites play the most crucial function in the sustainability of agroecosystem (Bottinelli et al. 2015). Here we only study the diversity of earthworm because of our main concern in this chapter for earthworms (Table 2.1). Diversity and composition of earthworms vary from site to another site over a broad range, but they are mainly abundant in the tropical region (Fragoso et al. 1999b; Decaëns et al. 2004). All over the world almost 4200–4400 of oligochaetes of 20 families are noticed, out of them about 3200 species are magadrili (e.g. earthworm), and almost 280 species belong to microdrili (Munnoli et al. 2010; Goswami and Mondal 2015). The Indian subcontinent has bulk of oligochaete fauna in which indigenous species contribute approximately 89% of total earthworm diversity and are represented by nine families, 67–69 genera, and 418–509 species of earthworms (Munnoli et al. 2010; Dash and Saxena 2012; Sharma and Poonam 2014) of which approximately 51 are exotic species. The Western Ghats, Eastern Himalayas, and Western Himalayas contribute 53, 26, and 12% earthworm species, respectively (Paliwal and Julka 2005; Dash and Saxena 2012).

2.3 Beneficial Attributes of Earthworms

Soil organism lives in the soil as well as they are part of the soil, therefore, influences the soil properties such as aeration, gaseous composition, and hydrology. Earthworms improve soil structure through modification of different soil properties that are finally essential for improving soil richness and primary production for any ecosystem (Brussaard 1997). Earthworms have many benefits (Fig. 2.2), and due to

Table 2.1 Diversity of Indian earthworm

S. No.	Family	Number of species	Name of species	Place of study	References
1.	Monilgastridae	7	*Drawida paradox, D.* sp. *(nr. thurstoni Gates), D. ampullacea, D.* sp.1, *D.* sp.2, *D. kanarensis, D. sulcata*	Western Ghats	Blanchart and Julka (1997)
	Megascolecidae	3	*Megascolex* sp., *Perionyx* sp., *Lennoscolex* sp.		
	Octachaetidae	18	*Hoplochaetella* sp.1, *H.* sp.2, *H. sanvordemensis, Hoplochaetelia H. Gates, Konkadrilus tirthahalliensis, K.* sp.1, *K.* sp.2, *K.* sp.3, *Genus A* sp.1,*Genus* sp.2, *Genus B*.sp.1, *Genus C* sp.1, *Genus C* sp.2, *Genus C* sp.3, *Mallehtdla indica, Wahoscolex* sp., *Karmiella karnatakensis, Karmiella* sp.1		
2.	Glossoscolecidae Megascolecidae Ocnerodrilidae Octochaetidae	9	*Ramiella bishambari, Dichogaster bolaui, Amynthas morrisi, Octochaetona paliensis, Perionyx sansibaricus, Pontoscolex corethrurus, Ocnerodrilus occidentalis, L. mauritii, M. posthuma*	Arid regions of Jodhpur, Rajasthan	Tripathi and Bhardwaj (2004)
3.	Moniligastridae, Lumbricidae Almidae Ocnerodrilidae Acanthodrilidae Octochaetidae Megascolecidae	51	*Dendrodrilus rubidus, Drawida japonica, D. nepalensis, Allolobophora eiseni, A. parva, Eisenia fetida, Aporrectodea caliginosa,*	Western Himalaya states	Paliwal and Julka (2005)

(continued)

Table 2.1 (continued)

S. No.	Family	Number of species	Name of species	Place of study	References
			Aporrectodea trapezoides, Aporrectodea rosea, Lumbricus castaneus, L. terrestris, Dendrobaena hortensis, D. octaedra, Octolasion cyaneum, O. tyrtaeum, Glyphidrilus sp., *Malabaria levis, O. occidentalis, Eiseniella tetraedra, Thatonia exilis, T. gracilis, Microscolex phosphoreus, Plutellus sadhupulensis, D. bolaui, Eutyphoeus annandalei, E. incommodus, E. nainianus, E. nicholsoni, E.orientalis, E. pharpingianus, E. waltoni, Lennogaster chittagongensis, L. parvus, L. pusillus, L. yeicus, R. bishambari, Amynthas alexandri, A. corticis, A. gracilis, A. morrisi, Metaphire anomala, M. birmanica, M. houlleti, M. posthuma, Perionyx bainii, P. barotensis, Perionyx excavatus, P. nainianus, P. sansibaricus, P. simlaensis*		
4.	Moniligastridae Glossocolecida Megascolecidae Acanthodrilidae Octochaetidae Eudrilidae	10	*Octochaetona serrata, O. barnesi, P. excavatus, E. eugeniae, Pontodrilus bermudensis, L. mauritii, P. corethrurus,*	Pondicherry region	Sathianarayanan and Khan (2006)

			Drawida willsi, D. lamella, D. scanden		
5.	Eudrilidae Lumbricidae, Megascolecidae Ocnerodrilidae Octochaetidae Moniligastridae	30	*E. eugeniae, A. caliginosa, A. parva, D. rubidus, E. fetida, Octolasion tyrtaeum, A. alexandri, A. corticis, A. gracilis, A. morrisi, L. mauritii, Metaphire houlleti, M. posthuma, Polypheretima elongata, P. bainii, P. barotensis, P. excavatus, P. sansibaricus, P. simlaensis, Gordiodrilus elegans, O. occidentalis, D. bolaui, Eutyphoeus ibrahimi, Eutyphoeus incommodus, E. waltoni, L. chittagongensis, L. pusillus, O. beatrix, R. bishambari, D. japonica*	Northern Indian states	Dhiman and Battish (2006)
6.	Octochaetidae	6	*A. alexandri, Eutyphoeus oreintalis, E. incommodus, E. waltoni, E. nicholsoni, Octochaetona Beatrix*	Rajaji National Park, Uttarakhand (foothills of Shivalik Himalaya)	Joshi and Aga (2009)
7.	Moniligastridae Lumbricidae, Octochaetidae, Megascolecidae	9	*Drawida nepalensis, O. tyrtaeum, E. incommodus, E. orientalis, E. pharpingianus, E. nicholsoni, O. beatrix, E. waltoni, L. mauritii*	Doon valley of Western Himalayan, Uttarakhand	Deepshikha (2011)
8.	Glossoscolecidae, Megascolecidae, Lumbricidae, Ocnerodrilidae, Octochaetidae		*P. corethrurus, L. mauritii, A. parva, M. posthuma, D. bolaui, O. paliensis, A. morrisi, R. bishambari, O. occidentalis, Malabaria* sp., *P. sansibaricus*	Semiarid area, and western arid, Rajasthan	Suthar (2011)

(continued)

Table 2.1 (continued)

S. No.	Family	Number of species	Name of species	Place of study	References
9.	Moniligastridae, Megascolecidae, Lumbricidae	8	*A. caliginosa, Octolasion cyaneum, E. fetida, O. cyaneum, A. rosea, A. trapezoides, A. corticis, D. japonica*	Kashmir Valley, J&K	Najar and Khan (2011)
10.	Moniligastridae, Megascolecidae, Lumbricidae, Octochaetidae	8	*Metaphire birmanica, A. alexandri, P. excavatus, D. nepalensis, Bimastos parvus, M. anomala, O. beatrix, Lennogaster pusillus*	Bhiri-Banswara, Chamoli, central Himalaya	Bhadauria et al. (2012)
11.		30	*Perionyx sansibaricus, P. excavatus, O. beatrix, L. pusillus, R. bishambari, Eutyphoeus incommodus, E. michaelseni, E. waltoni, D. nepalensis, Thatonia gracilis, D. bolaui, A. alexandri, A. corticis, A. morrisi, M. houlleti, M. posthuma, D. japonica, O. occidentalis, A. parva, A. trapezoides, A. rosea, E. fetida, O. tyrtaeum, Perionyx* (4 species), *Eutyphoeus* (2 species), *Plutellus* sp.	Western Himalaya	Dash and Saxena (2012)
		19	*L. mauritii, P. excavatus, D. nepalensis, Dichogaster affinis, D. bolaui, A. alexandri, A. corticis, A. morrisi, M. houlleti,*	Eastern Himalaya	

