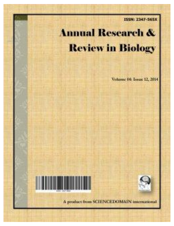

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Earthworms Impact in Sustainable Management of Intensively Managed Agro Ecosystems: Indian Scenario

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Authors' contributions

This work was carried out in collaboration between all authors. Author AS designed the study, wrote the protocol and wrote the first draft of the manuscript. Author TB managed the analyses of the study, and author GSS managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Direct effects of agrochemicals on soil and belowground diversity are through indiscriminate application in the agricultural field, but through run off the chemical compounds contaminate the soil. The chemical fertilizers contain many hazardous compounds that may cause severe ecological and social constraints to the farmers as well as affect the micro and macro-fauna present in the soil. The yield and production of crops increased but the food quality for human consume is affected. As, the population increases the food security issue become more underlined, as to maintain the soil fertility and its degradation minimization. Hence, in current years consumer concern increasing for the issues such as food quality, environmental safety, and soil conservation. And, scientists are shifting from agricultural systems depending upon inorganic fertilizers towards viable agricultural practices. Hence, the use of organic fertilizers are promoted over the agrochemicals, but due to the high cost of transportation and solo impacts on yield and productivity not satisfactory. So, the integrated use of vermicompost and chemical fertilizer is adopted nowadays, to maintain belowground biodiversity

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and crop yield. We focus on the role of earthworm in ecosystem management with prior emphasis on nutrient management of agro-ecosystems through their castings.

Keywords: Contaminated soil; earthworm cast; earthworm activity; soil physical properties; agro ecosystem.

1. INTRODUCTION

The intensive agriculture solely depend on the inorganic fertilizers, various pesticides and on the growth regulating factors to escalate crop production. It has been gradually documented that large use of agrochemicals and chemical fertilizers deteriorating the environment. Subsequent to the green revolution during early sixties the farmers began using chemical fertilizers because of their knack to improve crop productivity. As a result, the excessive usage of agrochemicals are causing a major dip in crop productivity along with polluting the soil ecosystem and the water bodies. In recent years, consumer concern about issues such as food quality, environmental safety, and soil conservation are increasing and causing a shift in the approach of scientists from agricultural systems depending upon inorganic fertilizer towards sustainable agricultural practice [1]. Sustainable agriculture means following such agricultural practices which can fulfill the human needs along with conservation of available resources without harming the environment [2]. The organic fertilizer is preferred over agrochemicals as it is rich in nutrients, easily available and also ecofriendly. It has been observed that the solo use of animal manure cannot meet crop growth which can improved productivity and fulfill demand of growing population. Further, the organic fertilizers application has declined as a result of high transportation charges with inappropriate and ill-timed applications into agricultural fields [3]. And, in developing countries like India, cow dung is used as a fuel source in rural areas. Therefore the Food and Agricultural Organization (FAO) of United Nation has proposed a new strategy in which integrated plant nutrients supply could be evolved to escalate crop yield and to improve fertility of the soil. Thus a low input technology using organo-mineral fertilizers has evolved to improve soil fertility status in agroecosystems [4]. It involves integration in which an application of inorganic fertilizers with organic manure is required. The integrated use of chemical fertilizers and composts have shown increased crop yield than the use of either of them solely, thus proving to be a successful management strategy for improving fertility of agroecosystems [5]. Thus it is persistent to adopt this strategy along with enhanced below ground diversity to improve crop yield expectancy of the farmers. Integrated and combined effect of the earthworm activated compost and chemical fertilizer have improved nutrient availability and crop yield [6].

