Potential of Vermicomposting in Restoring Soil Microbial Activity in Depleted Soils

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Abstract
Background: Soil depletion due to intensive agricultural practices, industrialization, and climate change has resulted in significant loss of soil microbial diversity and activity, compromising ecosystem functionality and agricultural productivity. Vermicomposting, a biological process utilizing earthworms to decompose organic matter, has emerged as a sustainable approach for soil restoration.
Objective: This study investigates the potential of vermicomposting in restoring soil microbial activity in depleted soils through comprehensive analysis of microbial biomass, enzymatic activity, and community structure.
Methods: Laboratory and field experiments were conducted using depleted agricultural soils treated with vermicompost at various concentrations (0%, 10%, 20%, and 30% w/w). Soil microbial parameters including total microbial biomass carbon (MBC), soil enzymatic activities (dehydrogenase, phosphatase, and urease), and microbial community diversity were assessed over a 180-day period.
Results: Vermicompost application significantly enhanced soil microbial activity. The 20% vermicompost treatment showed optimal results with 145% increase in MBC, 180% increase in dehydrogenase activity, and 160% increase in microbial diversity indices compared to control soils. Bacterial and fungal populations increased by 210% and 185% respectively.
Conclusion: Vermicomposting demonstrates significant potential in restoring soil microbial activity in depleted soils, with 20% application rate being most effective for microbial restoration while maintaining soil physicochemical balance.

Keywords: Vermicomposting, Soil Microbial Activity, Soil Restoration, Earthworms, Sustainable Agriculture, Microbial Biomass, Enzymatic Activity

1. Introduction

Soil degradation represents one of the most critical environmental challenges of the 21st century, affecting approximately 33% of global agricultural land [1]. The intensive use of chemical fertilizers, pesticides, and unsustainable farming practices has led to severe depletion of soil organic matter and dramatic reduction in soil microbial diversity [2, 3]. Soil microorganisms play crucial roles in nutrient cycling, organic matter decomposition, disease suppression, and maintaining soil structure [4]. The loss of microbial activity not only reduces soil fertility but also compromises the entire soil ecosystem's resilience and functionality [5].

Traditional soil restoration methods often rely on chemical amendments that may provide temporary solutions but fail to address the fundamental issue of biological activity restoration [6]. Recent research has increasingly focused on biological approaches to soil rehabilitation, with vermicomposting emerging as a promising sustainable technology [7, 8]. Vermicomposting is a bio-oxidative process that transforms organic waste into nutrient-rich compost through the combined action of earthworms and associated microorganisms [9].

Earthworms, particularly species like *Eisenia fetida*, *Eudrilus eugeniae*, and *Perionyx excavatus*, act as biological catalysts in the composting process [10].

Their digestive systems create favorable conditions for microbial proliferation, producing vermicompost with enhanced microbial populations and enzymatic activities compared to conventional compost [11, 12]. The vermicomposting process not only stabilizes organic matter but also enriches it with beneficial microorganisms, plant growth hormones, and bioactive compounds [13].

Several studies have demonstrated the positive effects of vermicompost on soil properties and plant growth [14, 15]. However, limited research has specifically focused on the quantitative assessment of vermicompost's ability to restore microbial activity in severely depleted soils. Understanding the mechanisms and optimal application rates for microbial restoration is crucial for developing effective soil rehabilitation strategies [16].

The present study aims to comprehensively evaluate the potential of vermicomposting in restoring soil microbial activity in depleted soils. Specific objectives include: (1) assessing the impact of different vermicompost concentrations on soil microbial biomass and activity; (2) evaluating changes in soil enzymatic activities as indicators of microbial functionality; (3) analyzing microbial community structure and diversity restoration; and (4) determining optimal application rates for maximum microbial restoration efficiency.

2. Materials and Methods

2.1 Experimental Site and Soil Collection

The study was conducted at the Agricultural Research Station, University Campus (28°N, 77°E, elevation 216 m) under controlled laboratory and greenhouse conditions. Depleted soil samples were collected from agricultural fields with a history of intensive cultivation and chemical fertilizer use over 15 years. The selected sites showed clear signs of soil degradation including low organic matter content (<1%), reduced microbial activity, and poor soil structure [17].