			M. posthuma, P. elongata, P. corethrurus, A. parva, A. trapezoides, A. rosea, E. fetida, O. tyrtaeum, Tonoscolex sp., *Kanchuria* sp.,		
		36	*L. Mauritii, P. excavatus, P. sansibaricus, O. beatrix, Octochaetona palniensis, R. bishambari, D. affinis, D. bolaui, Amynthas alexandri, A. corticis, A. morrisi, M. houlleti, M. posthuma, P. elongata, P. corethrurus, O. occidentalis, A. parva, A. trapezoides, A. rosea, E. fetida, O. tyrtaeum, Curgiona* sp., *Kotegeharia* sp., *Mallehulla* sp., *Priodochaeta* sp., *Karmiella* sp., *Troyia* sp., *Comarodrilus* sp., *Chaetocotoides* sp., *Parryodrilus* sp., *Dashiella* sp., *Moniligaster* sp., *Celeriella* sp., *Lampito* sp., *Travoscolides* sp., *Wahoscolex* sp.	Western Ghats	
12.	Acanthodrilidae, Glossoscolecidae, Moniligastridae, Megascolecidae, Octochaetidae		*Argilophilus* sp., *Perionyx ceylanensis, P. corethrurus, Drawida grandis, D. parva, D. travancorensis, D. sulcata, D. nr. parambikulamana, D.* sp., *D. robusta, Priodochaeta pellucid, A. corticis*	Nilgiri biosphere reserve, Western Ghats	Chandran et al. (2012)

(continued)

Table 2.1 (continued)

S. No.	Family	Number of species	Name of species	Place of study	References
13.	Megascolecidae, Octochaetidae, Lumbricidae		*M. posthuma, A. morrisi, L. mauritii, E. incommodus, O. beatrix, Bimastos parvus*	GNDU, Amritsar, Punjab	Mohan (2013)
14.	Moniligastridae, Megascolecidae, Octochaetidae, Lumbricidae	18	*Amynthas robustus, A. morrisi, M. posthuma, L. mauritii, D. bolaui, D. nepalensis, E. incommodus, E. waltoni, E. nicholsoni, O. occidentalis, O. beatrix, Bimastos parvus, R. bishambari, L. pusillus, M. birmanica, M. houlleti, P. simlaensis*	Haryana	Sharma and Poonam (2014), Bhardwaj and Sharma (2016), and Garg and Julka (2016)
15.	Moniligastridae, Megascolecidae, Almidae, Glossoscolecidae, Lumbricidae, Ocnerodrilidae	17	*M. posthuma, D. nepalensis, Drawida* sp.1, *Drawida* sp.2, *G. elegans, Glyphidrilus gangeticus, Eutyphoeus* sp., *P. excavatus, P. annandalei, P.* sp., *Amynthas diffringens, A. alexandri, L. mauritii, E. fetida, Eisenia* sp., *P. corethrurus, Dichogaster saliens*	Assam, an indo-Burma biodiversity hotspot.	Rajkhowa et al. (2015)
16.	Megascolecidae, Octochaetidae	6	*M. posthuma, P. excavatus, A. diffringens, L. mauritii, D. bolaui, E. orientalis*	West Bengal	Goswami and Mondal (2015)
17.	Naidae, Tubificidae, Lumbricidae, Megascolecidae, Octochaetidae, Moniligastridae	51	*Aulophorus tonkinensis, Branchiodrilus hortensis, Dero limosa, D. bolaui, Nais communis,*	Uttar Pradesh	Verma and Bharti (2010); Prakash (2017)

			Nais obtuse, N. inaequalis, Pristina aequiseta, Haemonais laurentii, Aulodrilus kashi, A. stephensoni, Branchiura sowerbyi, Allolbophora papillatus, Glyphidrilus tuberosus, G. papillatus, P. corethrurus, E. fetida, A. morrisi, L. mauritii, M. posthuma, M. houlleti, M. anomala, M. birmanica, M. elongata, P. excavatus, P. sansibaricus, P. elongata, O. occidentalis, Malabaria sulcata, L. pusillus, Pellogaster bengalensis, E. incommodus, E. mohammedi, E. waltoni, E. masoni, E. pharpingianus, E. orientalis, E. paivai, E. nicholsoni, E. gigas, Eudichogaster ashworthi, E. parvus, E. prashadi, R. bishambari, O. fermori, O. paliensis, O. beatrix, O. surensis, D. calebi, D. willsi		

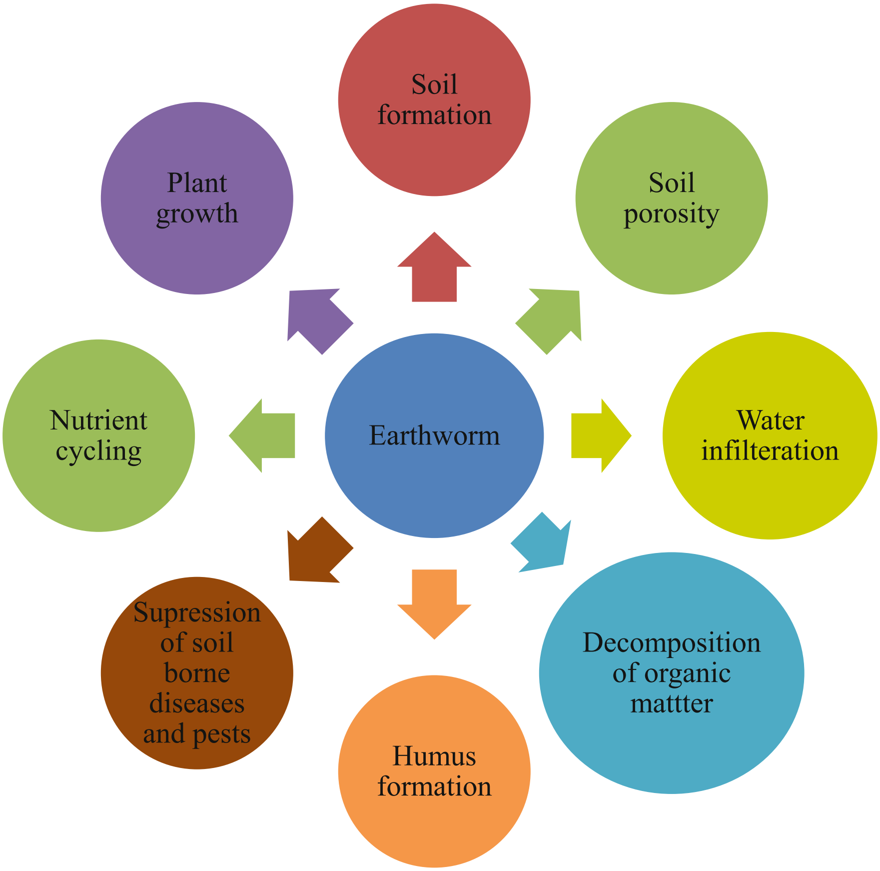

Fig. 2.2 Benefit of earthworms

that, Darwin and Aristotle, respectively, called them as "friend of farmer" and "intestine of earth" (Ismail 1997).