Agriculture intensification is not only expensive to improve crop productivity but eventually increases environmental risk making the soil non-aerated [7,8]. Consequently, human confronts severe ecological and social constraints. With increased population and food constraints, agriculture is merely a way to fulfill food needs. Hence, it is a vital topic of concern today, where sustainable agriculture needs substantial attention to increase the productivity [9,10]. In addition, unscientific and inexpedient use of inorganic fertilizers in forms of insecticides, pesticides, and herbicides have resulted in the deterioration of health of soil ecosystem [11,12]. Further, intensifying agriculture have also shown the remarkable environmental impacts [13], Soil as a habitat should be protected with utmost urgency as first step for sustainable management and prolonged fertility. Most scientists believe and accept that below ground diversity in soil benefits its productivity, but not much information is available about these organisms occupying different niches in soil and their functional role. The earthworms (EWs) prominence as soil fertility managers have been highlighted since the time of Darwin (1809-1882) book “The formation of the vegetable mould through the action of worms”. Since then, number of studies have been carried to point out the soil organisms significance in managing the sustainability of major ecosystems [14,15]. Earthworm is an important animal in modifying the soil layers through production of casts and pellets. Nutrient recycling is a perilous function of an ecosystem which is essential for the being of life on earth. Presently scientist are showing interest to develop economically efficient productive agricultural practices with aggrandized use of efficient internal resources with lesser external input requirements [12,15]. The important character of soil macro invertebrates in organic matter dynamics and nutrient management and their transformation at various spatiotemporal level by producing various biogenic structures [16-18]. Earthworms form a greater portion of below ground faunal diversity constituting about 80% of its biomass. They largely influence the characteristics of soil by organic matter transfer and through construction and destruction of soil particles [19,20].

The soil fed by earthworm has passed through physico-chemical and microbial changes in gut result in enhanced microbial activity, improved pH and moisture level [21,22]. In agroecosystems organic matter is normally associated to soil fertility status and productivity; earthworm's communities can accelerate (SOM) dynamics by regulating mineralization processes [23]. However, these activities can divaricate built on the functional categories of species and also their interaction with the other soil biota [24]. Studies have attributed degradation of any ecosystem to above ground stresses [18]. But, rarely have been attributed to the shortfall of belowground biodiversity (soil fauna), therefore it becomes imperative to conserve soil faunal biodiversity for any ecosystem function. In addition, the earthworm impressions can be seen in paedogenesis processes through bioturbation of soil creating galleries and pellets depending upon its community structure and ecological group composition [25-27]. Exacerbation of agriculture has led to degradation of soil profile as well biological attributes correlated with decline in belowground soil biodiversity such as earthworm abundance along with further soil organisms [28,29]. Thus, an effort should be made to understand earthworms role in soil ecosystem process such as soil nutrient management and in cohesive management of intensively managed agroecosystems. Therefore, this paper targets to address the present scenario on the study of earthworm effect on ecosystems management with special focus on nutrient management in agroecosystems through their casting action. Future research needs to be focused on how vermicompost plays an important role and exact procedure involved in synchronizing the nutrient availability to the crop growth and this aspect needs to be studied in a systematic and scientific manner. There are many unexplored avenues as far as vermi technology is concerned and therefore more research needs to be done to unravel various technological hiccups interfering with the field studies associated with management strategies.

2. FUNCTIONAL SIGNIFICANCE OF EARTHWORMS

The earthworm influence on soil biological properties, altering soil profile and wangling of soil fertility level varies with the ecological categories [27,30]. Anecic species construct excavate small burrows into deeper soil layers, they are larger sized species and drag decayed or putrid organic matter and leaves from soil surface inside their burrows [31] and thus redistribute the organo-mineral layers. Endogeic earthworms exclusively build extensive galleries inside the soil layers, ingest mineral soil matter, and are known as "ecological engineers," or "ecosystem engineers." Through biogenic physical structure assembly they create suitable environment and resources availability for other organisms in the soil [32]. They do so by mixing intestinal mucus and available water to the consumed mineral soil thereby enhancing microbial activity [33]. Epigeic species are surface colonizers, feeding on litter and decomposing plant byproducts while not mixing organic and inorganic matter [34]. They strongly affect the decomposition processes and have a wider range of enzymatic activities probably due to ingestion of microflora and thereby affected the decomposition [35,36]. The earthworm affect microbes activities which is dependent on the prevailing soil conditions and the food type source availability [37-39]. The combined or individual effects of these three functional categories are responsible for maintaining the soils fertility in ecosystems and soil food web [40-43].

2.1 Impact in Soil Nutrient Management

Earthworms make nutrients available to plants through production of various bio aggregates and pellets within the soils (endogeic species) or in the litter layer or soil litter interface (epigeic species) [44]. The cast of earthworm called as biogenic structures consist of assemblies of organo-mineral aggregates. The stability of these casts has affected the soil organic matter dynamics and its physical properties thus impact on nutrient cycling and plant growth [7,23]. The earthworms are also affected some important ecological processes in soil ecosystem referred to as their "functional domain" [43,45] also called as drilosphere [46] where they concentrate their byproducts to be used by further soil organisms [41,47,48]. The Earthworms impact on the animate matter dynamics is also directly reliant on the space and time scales considered [13]. Endogeic EWs has accelerated initial animate matter turnover due to indirect effect on carbon present in soil through microorganisms activities.