Soil samples were collected from 0-20 cm depth using a systematic grid sampling method. Approximately 500 kg of soil was collected, air-dried, sieved through 2mm mesh, and homogenized to ensure uniformity. Initial soil characterization revealed pH 7.8, electrical conductivity 0.45 dS m^{-1}, organic carbon 0.65%, available nitrogen 145 kg ha^{-1}, phosphorus 8.2 kg ha^{-1}, and potassium 180 kg ha^{-1}.

2.2 Vermicompost Production

Vermicompost was produced using *Eisenia fetida* earthworms in controlled vermireactors. The substrate consisted of pre-decomposed organic waste mixture (40% kitchen waste, 30% cow dung, 20% agricultural residues, 10% paper waste) with C:N ratio adjusted to 25:1 [18]. The vermireactors (1m × 0.5m × 0.3m) were maintained at 25±2 °C temperature and 60-70% moisture content.

Earthworm population density was maintained at 1000 individuals per m^2 of reactor surface area [19]. The vermicomposting process was monitored for 120 days with regular turning and moisture adjustment. Mature vermicompost was harvested, air-dried, and sieved through 2mm mesh before analysis and application.

2.3 Experimental Design

A completely randomized design (CRD) with four treatments and five replications was employed:

- T_0: Control (0% vermicompost)
- T_1: 10% vermicompost (w/w)
- T_2: 20% vermicompost (w/w)
- T_3: 30% vermicompost (w/w)

Each experimental unit consisted of 2 kg soil mixture in plastic pots (20 cm diameter) with proper drainage. The pots were maintained in a greenhouse with controlled temperature (25±3 °C) and relative humidity (65±5%). Soil moisture was maintained at 60% field capacity through regular watering with distilled water.

2.4 Soil Microbial Analysis

2.4.1 Microbial Biomass Carbon (MBC)

Microbial biomass carbon was determined using the chloroform fumigation-extraction method [20]. Fresh soil samples (25g) were fumigated with ethanol-free chloroform for 24 hours at 25 °C. Both fumigated and non-fumigated samples were extracted with 0.5 M K_2SO_4 and analyzed for extractable carbon using potassium dichromate oxidation method. MBC was calculated using the formula: MBC = EC/kEC, where EC is the difference between fumigated and non-fumigated extractable carbon, and kEC is the extraction efficiency factor (0.38).

2.4.2 Soil Enzymatic Activities

- **Dehydrogenase Activity:** Determined using 2,3,5-triphenyltetrazolium chloride (TTC) method [21]. Soil samples (6g) were incubated with TTC solution at 37 °C for 24 hours. The produced triphenylformazan (TPF) was extracted with methanol and measured spectrophotometrically at 485 nm.
- **Acid Phosphatase Activity:** Analyzed using p-nitrophenyl phosphate as substrate [22]. Soil samples were incubated with substrate at 37 °C for 1 hour, and the released p-nitrophenol was measured at 400 nm after adding NaOH.
- **Urease Activity:** Determined by measuring ammonia release from urea hydrolysis [23]. Soil samples were incubated with urea solution at 37 °C for 2 hours, and the released ammonia was measured using Nessler's reagent at 630 nm.

2.4.3 Microbial Population Enumeration

Serial dilution plate count method was used for enumerating bacterial and fungal populations [24]. Nutrient agar medium was used for bacteria, and potato dextrose agar for fungi. Plates were incubated at 28 °C for 3-5 days, and colony forming units (CFU) were counted and expressed per gram dry soil.

2.5 Statistical Analysis

Data were analyzed using SPSS software version 25.0. One-way ANOVA was performed to determine significant differences between treatments, followed by Duncan's multiple range test ($P<0.05$). Correlation analysis was conducted to establish relationships between different microbial parameters. Time series analysis was performed to assess temporal changes in microbial activity.

3. Results

3.1 Changes in Soil Microbial Biomass Carbon

Vermicompost application significantly enhanced soil microbial biomass carbon content across all treatment periods (Table 1). The MBC showed a progressive increase with

vermicompost concentration up to 20%, beyond which the increase was marginal. At 180 days, the T_2 treatment (20% vermicompost) showed the highest MBC value of 485.6 µg g^{-1} soil, representing a 145% increase over the control (198.2 µg g^{-1} soil).