2.3.1 Soil Formation

Soil formation is a long-time process which is influenced by surrounding environment condition and parent material. Earthworm helps in soil development through different ecosystem services like mineral weathering, humus formation, vermiform soil formation, and mixing of organic material with soil to create water-stable aggregate (Pop 1998; Blouin et al. 2013). Darwin (1881) noticed that earthworm causes downward movement of small stones and gravel as well as additionally caused annual deposition of 10 tonnes (t) of fine soil to the soil surface. Sinha et al. (2010) also observed that three million earthworms in one-acre soil could transport 8–10 t of topsoil to the surface within 1 year. The "vermiform soil" contributes about 50% or more in the "A" horizon and 25% in the "B" horizon (Pop 1998; Blouin et al. 2013). Because earthworms ingest a huge amount of organic material and organically enriched soil, and finally release cast in the soil where they are inhabitant. These casts not only help in soil formation but also improve the soil structure and provide resistance to soil erosion (Le Bayon et al. 2002). These casts have MOs with some mucus, thus form water-stable aggregates (organo-mineral complexes) (Lavelle et al. 2006). The water-stable aggregate is deposited either on the surface or within the soil depending upon environmental condition and earthworm species ultimately help in soil formation (Le Bayon et al. 2002). In a temperate climate, earthworm's cast may be form 2 to 10 kg m^{-1} (kilograms per meter) soil that is corresponding to 5–25 mm thick soil layer (Bertrand et al. 2015). Jouquet et al. (2008) observed that *Amynthas khami* (anecic earthworm species) released 8–22 cast kg m^{-2} on the soil surface that could create 5–15 centimeter (cm) deep soil horizon (Bottinelli et al. 2015).

2.3.2 Soil Porosity

Compaction of soil is a serious problem in agriculture practice associated with running of heavy machinery on soil surface continuously. Due to soil compaction air volume can be reduced from 12% to 7% (Hansen 1996; Jégou et al. 2002). It is well understood that the earthworm burrow system plays the most important contribution in increasing soil porosity by changing physical, chemical, and biological properties of soil. Soil pores formed by earthworm influence decomposition of organic material, water infiltration rate, distribution of nutrient, and gas exchange during the plant respiration and thus promote root growth. Burrow system formed by earthworm also influences the microbial action and movement of other soil organisms in their surrounding environment. It is also observed that to improve the plant yield in organic farming; there is a need to avoid the soil compaction rather than to increase manure (Langmaack et al. 1999; Jégou et al. 2002). Depending on the ecological group (i.e., epigeic, anecic, and endogeic), earthworms created macropores 2–11 mm in diameter. Epigeic earthworms have no major contribution to soil porosity. However, a diameter of endogeic earthworm's pores ranging between 2 and 5 mm and anecic earthworms form large vertical orientated, semi-permanent dig (larger than 5 mm diameter) that can extend greater than 2 m in soil depth. Thus, endogeic and anecic species have a major contribution in soil porosity (Langmaack et al. 1999; Fischer et al. 2014).

2.3.3 Water Infiltration

Water infiltration in the soil is mainly dependent upon the soil porosity than the other soil properties (Gupta and Kumar 2018). It was also expected that the spatial distribution of plant roots is controlled by macropores (Dahiya et al. 2018). Large macropores play a primary role in the regulation of water infiltration (Bottinelli et al. 2015). Water infiltration rate depends upon the geometry (diameter and length), and spatial properties of earthworm's burrow system (Chan 2004). In dye infiltration experiment showed that only 53% macropores were able to conduct water and rest may be blocked due to casts and plant roots (Chan 2004). Shuster et al. (2002) found that water percolation rate is defiantly associated with earthworm's biomass, burrow surface area and its length. For examples, earthworm presence (10 years) increased water infiltration rate from 15 to 27 mm h^{-1} (Clements et al. 1991). Soil pore formed by earthworm is responsible for two- to tenfold increment of water infiltration (Lee 1985; Chan 2004), and in the United States, 50% water penetration increment was observed which is equivalent to benefit given by three farmers (8 h day^{-1}) all over the year with using manure (Li et al. 2010; Sinha et al. 2010). Water infiltration by anecic earthworms reduced the soil erosion by up to 50% (Shuster et al. 2002).

2.3.4 Organic Matter Decomposition

The organic matter decomposition represents the most important catabolic process of photosynthesis performed by soil organisms (Jangir et al. 2017, 2019). It is the conversion of complex organic material in to simpler one by soil organism (Barrios 2007). Earthworms are involved in the breakdown of soil organic material. They break down large soil particles, plant litter, and any other organic material into small particles, as a result, it increased the surface area for microbial degradation. Microbial number and activities were increased when organic material passes through the earthworm's gut that helps in its degradation. Earthworm's cast is rich in clay, glycoprotein, polysaccharides, bacteria, fungi, and many other MOs which increased the efficiency for microbial degradation (Edwards et al. 1996; Furlong et al. 2002). Brussaard (1997) observed that 90% of organic material decomposition caused by MOs such as bacteria, fungi, etc. Water-soluble nutrients (like Ca, Mg, K) are also increased during and after the passage through the earthworm's gut (Carpenter et al. 2007). Due to earthworm, rearrangement of organo-mineral material occurred through decomposition, and finally, they provide a nutrient that can be easily absorbed by the plants (Araujo et al. 2004). There are mainly four mechanisms involved for earthworm and microbe's interaction that help in the breakdown of organic material (Fig. 2.3) (Brown 1995; Bertrand et al. 2015).

2.3.5 Humus Formation

The process of humus formation is slow in which darkening of soil mold occurs primarily by chemical reactions and microbial activity (Edwards et al. 2010). Humic acid is the major part of humus which is characterized by dark-colored, alkali-soluble, and acid-insoluble organic material. Organic materials can form the humus within a few months depending upon the environmental condition and earthworm species (Canellas et al. 2002). For examples; in vermicomposting, earthworms

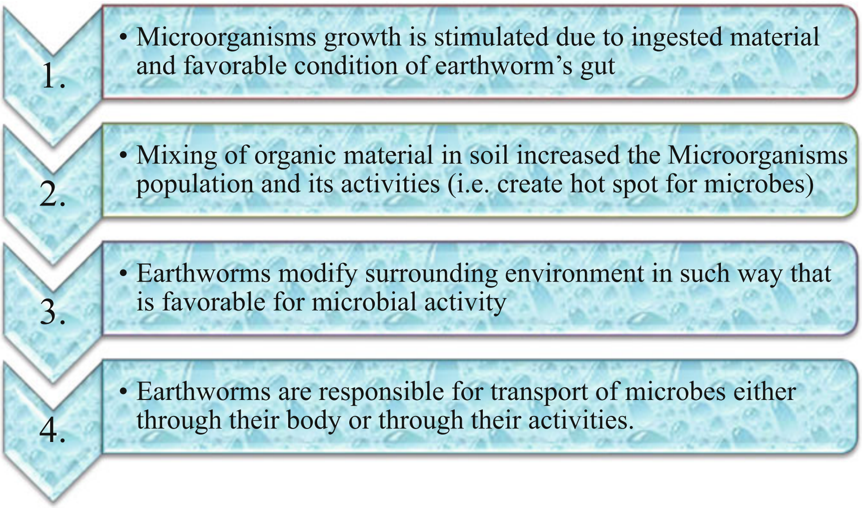

Fig. 2.3 Mechanisms involved in organic matter decomposition by earthworm

provide a favorable condition that leads to an increase of 40–60% humus substances as compared to compost (CM) (Dominguez et al. 1997). Humification rate in the soil is controlled by earthworm's activities such as mixing of leaf litter, burrowing, feeding habit, casting, and interaction with microbes (Edwards et al. 2010). As compared with other manure, earthworm's cast has higher humic acid (Li et al. 2010). Earthworms ingest 12 t of soil/organic material per hectare per year, as a result, turning 18 t of soil per hectare per year. Thus, it was producing 2 inches humic fertile layer that is essential for plant health (Sinha et al. 2010). In the absence of humus, plant growth is retarded (Li et al. 2010). Transferable auxin was noticed in the macrostructure of composted humus that suggests that hormonal activities in humus (Canellas et al. 2002).