2.2 Impact of Earthworms on Soil Microbial Activity

Earthworms selectively hinge on organic particles due to which their alimentary canal contents become enriched with organic matter, N P K and have greater soil moisture content than the control soil. Due to their feeding and mechanical mixing processes earthworms fragment the organic matter and subsequently modify its physicochemical status. And, reduce C:N ratio of ingested soil and also increased the surface area imperiled to microorganisms thus creating more space for microorganisms activity and further decomposition [49] as compared to normal soil. The epigeic and anecic earthworms have improved the process of mineralization by initiating the breakdown of soil animate matter and then mixed it with mineral particles and microorganisms, thereby further create a more suitable environment for microorganisms and SOM [50]. It has been proven that worm casts rich in ammonium nitrogen and animate matter and therefore provided a good substrate for microorganism growth [51-54]. Over a smaller time scale a more prominent effect is due to concentrations of N, P, K and Ca easily assimilable by plants in the freshly deposited cast [39], obtained from earthworm tissues, mucus and the urine of the earthworms [51,55]. Also, enormous amount of mucus formed by earthworms and excretion of water promote micro-organisms activity in their gut [56].

In the highly degraded soils of tropics and under intensified agricultural systems earthworm activity becomes more beneficial due to rapid incorporation of dead and decayed matter into the soil [34], so fresh casts have higher nutrient contents than the neighboring non digested soils. Casts of earthworms have about 1.5, and 1.3 times higher concentration of C and N as than normal surrounding soils [34,41,57]. This higher concentration appears in all particle fractions of agroecosystem soils [58]. This further highlights earthworms role in soil carbon protection in microaggregates and thus longer stability of soil carbon [59]. There are also reports of enhanced earthworm activities in incorporating mulch or cover crop derived C into larger worm casts and smaller microaggregates present within these larger casts, this further emphasizes the earthworm potential in facilitating accumulation and stabilization of animate matter in soils of agroecosystems [60]. Earthworms enhance nitrogen mineralization by affecting the microbial community [61]. Through our studies done in Northeast India on earthworms role in nitrogen cycling during the cropping period of shifting agriculture, it has been highlighted that total plant available soil nitrogen higher in soil with earthworms activity as compared to total nitrogen input of soil after adding lopped vegetation, inorganic fertilizer, compost or organic manure, weeds and recycled crop byproducts [51]. The increased total nitrogen through earthworm activity in agro ecosystems is also due to release of mucus, urine, coelomic fluid and through the death and decay of tissues [62] (Table 1). It has been revealed in studies [12,26,52,63] that earthworms improved the soil pH which provides a suitable condition for microorganism's activity and thus improved N fixation in the soil. Hence, the earthworm cast has higher nitrogen concentration. The mineralization of nitrogen by the microorganism is intensive in worms gut and continued for many hours in freshly deposited casts [64,65]. Further, this process takes place either through the incorporation of primal matter in the soil or by feeding on bacterial community. However, the earthworms prominence in managing nutrient is largely influenced by cropping pattern, and the chemical/organic matter input [9] (Fig. 1.) The composition of earthworm species exists in the agroecosystems and their contact with other species or other organisms also influence the nutrient availability for crops. Subsequently, interaction has caused nutrient immobilization or mineralization that depends on species composition and availability of substrate. Earthworms have also improved Phosphate-phosphorus, calcium, and potassium availability in their casts as compared to surrounding soil [25,57,66,67]. However, to maintain earthworm population to emphasize the agroecosystem management for which organic matter should be managed properly as has been highlighted in the soil reclamation experiments in Indo-Gangetic plains [42] and also study done in their soil restoration experiments [68].