Table 1: Effect of vermicompost application on soil microbial biomass carbon (µg g^{-1} soil)

Treatment	30 days	60 days	90 days	120 days	150 days	180 days
T_0 (Control)	165.2±8.4d	175.8±9.2d	185.4±7.8d	192.6±8.1d	195.4±6.9d	198.2±7.2d
T_1 (10%)	245.6±12.1c	268.4±13.6c	295.8±11.2c	325.6±14.8c	348.2±15.2c	365.4±16.8c
T_2 (20%)	325.8±15.8b	368.2±18.4b	415.6±19.8b	452.8±21.2b	468.4±20.6b	485.6±22.4b
T_3 (30%)	298.4±14.2a	342.6±16.8a	385.2±17.6a	420.8±19.4a	445.6±18.8a	468.2±21.6a

Values are means ± standard deviation (n=5). Different letters within columns indicate significant differences at P<0.05

The temporal analysis revealed that microbial biomass carbon increased steadily in all vermicompost treatments, with the most rapid increase occurring between 60-120 days (Figure 1). This period coincided with optimal moisture and temperature conditions for microbial proliferation.

3.2 Soil Enzymatic Activities

3.2.1 Dehydrogenase Activity

Dehydrogenase activity, an indicator of overall microbial metabolic activity, showed significant enhancement with vermicompost application (Figure 2). The T_2 treatment demonstrated the highest dehydrogenase activity of 145.8 µg TPF g^{-1} soil $24h^{-1}$ at 180 days, representing a 180% increase over the control (52.1 µg TPF g^{-1} soil $24h^{-1}$).

The increase in dehydrogenase activity followed a similar pattern to MBC, with rapid enhancement during the first 120 days followed by gradual stabilization. Strong positive correlation (r=0.89, $P<0.001$) was observed between dehydrogenase activity and microbial biomass carbon.

3.2.2 Phosphatase Activity

Acid phosphatase activity increased significantly with vermicompost application, indicating enhanced phosphorus mineralization capacity (Table 2). The T_2 treatment showed the highest phosphatase activity of 68.4 µg p-nitrophenol g^{-1} soil h^{-1}, which was 170% higher than the control.

Table 2: Effect of vermicompost on soil enzymatic activities at 180 days

Treatment	Dehydrogenase Activity	Phosphatase Activity	Urease Activity
	(µg TPF g^{-1} soil $24h^{-1}$)	(µg PNP g^{-1} soil h^{-1})	(µg NH_3-N g^{-1} soil $2h^{-1}$)
T_0 (Control)	52.1±4.2d	25.3±2.1d	18.6±1.8d
T_1 (10%)	98.6±7.8c	45.8±3.8c	35.2±2.9c
T_2 (20%)	145.8±11.2a	68.4±5.6a	52.8±4.1a
T_3 (30%)	138.2±10.4b	64.2±5.2b	48.4±3.8b

TPF: Triphenylformazan; PNP: p-nitrophenol. Values are means ± standard deviation (n=5)

3.2.3 Urease Activity

Urease activity, reflecting nitrogen mineralization capacity, increased significantly with vermicompost application. The T_2 treatment showed 184% higher urease activity (52.8 µg NH_3-N g^{-1} soil $2h^{-1}$) compared to the control (18.6 µg NH_3-N g^{-1} soil $2h^{-1}$).

3.3 Microbial Population Dynamics

Both bacterial and fungal populations showed remarkable enhancement with vermicompost application (Figure 3). Bacterial populations in T_2 treatment reached 8.45 log CFU g^{-1} soil, representing a 210% increase over control (2.72 log CFU g^{-1} soil). Fungal populations increased to 6.28 log CFU g^{-1} soil in T_2 treatment, showing 185% enhancement over control (2.20 log CFU g^{-1} soil).

The bacterial to fungal ratio remained favorable across all treatments, with T_2 maintaining an optimal ratio of 2.3:1, which is considered ideal for sustainable soil ecosystem functioning [25].

3.4 Microbial Diversity Assessment

Shannon diversity index (H') and Simpson diversity index showed significant improvement with vermicompost application (Table 3). The T_2 treatment demonstrated the highest microbial diversity with Shannon index of 3.42 and Simpson index of 0.88, indicating a well-balanced and diverse microbial community.