2.3.6 Suppression of Soil-Borne Diseases and Pests

The occurrence of soil-borne diseases and pests in a natural ecosystem is rare, but it is common in agriculture. Plant-parasitic nematodes are a significant problem in agricultural which reduce the yield of plant and this cause economic loss worth over 100 billion annually (Barker 2003). Earthworms indirectly control the nematodes population (Räty and Huhta 2003; Blouin et al. 2005), also in the presence of earthworms, the expected inhibition of plant photosynthesis is suppressed, and root biomass was not affected by a nematode. External cysts on rice (*Oryza sativa*) roots formed by *Heterodera sacchari* but in the presence of earthworm suppression of infestation up to 82% was observed (Blouin et al. 2005), e.g. *Reginaldia omodeoi* (formally known as *Millsonia anomala*) (Bertrand et al. 2015). The severity because of the soil-borne fungal pathogen also gets reduced in the presence of earthworms, e.g. *A. rosea* and *A. trapezoides* (Stephens and Davoren 1997; Bertrand et al. 2015).

2.3.7 Nutrient Cycling

Nutrient cycling is a very difficult task to measure the accurate flow and transformation of nutrient from the soil (Kakraliya et al. 2017a, b; Kumar et al. 2020). Therefore, to evaluate the potential contribution of earthworms to nutrient cycling in an ecosystem, data from the laboratory has been combined with the result of biomass and climatic condition (Haimi and Huhta 1990). After the digestion, some nutrient flows in the environment whereas some remain in the soil. Earthworms modified the complex nutrient into more simple reusable form for the plant, especially N compound. Earthworms contribute in N mineralization directly through their dead body and metabolic waste (like cast and mucus; that may contain ammonium, allantoin) as well as indirectly through changing soil properties, fragmentation, and interactions of organic material with MOs (Blouin et al. 2013). Carpenter et al. (2007) studied that, 300 earthworms m^{-2} could have 14 kg N ha^{-1}(hectare) and most of the N is present in the 0–15 cm soil layer (Bertrand et al. 2015).

2.3.8 Plant Growth

In several ways, soil invertebrates have found to affect plant growth by influencing plant competition and susceptibility to herbivores. Earthworm burrows system is one of the belowground associations that affect plant growth (Meysman et al. 2006). Plant uses earthworms burrow to grow its root and also for respiration. Earthworm's activities increased the nutrient turnover for plant growth (Lavelle et al. 1998). For examples, *R. omodeoi* presences in soil increased shoot biomass and carbon dioxide (CO_2) assimilation by 40% and 13%, respectively (Blouin et al. 2007). Earthworm helps to improve the nodulation process of legumes led by *Rhizobium* species (Bertrand et al. 2015). Five mechanisms are responsible for plant growth by earthworms (Fig. 2.4) (Brown et al. 2004; Bertrand et al. 2015).

2.4 Earthworm as Agent for Ecological Engineer

Ecological engineers are those who have directly and indirectly affect physical, chemical, and biological properties of the surrounding soil environment (Fig. 2.5). In other words, the presence of organism affects the surrounding abiotic environment, but real ecological engineers are those which impart themselves in a way that their absence or presence has a significant effect on ecological services. In short, earthworm as an ecological engineer has direct or indirect effect on surrounding abiotic and biotic factor of soil (Coleman and Williams 2002; Meysman et al. 2006).

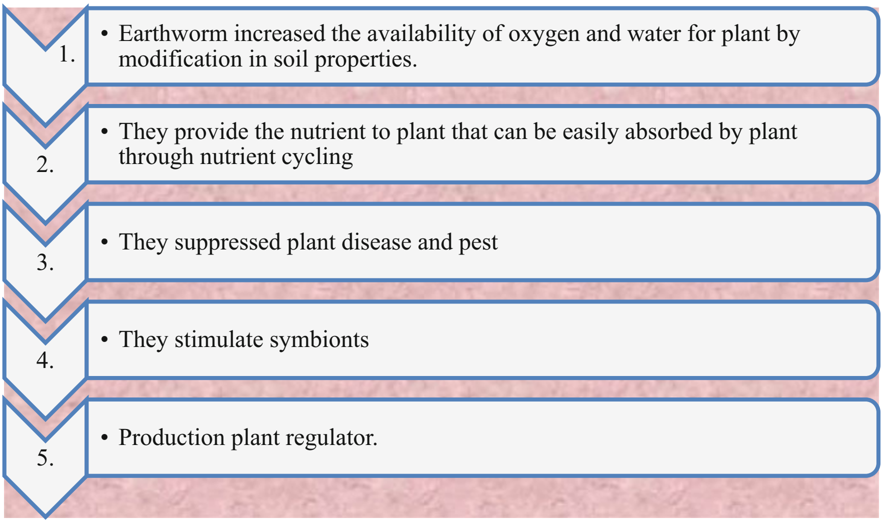

Fig. 2.4 Mechanisms involved in plant growth by earthworm

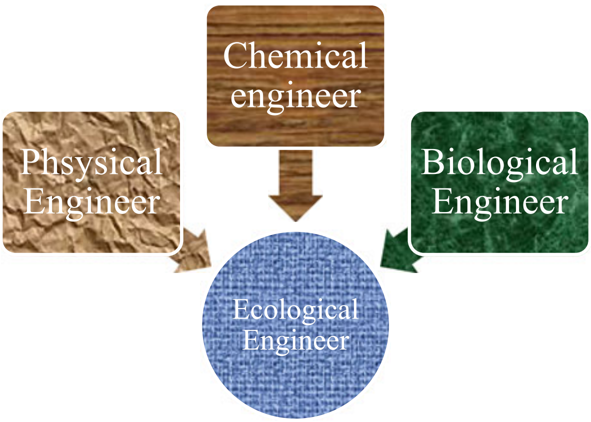

Fig. 2.5 Component of ecological engineer

Over 600 million years, earthworms are considered as "ecosystem engineers" due to their vital role to sustain the soil ecosystem (Sinha et al. 2010).

2.4.1 Earthworm as Physical Engineer

The earthworms form the horizontal and vertical burrows; thus, increase soil porosity, water infiltration rate and reduce soil compaction. They also carried out the physical breakdown of organic materials (Carpenter et al. 2007; Sinha et al. 2010). Earthworm's gizzard is capable for the breakdown of the ingested food material up to 2–4 micron and increases the surface area for the microbial action in its intestine and in the soil where they are inhabitant (Drilosphere) (Sinha et al. 2010; Fusaro et al. 2018).