2.3 Casting Activity Effects on Soils

Various structures formed by earthworms has been recognized by the farmers only from last few years, scientific studies reported impact of micro or macroaggregates formed by earthworms on soil structures in details [69]. Castings of endogeic earthworms may be round or dome shaped small mounds while those of epigeics are small may be pellets or spindle-like masses. The type of worm cast produced is characteristic of a species, amount of cast produced may serve to measure earthworm activity [70]. The casts produced by earthworms are highly stable pellets (the size may vary depending upon the functional categories of earthworms) because microbial products together with the worm mucus bind the consumed soil particles [71]. Microbial products helps in stabilizing and protecting animate matter in a cast over the longer duration [65,72-74] because in dry casts microbial activity declines which result in slowing down mineralization process. Therefore, this ensures a slow nutrients release and are preventing the excessive loss through leaching [72,75,76]. Subsequently, became accessible to microflora when broken down into smaller fragments [65, 77,78].

The chemical mechanism involved in earthworm casts formation enhanced bacterial polysaccharides and fungal hyphae those bound by the mineral particles and animate matter which might be a reason for the longer stability of worm casts [79,80]. Worm cast which has significantly higher percentage of moisture content, organic carbon, and total nitrogen than the soil surroundings in agrosystems [81].

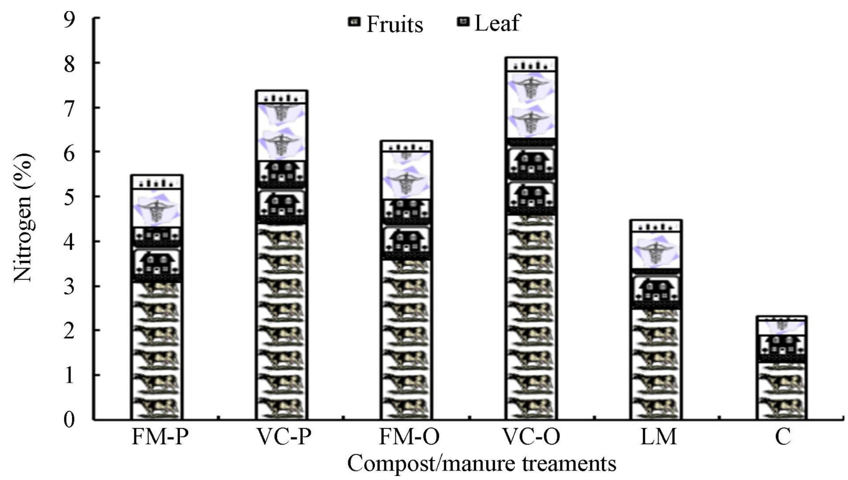

Fig. 1. Effect of application of different treatments on nitrogen uptake by pea crop in the agricultural system [51]

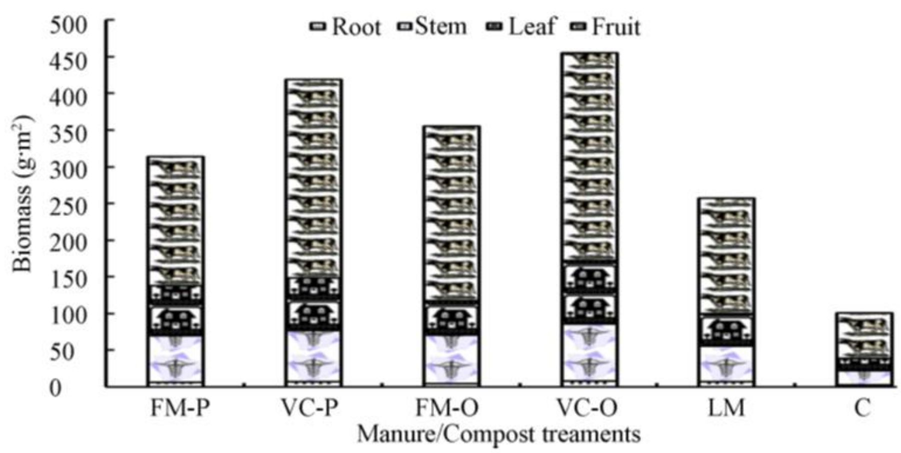

Fig. 2. Effect of application of different treatments on production of Pea Crop in agricultural system. FM-P farmyard manure pine, VC (P) vermicompost Pine, FM (O) farmyard manure (oak) VC-O (oak) LM litter and C control [51]

Earthworm casts as vermicompost are also very important in integrated plant nutrient supply and also for keeping soil healthy to conserve soil productivity [16]. This becomes more pertinent in regions where farmers are reliant on forest biomass for fodder and manure. Hence, rely upon soil biological functions and organic inputs for crop productivity or for soil health management [51]. Farmers stressed to increase productivity through continuous cropping with lesser input of animate matter into soil on the same plot of land, resulted in alteration of soil habitats, crop productivity and fertility especially pea crop. The prominent variation exists between opus of compost and vermicompost owing to disparity in the biological process involved which results difference in final properties of substrate [82,83] (Table 2). These differences are also exhibited in their effect on morphological growth of plants and productivity The vermicompost application in comparison to conventional compost has improved the productivity of pea crop and soil fertility [51].