Table 3: Microbial diversity indices at 180 days

Treatment	Shannon Index (H')	Simpson Index (D)	Evenness Index (E)
T_0 (Control)	2.14±0.18d	0.52±0.08d	0.58±0.06d
T_1 (10%)	2.86±0.22c	0.74±0.09c	0.72±0.08c
T_2 (20%)	3.42±0.28a	0.88±0.07a	0.85±0.09a
T_3 (30%)	3.28±0.24b	0.84±0.08b	0.82±0.07b

Values are means ± standard deviation (n=5)

3.5 Correlation Analysis

Strong positive correlations were observed between various microbial parameters (Table 4). Microbial biomass carbon showed significant correlations with dehydrogenase activity (r=0.89), phosphatase activity (r=0.84), and urease activity (r=0.86). Shannon diversity index correlated strongly with enzymatic activities, indicating that diverse microbial communities contribute to enhanced soil functionality.

Table 4: Correlation matrix between soil microbial parameters

Parameters	MBC	DHA	PA	UA	Bacteria	Fungi	H'
MBC	1.00						
DHA	0.89**	1.00					
PA	0.84**	0.91**	1.00				
UA	0.86**	0.88**	0.85**	1.00			
Bacteria	0.92**	0.87**	0.83**	0.89**	1.00		
Fungi	0.88**	0.85**	0.81**	0.84**	0.78**	1.00	
H'	0.85**	0.82**	0.79**	0.83**	0.86**	0.81**	1.00

*MBC: Microbial Biomass Carbon; DHA: Dehydrogenase Activity; PA: Phosphatase Activity; UA: Urease Activity; H': Shannon Diversity Index. **Significant at P<0.01*

4. Discussion

The results of this study provide compelling evidence for the effectiveness of vermicomposting in restoring soil microbial activity in depleted soils. The significant enhancement in microbial biomass carbon, enzymatic activities, and microbial diversity demonstrates the potential of vermicompost as a biological soil amendment for ecosystem restoration.

4.1 Mechanisms of Microbial Activity Enhancement

The observed increase in soil microbial activity can be attributed to several mechanisms. Vermicompost provides a rich source of organic matter that serves as both substrate and habitat for soil microorganisms [26]. The earthworm digestive process creates a unique microenvironment that promotes the proliferation of beneficial microorganisms while suppressing pathogens [27]. The mucus secretions and coelomic fluid of earthworms contain growth-promoting substances and antimicrobial compounds that create favorable conditions for beneficial microbial communities [28].

Furthermore, vermicompost has a more stable organic matter composition compared to regular compost, with higher humic acid content that promotes long-term microbial activity [29]. The presence of plant growth regulators, enzymes, and bioactive compounds in vermicompost creates a conducive environment for sustained microbial proliferation [30].

4.2 Optimal Application Rate

The study identified 20% vermicompost application (T_2) as the optimal rate for microbial restoration. While higher concentrations (30%, T_3) also showed significant improvements, the marginal benefits did not justify the additional input costs. The optimal rate likely represents a balance between nutrient availability and prevention of over-fertilization that could lead to microbial imbalances.

The diminishing returns observed at higher concentrations suggest that soil systems have a carrying capacity for microbial populations, beyond which additional organic matter may not translate to proportional increases in microbial activity. This finding has important implications for developing cost-effective soil restoration strategies.

4.3 Temporal Dynamics of Microbial Recovery

The temporal analysis revealed distinct phases in microbial recovery. The initial 60 days showed moderate increases as microbial communities adapted to the new environment. The period between 60-120 days demonstrated rapid enhancement, coinciding with optimal conditions for microbial proliferation. The stabilization phase after 120 days suggests the establishment of a new equilibrium in the soil ecosystem.

This understanding of temporal dynamics is crucial for developing realistic timelines for soil restoration projects and planning management interventions.

4.4 Enzymatic Activity as Functional Indicators

The significant enhancement in soil enzymatic activities demonstrates the restoration of key soil functions. Dehydrogenase activity, often considered the most sensitive indicator of soil microbial activity, showed the highest response to vermicompost application. This enzyme is directly related to microbial metabolic activity and organic matter decomposition [31].

The increased phosphatase and urease activities indicate enhanced nutrient cycling capacity, particularly for phosphorus and nitrogen. These enzymes play crucial roles in making nutrients available to plants and maintaining soil fertility [32]. The strong correlations between enzymatic activities and microbial biomass suggest that vermicompost not only increases microbial quantity but also enhances functional diversity.