2.4.2 Earthworm as Chemical Engineer

As a chemical engineer, enzymatic action was done by the earthworm. Biochemical conversion occurred by different enzymes like amylase, cellulase, protease, lipases, and chitinases and that convert complex organic materials into more unaffected digestible materials. Chemical degradation via enzymes was also due to enzymes produced by bacteria, fungi, protozoa, etc., The intestine of earthworm further mixed this digested organic material with microflora. Therefore, we can say both gizzard and intestine work as "bioreactor." Thus; they also act as a biochemical engineer (Barrios 2007; Sinha et al. 2010).

2.4.3 Earthworm as Biological Engineer

The earthworms act as a biological engineer because of their interactions (symbiosis) with soil MOs, such as bacteria and fungi, including VAM (vesicular-arbuscular mycorrhizae). Earthworm's gut has numerous beneficial MOs for plant growth, and they are released in earthworm's cast. These cast's MOs further help in the digestion of organic material (Rabatin and Stinner 1988; Fusaro et al. 2018; Sinha et al. 2010).

It is a crucial point to notice here that mineral weathering may be legend acted mechanism due to both earthworm's enzyme and by microbial activities. Hence, it is a difficult task to measure the contribution of earthworms in this weathering as the survival of earthworm dependence on MOs (Carpenter et al. 2007; Fusaro et al. 2018).

2.5 Composting and Vermicomposting

Millions of tonnes of waste are generated every day, and we are facing the environment cost and socio-economic cost of managing this waste. This waste has primary biodegradable organic material that must be reused for efficient agriculture. By vermicomposting and composting, we can achieve the goals of efficient agriculture and overall sustainable development. There are some similarities (Fig. 2.6) and dissimilarities (Table 2.2) between vermicomposting and composting, but overall, vermicomposting had better results than composting (Loehr et al. 1984; Edwards 1998; Sinha et al. 2010).

Vermicompost is an environment-friendly, socially acceptable, and economically viable odorless process in which waste organic materials are digested in the presence of earthworms (Sinha et al. 2010). Depending upon the organic material used for vermicomposting, the physio-chemical composition of VCM varies, i.e. pH

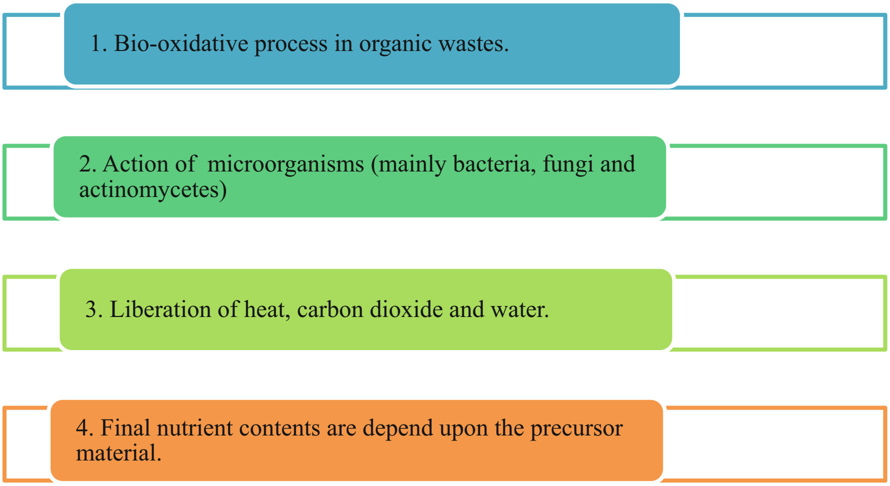

Fig. 2.6 Similarity between composting and vermicomposting (Tognetti et al. 2005)

Table 2.2 Dissimilarities between composting and vermicomposting (Arancon et al. 2004; Tognetti et al. 2005)

S. No.	Compost	Vermicompost
1.	Due to the action of microorganisms	Due to couple action of earthworms and microorganisms
2.	Involvement of the thermophilic stage (45 to 65 °C)	Involvement of mesophilic stage (temperatures above 35 °C may kill earthworms)
3.	Mainly turning and aeration processes occur	Mainly turning, fragmentation, and aeration processes occur
4.	Moisture content is 40 to 60%	Moisture content is 70–90%
5.	Pathogens are effectively reduced in product	Pathogens may or may not be effectively reduced in product
6.	Less microbial activities and nutrient contents	Higher microbial activities and nutrient contents
7.	The final product is somewhat in compact clumps	The final product is homogenous
8.	It is less strongly humified	It is more strongly humified

(6.5–7.5), moisture content (60–70%), aeration (50%), temperature (18–35 °C), N (0.8–3.0%), P (0.5–1.7%), and K content (0.5–1.6%) (Ansari et al. 2020). In composting, earthworms are not involved, and self-heating phase and fewer humidity (3–6%) may be the reason for less bacterial diversity in it as compared to VCM (Fracchia et al. 2006).

Vermicomposting of buffalo dung led to the better microbial processed end product as compared to composting (Ngo et al. 2011). There is also quantitatively more functional microbial diversity in the presence of earthworm, and this is due to the modification of physicochemical properties of waste material as a result of this it

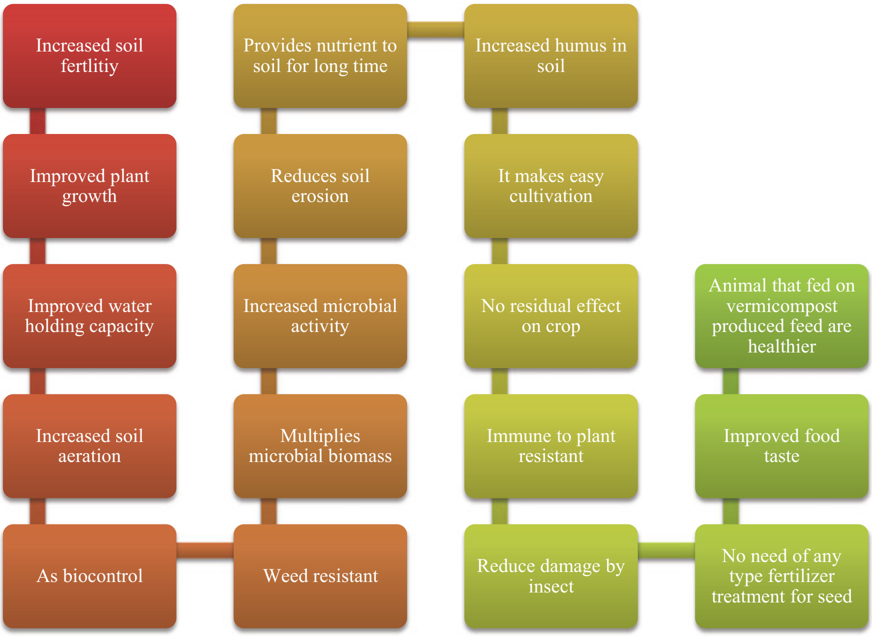

Fig. 2.7 Advantages of vermicompost

provides favorable microhabitats for microbial action (Vivas et al. 2009). Dominant bacterial communities in composting material were *Firmicutes* and *Actinobacteria,* whereas in VCM were *Chloroflexi*, *Bacteroidetes*, and *Gemmatimonadetes*. Generally, CM has spore-forming bacteria that allow them to be active in the thermophilic stage (Fracchia et al. 2006; Vivas et al. 2009).