3. EARTHWORM ACTIVITIES IMPACT ON CROP GROWTH

Vermicompost has stimulated seed germination of green gram [84], tomatoes [85,86], petunia [87]. It has also enhanced shoot and root development [88] through increment in leaf area and well developed branching of roots [89]. Vermicompost also increased fruit yield [90-92]. Vermicomposts is a mixture of humus and animate matter which influence the plant growth and highlighted through the studies done in the central Himalayas on pea crop growth by using vermicompost and farm yard manure (Fig. 2.). This can be because of humic constituents associated with worm casts as humic acids enhance uptake of nutrients in plants by either increasing the permeability of root cell membrane [93] or it could also be due to plant growth hormones like activities in humic acids [94]. The plant genotypes may also enhance root activity by modifying its exudation processes in response to vermicompost input so as to enhance nutrient uptake [95,96]. Thus, vermicompost can be inferred as the promising resource for plants by balanced fertilization to promote plant efficiency that sustain productivity of agroecosystem soils. Recycling of residue is a vital factor to determine the biotic activity and below ground faunal diversity in agro ecosystems. This is more important for marginal farmers who depend on manure and soil biological function owing to the reliance of crop productivity with organic inputs for soil health management. Not much information is as yet available on impact of vermicompost addition to soil biota in an agroecosystem. Studies done in central Himalayas have revealed that addition of vermicompost to agroecosystem positively impacted soil decomposer biota which also positively affected growth of pea crop [51] (Table 3).

4. EARTHWORMS AS BIO AGENTS IN PEST CONTROL

Large scale expenditure of chemical pesticides are threat to environment and causing pests recurrence and also becoming a menace to useful biocontrol agents. These pesticides are also causative agents for bio magnification of harmful chemicals. Various studies have highlighted that the earthworms can be utilized as bioagents to adjure organic amendments as a substitute of synthetic pest management strategies, through the making of vermicompost tea and aqueous earthworm extracts completely safe for the consumers. Aqueous extract of worm casts have shown inhibitory effect on powdery fungus and also induce systemic resistance in pea and balsam. Soil ameliorated with tea formed from vermicompost has significantly inhibited pathogen growth [97,98]. Earthworm feeding activity has reduced infestation of pathogens such as *Fusarium sp*. and *Verticillium dahliae* [99,100] and also enhanced the antagonistic number of pseudomonads and actinomycetes. Earthworm are known to decrease root diseases and the prevalence of field diseases of clover, grains, and grapes induced by *Rhizoctonia* spp. [101,102]. Augmentation of pest beleaguered agriculture soils with earthworms have shown an increase plant weight by 60-80% and a substantial decline in disease severity by 50-70% [103-105]. Amalgamation of soil with vermicompost has suppressed occurrence of various pathogens like of *R. solani* in wheat, in cucumber and radish with inhibition of *Pythium* and *Rhizoctonia* causing root rot, *Sphaerotheca fulginae* in grapes [106,88,107]. Aqueous extracts of vermicompost are restrained the growth of mycelia of *B. cineria, Sclerotinia sclerotiorum* and *F. oxysporum* [108]. This suppuration activity of different earthworms species on pests could be because of microbial mediated competition or antibiosis and biparasitism [109].

Table 1. Nitrogen input/output budget during the cropping phase under 5- year and 15-year Jhum cycle, (±SE, *n* = 5) (digits in italics signify the nitrogen input by earthworm activities. Nitrogen balance (kg ha^{-1} yr^{-1}) in different shifting agriculture cycles [50]