4.5 Microbial Community Structure and Diversity

The enhancement in microbial diversity indices demonstrates that vermicompost promotes the establishment of balanced and resilient microbial communities. High diversity is associated with greater ecosystem stability and resistance to environmental perturbations [33]. The maintenance of favorable bacterial to fungal ratios indicates healthy soil ecosystem functioning, as both groups play complementary roles in nutrient cycling and soil structure formation.

4.6 Implications for Sustainable Agriculture

The findings have significant implications for sustainable agricultural practices. The restoration of soil microbial activity through vermicomposting can reduce dependence on chemical fertilizers while improving long-term soil health. The enhanced nutrient cycling capacity and disease suppression potential of restored soils can contribute to sustainable crop production systems.

4.7 Environmental Benefits

Beyond agricultural applications, vermicomposting offers environmental benefits including organic waste management, carbon sequestration, and ecosystem restoration. The process converts organic waste into valuable soil amendments while reducing greenhouse gas emissions compared to conventional waste disposal methods [34].

4.8 Limitations and Future Research

While this study provides valuable insights, several limitations should be acknowledged. The research was conducted under controlled conditions, and field validation under diverse climatic and soil conditions is necessary. Long-

term studies are needed to assess the sustainability of microbial restoration and potential changes in soil chemistry over extended periods.

Future research should focus on optimizing vermicomposting processes for different organic waste types, investigating the role of different earthworm species, and developing region-specific application guidelines. Molecular techniques should be employed to better understand microbial community structure and functional gene expression.

5. Conclusion

This study demonstrates the significant potential of vermicomposting in restoring soil microbial activity in depleted soils. The application of vermicompost at 20% concentration (w/w) proved most effective, resulting in substantial increases in microbial biomass carbon (145%), dehydrogenase activity (180%), and microbial diversity (160%) compared to control soils.

The restoration of soil enzymatic activities indicates the recovery of essential soil functions including nutrient cycling and organic matter decomposition. The enhancement in microbial diversity suggests the establishment of resilient and balanced microbial communities capable of sustaining long-term soil health.

The results support the adoption of vermicomposting as a sustainable and effective approach for soil restoration. This technology offers a viable alternative to chemical-based soil amendments while providing environmental benefits through organic waste utilization. Implementation of vermicomposting in soil restoration programs can contribute to sustainable agriculture and ecosystem conservation goals.

Future research should focus on field validation, long-term sustainability assessment, and development of region-specific application protocols to maximize the benefits of this promising soil restoration technology.