Vivas et al. (2009) observed that faster mineralization of olive-mill waste occurs in VCM than CM. Increment of phytohormone (milligrams—mg kg^{-1}) in VCM was recorded as indole-3-acetic acid (IAA) (7.37), kinetin (2.8), and gibberellic acid-3 (GA)(5.7); whereas, in composting as IAA (5.84), kinetin (2.7), and GA-3 (4.0). It may be associated with earthworm's microbial population in its gut (Ravindran et al. 2016). Vermicompost could also be used as an alternative to inorganic fertilizers, whereas there is a limitation of using CM when we expected a short-term effect on plant growth (Jouquet et al. 2011). Numerous advantages of vermicomposting to the soil and plant health are diagrammatically represented in Fig. 2.7 (Munnoli et al. 2010).

2.6 Earthworm for Bioremediation

Bioremediation is a novel method of waste management for sustainable development. Bioremediation using microbes, economically and environmentally are considering safe (Gupta and Prakash 2020). The earthworm and soil microbes play a vital role in bioremediation wastes management because of their synergistic association (Sun et al. 2020). Earthworm helps in soil remediation by making the lining of burrows (*L. terrestris*), which reduces vertical transport of pesticides, by facilitating metal uptake by plants (phytoremediation), by inducing pesticide-detoxification enzymes in soil, and contribution in the breakdown of organic pollutants (Sanchez-Hernandez et al. 2019). Earthworms were also utilized for dispersing of MOs which can degrade the pollutant. For examples, bio-augmented polychlorinated biphenyl (PCB) degrading MOs were dispersed by *Pheretima hawayana,* and due to that 55% contaminant were removed than control (39%) having no earthworm (Singer et al. 2001). The presence of *Hyperiodrilus africanus* earthworm has significantly reduced the total petroleum hydrocarbon (84.99%), benzene (91.65%), ethylbenzene (100%), xylene (100%), and toluene (100%) from crude oil contaminated soil (Ekperusi and Aigbodion 2015). Similarly, *E. fetida* accelerates the degradation of oxytetracycline and its main metabolites (4-epi-oxytetracycline and 2-acetyl-2-decarboxamido-oxytetracycline) by remediating microbes (Liu et al. 2020). Huang et al. (2020) studied that sludge-VCM formed by *E. fetida* reduced the antibiotic resistance gene encoding plasmids and integrins as well as also reduced the total human pathogenic bacteria.

2.7 Ecosystem Indicator

Assessment of soil quality defined as the ability of soil to provide ecological services sustainably (Pérès et al. 2011). Soil invertebrates are an essential organism of soil and any change in soil quality directly affects them. Therefore, they can be used as an ecosystem indicator (Lavelle et al. 2006). Some of the key-features calling of earthworms as bioindicator are highlighted in Fig. 2.8 (Edwards et al. 1996).

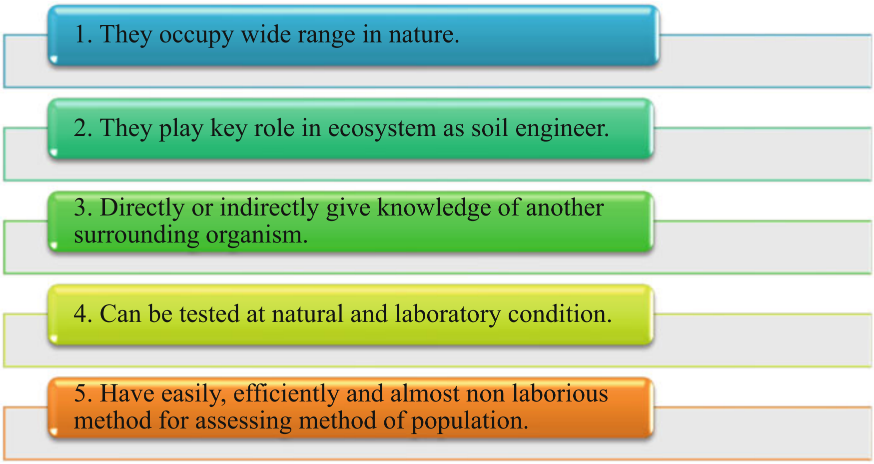

Fig. 2.8 Key feature which makes earthworms as bioindicator

Various changes in earthworm can be used as ecosystem indicators such as earthworm communities (abundances and activities) (Suthar 2009), bioaccumulation in casts and tissues (Suthar et al. 2008), and histopathological changes (Shi et al. 2020). Earthworm abundance and activities can act as a bioindicator for management practices of agricultural soil. For example; at the different study site, it was found that a maximum number of earthworms are present in integrated farming (100%), followed by in organically managed soil (70%) and minimum in conventional agricultural soil (Suthar 2009). Shi et al. (2020) studied that histopathological change like damage of microvilli and cuticle are early warning bioindicator of pesticide (endosulfan) contamination. Change in sperm parameter can be used as a sensitive biomarker to indicate metal toxicants in soil (Sinkakarimi et al. 2020b). *Eisenia fetida* is proved less sensitive than *A. rosea* and *A. trapezoides* to cadmium (Cd) and lead contamination. This difference in sensitivities suggests that native earthworm species should be considered for toxicant (Sinkakarimi et al. 2020a).

2.8 Declining Earthworm Population: A Challenge to Sustainability

The promotion of usages of chemical fertilizers during the period of green revolution improved the crop growth, but their unsustainable use reduced soil fertility (Varma et al. 2017; Meena et al. 2017; Sharma et al. 2019). After sometime saturation point of soil will come and we will not be able to get yield by these chemicals. Then we need to follow the advanced techniques for sustainable development (Densilin et al. 2011). In this line, Sinha et al. (2010) developed some by using earthworms like the vermicomposting technology, the vermi-filtration technology, the vermi-remediation technology, the vermi-agro-production technology, and the vermi-industrial production technology.

We already studied in detail different direct and indirect benefit of earthworm in soil fertility, decomposition of organic material, bioremediation, nutrient cycling, ecological engineers, biocontrol, bioindicator, and plant growth. That is why earthworms are very most important for efficient agriculture (Blouin et al. 2013; Bertrand et al. 2015; Shi et al. 2020). Nowadays weed also becomes a major problem in agriculture land. The harvested weed can be used to form vermicompost. For examples; vermicomposting of water hyacinth (*Eichhornia crassipes*) improves the growth of crossandra (*Crossandra undulaefolia*), lady's finger (*Hibiscus esculentus*), brinjal (*Solanum melongena*), cluster bean (*Cyamopsis tetragonoloba*), chili (*Capsicum annuum*), and tomato (*Lycopersicon esculentum*). Thus, it is an approach towards sustainability because as VCM, weed volume is decreased and we also get organic fertilizer. Therefore, we can say earthworms by using VCM indirectly control the volume of weed (Gajalakshmi and Abbasi 2002).

Food demand is growing every day for the increasing population, and agriculture in the next decades will depend upon sustainable development to obtain abundant food from less agricultural land. For sustainable development, we cannot neglect the different important benefit of earthworms. The decline of earthworm directly or indirectly affects the sustainability of the environment. If earthworms are extinct from the earth, we cannot imagine sustainable development (Hobbs 2007).

2.9 Factors Affecting Earthworm Population

Due to beneficial attributes of earthworms, they are vital for sustainable development but still, their performance of worked depends on several factors (Fig. 2.9). Earthworms are a susceptible organism, and their abundance richness and evenness were strongly related to the different environmental condition (Edwards and Bohlen 1996; McCallum et al. 2016).