Input	5-years	15-years
Slash	27.60 (±1.30)	51.4 (±3.6)
Organic manure	14.0 (±1.1)	—
Inorganic fertilizer	0.80 (±.04)	—
Crop biomass	0.42 (±.05)	0.9 (±.01)
Weed biomass	2.85 (±1.1)	0.7 (±.03)
Precipitation	4.20 (±.28)	4.2 (±.26)
Input total	**49.90**	**57.2**
Worm casts	***27.0 (±1.3)***	***65.6 (±4.8)***
Worm tissues	***9.5 (±.13)***	***12.1 (±1.4)***
Mucus production	***75.9 (±3.2)***	***95.3 (±4.5)***
Input total	***112.4***	***173.0***
Output	**5-years**	**15-years**
Fire	277.6 (±23.2)	657.9 (±23.9)
Sediment	158.0 (±10.2)	116.0 (±4.5)
Percolation	1.0 (±.04)	1.2 (±.08
Runoff	7.3 (±0.3)	14.0 (±1.3)
Weed removal	14.25 (±3.86)	3.33 (±.26)
Crop removal	15.24 (±1.28)	43.52 (±3.20)
Output total	**474.39**	**835.96**
Input-Output difference	**312.12**	**605.75**

Earthworms are also suppressed the activity of arthropod pests. Soil amendments using vermicompost, vermicompost tea or aqueous extract have suppressed the occurrence of *Spodoptera litura, H armigera, A. modicella*, (E kerri), aphids (*Aphis craccivora*) and spider mites on groundnuts [110-112]. In addition, vermicompost application to soils caused a distinct dip in the frequent occurrence of sucking pests in the agricultural soils. Also, suppressing the loss which is caused by spider mite (*Tetranychus* spp.), aphid (*Myzus persicae*) [113] and mealy bacterium (*Pseudococcus* spp.) [114; 115]. The earthworms bind the nutrients in worm casts as has been mentioned earlier and release bound nutrients slowly over a longer time span especially nitrogen and cations [116]. Earthworm casts have higher concentration of humic acids and phenolic compounds [57,117]. They are taken up by the crop tissues which become unpalatable to arthropod pest and feeding determents thus resulted decline in the arthropod pest infection [115,118,119]. Composts have improved composition of nutrients but they release them at a slower rate [120]. Similarly, vermicomposts have also released nutrients slowly especially available N, soluble K, exchangeable Ca, Mg and P [121]. Therefore, plants grown on vermicompost possess lower N levels [122] and have high phenol content. Thus, probably these plants have become impervious to the pest attack [118,119,123-127]. Studies carried out by scientists have revealed that soils rich in earthworms have polychlorinated phenols [128]. Also, *L. rubellus* has an endogenous phenol oxidase which bioactivates compounds to form p-nitrophenol [129]. Monomeric phenols might be imbibed by humic acids in the earthworms gut [130]. Uptake of phenolic compounds by plants from vermicomposts also probably alters the survival rate and reproductive pattern of the pests.

5. EARTHWORMS AS BIOINDICATORS IN LAND USE PRACTICES

Any change in land use practices has affected the structure of earthworm community altering the earthworm species composition and their distribution pattern [18]. Earthworms are the keystone species in the ecosystems and therefore they could be utilized as biological indicators of several factors associated with agroecosystems. Numbers of studies have clearly shown the earthworms to be best indicators of direct and indirect anthropogenic changes in the soil ecosystems [18]. In intensive agriculture, various paraquats in soils may affect the earthworm behavior which can be applied to monitor the changes in characteristics of soils as highlighted in soils [12].

Table 2. Physico-chemical characteristics of soil under different treatments subsequent to the crop harvest (±SE, n = 5; Average mean values subsequent to the crop harvest). Values for any variable with different superscript letters are significantly (P < 0.05) different within columns [22]

	Sand (%)	Silt (%)	Clay (%)	pH	BD (g/cm^3)	OC (%)	N (%)	C:N
FM-O	53.4 ± 3.1	26.6 ± 1.8	19 ± .32	6.17 ± 0.18a	1.13 ± .08a	1.3 ± .18a		10.95
FM-P	52.7 ± 3.3	27.3 ± 3.2	20 ± 2.3	6.38 ± 0.4a	1.15 ± 0.05a	1.5 ± 0.05a	0.17 ± 0.01a	10.62
LM	54 ± 3.2	27 ± 1.5	19 ± 0.5	6.3 ± 0.05a	1.32 ± 0.03b	1.8 ± 0.03b	0.11 ± 0.01b	16.34
VC-O	52.9 ± 0.2	28.7 ± 0.15	18 ± 0.5	6.7 ± 0.3b	1.04 ± 0.02c	2.01 ± 0.4c	0.24 ± 0.01c	8.37
VC-P	53.2 ± 0.4	25.9 ± 0.02	20.9± 0.1	6.5 ± 0.06a	1.06 ± 0.04 c	2.1 ± 0.13c	0.23 ± 0.01c	9.13
C	54.8 ± 3.2	27.2 ± 1.6	18.0 ± 1	6.3 ± 0.3a	1.3 ± 0.3b	1.6 ± 0.2a	0.12 ± 0.02b	13.4