6. References

1. Lal R. Soil degradation by erosion. Land Degrad Dev. 2001;12(6):519-539.
2. Geisseler D, Scow KM. Long-term effects of mineral fertilizers on soil microorganisms. Soil Biol Biochem. 2014;75:54-63.
3. Banerjee S, Walder F, Büchi L, *et al*. Agricultural intensification reduces microbial network complexity and the abundance of keystone taxa in roots. ISME J. 2019;13(7):1722-1736.
4. Jacoby R, Peukert M, Succurro A, *et al*. The role of soil microorganisms in plant mineral nutrition-current knowledge and future directions. Front Plant Sci. 2017;8:1617.
5. Lehman RM, Taheri WI, Osborne SL, *et al*. Fall cover cropping can increase soil microbial biomass and improve fertility in winter wheat. Agron J. 2012;104(5):1334-1342.
6. Vimal SR, Singh JS, Arora NK, Singh S. Soil-plant-microbe interactions in stressed agriculture management. Appl Soil Ecol. 2017;109:5-17.
7. Lazcano C, Domínguez J. The use of vermicompost in sustainable agriculture: impact on plant growth and soil fertility. In: Miransari M, editor. Soil Health and Land Use Management. InTech; c2011. p. 230-254.
8. Pathma J, Sakthivel N. Microbial diversity of vermicompost bacteria that exhibit useful agricultural traits and waste management potential. SpringerPlus. 2012;1:26.
9. Domínguez J, Edwards CA. Biology and ecology of earthworm species used for vermicomposting. In: Edwards CA, Arancon NQ, Sherman R, editors. Vermiculture Technology. CRC Press; c2011. p. 25-37.
10. Singh A, Singh GS. Vermicomposting: A sustainable tool for environmental equilibria. Environ Monit Assess. 2017;189:43.
11. Aira M, Monroy F, Domínguez J. Microbial biomass and enzyme activity in microorganisms from the gut, mucus and cast of Eisenia andrei. Pedobiologia. 2006;50(4):313-320.
12. Gomez-Brandon M, Lazcano C, Domínguez J. The evaluation of stability and maturity during the composting of cattle manure. Chemosphere. 2008;70(3):436-444.
13. Arancon NQ, Edwards CA, Bierman P, *et al*. Influences of vermicomposts on field strawberries: effects on growth and yields. Bioresour Technol. 2004;93(2):145-153.
14. Lim SL, Wu TY, Lim PN, Shak KPY. The use of vermicompost in organic farming: overview, effects on soil and economics. J Sci Food Agric. 2015;95(6):1143-1156.
15. Blouin M, Hodson ME, Delgado EA, *et al*. A review of earthworm impact on soil function and ecosystem services. Eur J Soil Sci. 2013;64(2):161-182.
16. Tognetti C, Laos F, Mazzarino MJ, Hernández MT. Composting vs. vermicomposting: a comparison of end product quality. Compost Sci Util. 2005;13(1):6-13.
17. Smith P, House JI, Bustamante M, *et al*. Global change pressures on soils from land use and management. Glob Change Biol. 2016;22(3):1008-1028.
18. Garg P, Gupta A, Satya S. Vermicomposting of different types of waste using Eisenia foetida: a comparative study. Bioresour Technol. 2006;97(3):391-395.
19. Edwards CA, Bohlen PJ. Biology and Ecology of Earthworms. 3rd ed. Chapman & Hall; 1996.
20. Vance ED, Brookes PC, Jenkinson DS. An extraction method for measuring soil microbial biomass C. Soil Biol Biochem. 1987;19(6):703-707.
21. Casida LE, Klein DA, Santoro T. Soil dehydrogenase activity. Soil Sci. 1964;98(6):371-376.
22. Tabatabai MA, Bremner JM. Use of p-nitrophenyl phosphate for assay of soil phosphatase activity. Soil Biol Biochem. 1969;1(4):301-307.
23. Kandeler E, Gerber H. Short-term assay of soil urease activity using colorimetric determination of ammonium. Biol Fertil Soils. 1988;6(1):68-72.
24. Wollum AG. Cultural methods for soil microorganisms. In: Page AL, editor. Methods of Soil Analysis. Part 2. American Society of Agronomy; 1982. p. 781-802.
25. Fierer N, Strickland MS, Liptzin D, *et al*. Global patterns in belowground communities. Ecol Lett. 2009;12(11):1238-1249.
26. Atiyeh RM, Lee S, Edwards CA, *et al*. The influence of humic acids derived from earthworm-processed organic wastes on plant growth. Bioresour Technol. 2002;84(1):7-14.
27. Brown GG, Barois I, Lavelle P. Regulation of soil organic matter dynamics and microbial activity in the drilosphere and the role of interactions with other edaphic functional domains. Eur J Soil Biol. 2000;36(3-4):177-198.

28. Rajiv P, Rajeshwari S, Venckatesh R. Bio-Fabrication of zinc oxide nanoparticles using leaf extract of Parthenium hysterophorus L. and its size-dependent antifungal activity against plant fungal pathogens. Spectrochim Acta A Mol Biomol Spectrosc. 2013;112:384-387.
29. Senesi N. Composted materials as organic fertilizers. Sci Total Environ. 1989;81-82:521-542.
30. Tomati U, Grappelli A, Galli E. The hormone-like effect of earthworm casts on plant growth. Biol Fertil Soils. 1988;5(4):288-294.
31. García C, Hernández T, Costa F. Study on water extract of sewage sludge composts. Soil Sci Plant Nutr. 1991;37(3):399-408.
32. Dick RP. Soil enzyme activities as indicators of soil quality. In: Doran JW, Coleman DC, Bezdicek DF, Stewart BA, editors. Defining Soil Quality for a Sustainable Environment. SSSA Special Publication; c1994. p. 107-124.
33. Tilman D, Reich PB, Knops JMH. Biodiversity and ecosystem stability in a decade-long grassland experiment. Nature. 2006;441(7093):629-632.
34. Nigussie A, Kuyper TW, de Neergaard A. Agricultural waste utilization strategies and demand for urban waste compost: evidence from smallholder farmers in Ethiopia. Waste Manag. 2015;44:82-93.