2.9.1 Soil pH

Soil pH affects the bioavailability of nutrient, pesticides, and HMs in soil (Cheng and Wong 2002). Edwards and Bohlen (1996) observed that earthworms are difficult to see below the soil pH 4.3 (Mccallum et al. 2016). They are unusually found in soil pH more than 4.0–4.5 and usually absent in less than 3.5 soil pH (Räty and Huhta 2003; Chan et al. 2004). Most of the earthworm's species have optimum soil pH near to neutrality, i.e. pH =7.0. However, each earthworm species has different tolerance range to soil pH (Edwards and Bohlen 1996; Chan 2003). For example, *Allolobophora chlorotica* is an acid intolerant species and is found in a narrow range of pH 4.7 to 5.7 (Mccallum et al. 2016). Räty and Huhta (2003) observed that *A. caliginosa*, *L. terrestris*, and *L. rubellus* are found between soil pH 4 and 7. Earthworms grow and reproduce better in its optimum soil pH. For example, the survival and reproduction of *E. fetida* get reduced in acidic soil (Bernard et al. 2009).

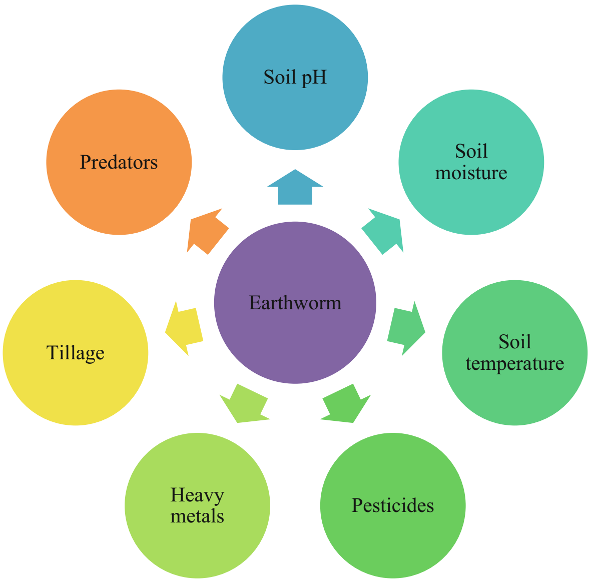

Fig. 2.9 Factors affecting the earthworm population

2.9.2 Soil Moisture

The presence of soil moisture influences the earthworm activities, survival, growth, abundance, sexual maturation, reproductive success, and longevity (Edwards and Bohlen 1996; Berry and Jordan 2001; Ivask et al. 2006). For instance, most favorable moisture for *P. excavatus* is 80%. Nevertheless, juvenile and clitellate of this earthworm prefer 81% moisture content, whereas maximum cocoon deposition occurred at 78.5% moisture. Thus, it was concluded that moisture content affects the reproduction and growth of earthworms (Hallatt et al. 1992). The optimum moisture for *L. terrestris* and *Amynthas hupeiensis* is 30% (Berry and Jordan 2001; Richardson et al. 2009). Perreault and Whalen (2006) observed that *A. caliginosa* and *L. terrestris* have maximum surface casting at −5 kPa (kilo Pascal) than −11 kPa whereas maximum burrows length at -11 kPa than -5 kPa.

2.9.3 Soil Temperature

Soil temperature affects the earthworm survival rate, growth, and reproduction. Survivorship and growth have occurred at different soil temperature (Presley et al. 1996). The hatchling growth and cocoon development of *L. terrestris* occurred rapidly at 20 °C but the greatest annual production at 15 °C. So, we can say that maximum weight gain was noticed at the optimum temperature range 15–20 °C (Berry and Jordan 2001; Perreault and Whalen 2006). An almost similar effect was seen in *A. caliginosa* (Perreault and Whalen 2006). They developed better at optimum temperature, e.g. *E. eugeniae* optimum temperature for reproductive success at 22–25 °C, but it can survive up to 30 °C (Viljoen and Reinecke 1992; Richardson et al. 2009). *Aporrectodea caliginosa* and *L. rubellus* are also remained unaffected up to a wide range of soil temperature (Eggleton et al. 2009). Soil temperature and moisture together influence the earthworms, for example; in case of *E. fetida*, maximum survival occurred at moderate temperature, and moisture 20 °C and 3 ml (milliliter) g^{-1}, respectively, and this pattern remains up to ontogeny. Generally, survivorship more depends upon soil temperature than its moisture (Presley et al. 1996).

2.9.4 Pesticides

Pesticides directly affect earthworm actions, e.g. *E. andrei* significantly avoids the methomyl (1.36–23 mg kg^{-1}) contaminated soil (Pereira et al. 2009). *Eisenia fetida* lost 14.8–25.9% of their biomass in pure glyphosate (26.3 $mgkg^{-1}$) contaminated soil (Pochron et al. 2020). Gowri and Thangaraj (2019) observed that with increasing Monocrotophos (agrochemical pesticide) concentration, there was an increase of earthworms mortality, abnormal sperm count (necrospermia, oligospermia, and asthenospermia) and defective cocoons in *E. eugeniae* and *P. barotensis*, whereas

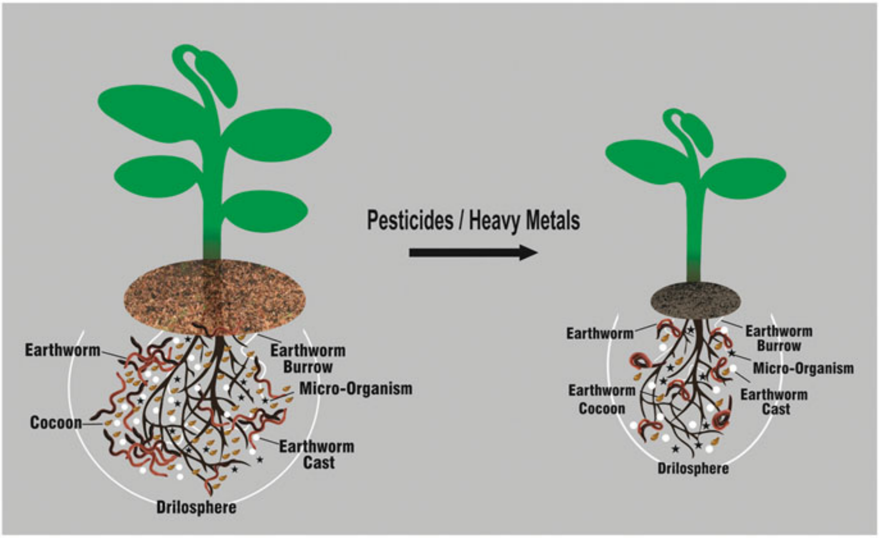

Fig. 2.10 Effect of pesticides and heavy metals on earthworms

microbial proliferation was decreased in *L. mauritti* as concentration was increased (Kavitha et al. 2020). Agrochemical pesticides cause major histopathological changes in the body wall, chloragogenous tissue, villi, longitudinal muscle, vacuolization, blood sinus, and necrosis in *E. eugeniae, P. barotensis*, and *L. mauritti.* Therefore, effects the growth, reproductive potential and survivability of these earthworms (Gowri and Thangaraj 2019; Yao et al. 2020; Kavitha et al. 2020). The DNA (deoxyribonucleic acid) is the genetic material of organisms, which is a vital component in cells. Pesticides damage the DNA, which is a very fatal condition for earthworms. This damage increases as concentration and period of exposure to pesticides were increased. For example, the DNA damage of *E. fetida* even at a dose of 0.1 mg kg^{-1} of Cyantraniliprole (Qiao et al. 2019) and Endosulfan at 0.5 mg kg^{-1} doses injured the ultrastructure of the nucleus (Shi et al. 2020). The pesticidal impact on earthworm is illustrated in Fig. 2.10.