Table 3. Simpsons Diversity Index, Abundance ($No./m^2$), and Biomass (g/m^2) of soil fauna as well crop yield (g/m^2) in experimental plots under different treatments during cropping (±SE, n = 5). Numbers followed by the same letter are not significantly different (P < 0.05) within columns [9]

	Simpson diversity index	Soil fauna abundance	Soil fauna biomass	Yield of pea
LM	0.562429	1689 ± 57a	147.95 ± 76a	257.6 ± 4b
FM-O	0.716984	1705 ± 143a	40.78 ± 2d	355.5 ± 12c
FM-P	0.506881	1669 ± 137a	67.02 ± 6c	313.8 ± 7c
VC-O	0.737699	2332 ± 145b	128.29 ± 11b	455.8 ± 20e
VC-P	0.58287	1814 ± 164c	23.76 ± 3c	419 ± 11d
C	0.36894	78 ± 14d	0.552 ± 0.02e	169 ± 9.4a

6. NEGATIVE IMPACTS OF VERMICOMPOSTING

There are certain drawbacks that should also be taken into account during application of vermicompost. Applications of higher doses of vermicomposting reduce germination in some plants by reducing the aeration and porosity of the soils in the agroecosystems. Likewise, phytotoxic substances, high salt concentrations, and heavy metal concentrations in vermicompost can have detrimental effects on plant growth [131]. Vermicompost if not mature also prevents seed germination and plant growth [132]. Some elements in vermicompost can destroy the structure of soil, for example, sodium in high concentrations accelerates erosion and microbial death, and toxic metals, such as lead and calcium have also shown deleterious effects on soil and plants [132]. As a result, in-depth research is needed to develop proficiency in the technology of vermicomposting; however, the overall demand for sustainable agriculture increases the demand for vermicompost [133]. Thus, further research is needed to fill the gaps associated with immature vermicompost composition and its application failure with the fate and the effect of heavy metals in vermicompost.

7. CONCLUSION

The review highlights the earthworm's impact on agricultural systems through nutrient availability, enhanced microbial activity, managing soil structure through casting activities and burrow formation, pest management and as biological indicators of soil condition. However, the earthworm functions may differ based on substrate availability, the ecological categories of the species and also on management practices being followed. Further, if we deliberate these factors and manage them properly then the earthworms constituting 80% of soil faunal diversity will be a boon for converting intensive agroecosystem into sustainable agroecosystem. The earthworms importance in agriculture systems is a traditional knowledge known to the farmers but improved by scientific inputs emerging from various research studies. This is a process where technology developed in a field is reproduced under lab conditions. So, as to further improve the technique circumstantiated from the feedback received from the end users to give more appropriate and acceptable technological information to them. As the review has highlighted that earthworms played a major role in managing soil fertility. Therefore, they are considered to be important participant in any decision making with regards to management of agricultural to increase sustainable land use.

8. FUTURE RESEARCH NEEDS

Majority of research work done to understand the earthworm role in nutrient cycling through casting activity which is only confined to surface casting species. Therefore, to have a holistic understanding of impact of casts production by the earthworms and detailed research needed to study the earthworms burrows, their structure based on soil quality. The variations were observed therein under various land management practices. Based on many types of biodegradable material and agro-based residue availability more research should be focused to identify locally available endemic earthworms species. However, in these species fast breeders, voracious feeders with shorter life cycle and higher adaptability to changing physicochemical properties of the substrate are required. The species identified must be easily available and should accept various substrate with minimal effort and investment and perform well under field conditions. More research should also be focused on the exact procedure involved in enhancing the availability of nutrient to the plants. Not much work has been carried out in India therefore, this aspect needs further detailed, systematic and scientific study. There are many avenues which are still unexplored with regards to earthworms technology and therefore more research work is required to unravel various technological hiccups interfering with the field studies associated with management strategies.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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