2.9.5 Heavy Metals

Exposure time and dose-dependent effect of HMs were observed in earthworms (Zheng and Canyang 2009; Höckner et al. 2020). Heavy metals can accumulate in earthworm's tissue and cast. Therefore, these metals harm earthworms (Zhang et al. 2020). Comparatively, a higher concentration of HMs in the tissue of endogeic species (*M. posthuma*) was noticed than anecic species (*L. mauritii*) (Suthar et al. 2008). Heavy metals contaminated soil retards the growth, locomotory ability, sperm morphology, fertility rate and also causes the death of earthworm. Cocoon production is more sensitive to soil contamination than mortality of earthworm

(Žaltauskaitė and Sodienė 2010; Zheng and Canyang 2009). Zinc (39.9%) and Cd (84.1%) were noticed in *A. morrisi* cast, and these metals affect the earthworm growth (Zhang et al. 2020). This may be due to changes in the immune system of earthworms by Cd (Höckner et al. 2020). Poor survival of *A. chlorotica* in highly HMs contaminated Bukowno soil might be due to lack of adaptive immunity (Höckner et al. 2020) and/or maybe due to impairment of immune functions of earthworm (Homa et al. 2003). Wang et al. (2020) observed that *E. fetida* shows the dose-dependent effect with Nickel (Ni) concentration in growth rate, respiration and histological change in body wall, digestive and reproductive system. Analysis of mRNA expression showed that Cd affects the regeneration, glycolysis/glucogenesis pathways, biosynthesis of amino acids, and apoptosis of *E. fetida* (Fig. 2.10) (Chai et al. 2020).

2.9.6 Tillage

Earthworm burrows system is an important indicator to define its soil activity (Langmaack et al. 1999; Bertrand et al. 2015). A three-year experiment shows that conventional tillage causes reduction of 90% transmitting burrows (Chan 2004). Species richness, abundances, and biomass of earthworms are directly influenced by soil tillage (Emmerling 2001). However, *A. rosea* and *A. caliginosa* (endogeic species) are not much affected by soil tillage (Ivask et al. 2007).

2.9.7 Predators

Earthworms are used as food by different animals like Flatworm (Boag and Yeates 2001), beetles, ants, fishes, amphibians, reptiles, birds, and mammals (Muys and Granval 1997; Sazima 2007; Onrust et al. 2017). It has been reported that in Britain and Faroe, *Arthurdendyus triangulatus* (*Artioposthia triangulata*) flatworm affects the soil ecological system because of reducing lumbricidae earthworm populations. Some species of flatworm which act as a predator like *Bipalium kewense* survive at high temperatures and are only found in greenhouses while other species like *A. albidus* are obligate predators of earthworms. *A. australis, Australoplana sanguinea alba*, and *Caenoplana coerulea* also prey on earthworms. Tissue conversion from earthworms to the flatworm is 9.7% (Gibson et al. 1997; Boag and Yeates 2001).

Earthworm feeding by spiders is probably rare. Earthworm predation was in only eight araneomorphs and three mygalomorph families. In the wild, earthworms are generally eaten by larger (14–35 mm) spiders like *Ancylomedes rufus* but predation also is done by smaller (6–8 mm) spiders like *Amaurobius fenestralis* (Nyffeler et al. 2001; Ross 2008). *Platycryptus undatus* (Jumping spider) feeding on *Aporrectodea caliginosa* (Ross 2008).

Microscopic screening of gut contents of beetles showed the presence of earthworm cuticle and chaetae in their gut. Earthworm proteins are also reported in their gut (Nyffeler et al. 2001; Ingerson-Mahar 2002). Beetles eat earthworm as food because they improve fitness parameters, for example, Carabid beetle, *Pterostichus melanarius* (King et al. 2010).

In Amphibian, earthworms are secondary preferences as food, e.g. *Bufo bufo* (Macdonald 1983), *Xenorhina oxycephala* (Allison and Kraus 2000), and *Craugastor rhodopis* (Aguilar-López and Pineda 2013).

The legless lizard *Anguis fragilis* fecal samples showed that 86% of this lizard eats earthworms (Brown et al. 2012). Worm snake (*Carphophis vermis*), *T. ordinoides*, *Helicops angulatus* (brown-banded water snake), *Atractus, Diadophis, Geophis, Ninia, Virginia, Gomesophis*, and *Sordellina* also eat earthworms. Earthworms, respectively, form 3.4 and 30.8% stomach content of *T. sirtalis* and *T. ordinoides* (Grazziotin et al. 2012; Strüssmann et al. 2013).

Earthworms are reported in the diet of various birds like Mockingbird (*Mimus saturninus*), tawny owl (*Strix aluco*), wryneck (*Jynx torquilla*), song thrush (*Turdus musicus)* (Macdonald 1983), *oystercatchers* (*Haematopus ostralegus*), starling (*Sturnus vulgaris*), crows, gulls, wrens, and grackles (Muys and Granval 1997; Stephenson et al. 1997; Seamans et al. 2015; Sazima 2007). Earthworms form about 5.5, 2.4, and 0.3% contribution in the diet of *Falco tinnunculus* (kestrels), blackbird (*Turdus merula*) (Macdonald 1983), and starling (*Sturnus vulgaris*), respectively (Muys and Granval 1997; Onrust et al. 2017).

From the mammals, maximum records for predation on earthworm noticed in order Insectivora particularly by Soricidae (Silcox and Teaford 2002). *Myosorex varius* (Shrews), *Microtus agrestis* (vole) (Reinecke et al. 2000) also used earthworms in their diet. Earthworms contribute about 3.4 and 4.3% as a diet of *Sorex fumeus* and *S. cinereus* (Macdonald 1983). About 20% caloric contribution of the fox (*Vulpes vulpes*) was through consumption of earthworms. 77.1% of foxes were feeding at a place where a large number of earthworms were present (Muys and Granval 1997).

2.10 Conclusions

As the world population is increasing agricultural land is decreasing day by day. Food scarcity is becoming a major problem to the present period of the escalating global population. Due to this tremendous population agriculture land is decreasing. For the next decade, to generate more food from less agricultural land, we will be dependent on sustainable development, and earthworm can contribute a crucial role in this development as it is now playing a significant role in this. We already study vermicompost (VCM) has many beneficial roles for soil fertility and plant growth for sustainable development. That is why VCM also called organic gold. In short, we can say earthworms directly and/or indirectly play a vital role in the sustainability of the environment.

2.11 Future Perspectives

Modern agriculture practices produce high yield but also have trenchant amount of ill effects due to continuous input of chemicals fertilizers beyond a certain limit. Persistent chemical has effects on the public as well as environmental health along with its effects on soil health. Therefore, these practices become questionable. The current research highlights to overcome these problems by using earthworms in different ways. There is need to find some new techniques and sustainable way so that earthworms can be used efficiently to overcome these problems. A significant challenge for the future is also to identify a sustainable system to optimize the soil faunal diversity with biomass and their impacts on soil quality.

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