http://doi.org/10.1590/1678-992X-2022-0139

Scientia Agricola

ISSN 1678-992X

Research article

The role of local earthworms in plant nutrient addition in the Ethiopian Drylands

Kassa Teka

Mekelle University/College of Dryland Agriculture and Natural Resources – Dept. of Land Resources Management and Environmental Protection, P.O. Box 231 – Mekelle – Tigray – Ethiopia.

*Corresponding author <kassateka2012@gmail.com>

Edited by: Gabriel Ramatis Pugliese Andrade

Received July 28, 2022
Accepted October 26, 2022

ABSTRACT: The Ethiopian Drylands are rich in their variety of local earthworm species. However, the category of species, and the effect of their performance on additions to plant nutrients have not been adequately evaluated. Thus, local earthworm samples were collected from the three major agroecological zones (highland, midland, and lowland) in Tigray (northern Ethiopia) and classified down to species level. Moreover, a vermicomposting experiment with four treatments (three local earthworm species, *Eisenia fetida*, and a conventional composting method) and three replications was established. Finally, each bin's mature compost sample was taken to analyze plant nutrient content. The study results indicated that earthworm species in the highland, midland and lowland agroecological zones were *Dendrobaena veneta*, *Eisenia andrie* and *Lumbricus rubellus*, respectively. The use of these earthworms in the composting process (average of the four earthworm species) yielded higher nutrient content, ranging from 21.9 % for Sodium to 3300 % for Boron, compared to the conventional one. The highest total nitrogen (an increase of 44.4 %) and organic carbon (an increase of 33.4 %) were recorded in the *Eisenia fetida* and *Dendrobaena veneta* treated bins, respectively. Composting with *Eisenia andrie* has resulted in increases in P (96.1 %), K (125 %), Mg (83 %) and all micro-nutrients (between 91 % for Zn and 4400 % for B). Both *Eisenia andrie* and *Lumbricus rubellus* species contributed to the increased additions of Sulfur (85.7 %) compared to the control. It can be concluded that the use of local earthworms (particularly *Eisenia andrie)* in the composting process plays a significant role in plant nutrient addition.

Keywords: *Dendrobaena veneta*, *Eisenia andrie*, *Eisenia fetida*, *Lumbricus rubellus*, vermicompost

Introduction

Soils in the Ethiopian Drylands, covering about 60 % of the total area (Melese et al., 2015), are characterized by low soil fertility (Hailu et al., 2015; Henao and Baanante, 2006). The nutrient depletion rate has been estimated at 122 kg N ha^{-1} yr^{-1}, 13 kg P ha^{-1} yr^{-1} and 82 kg K ha^{-1} yr^{-1} (Haileselassie et al., 2005). The factors which influenced the decline were the inadequate replacement of nutrients removed in the harvested materials lost through erosion or leaching, and the absence of nutrient recycling earthworms (Hailu et al., 2015; Nederlof and Dangbégnon, 2007; Lauber et al., 2008; Delelegn et al., 2018). The presence of earthworm species in soils has been demonstrated to positively effect numerous soil properties (Drenovsky et al., 2010). However, most of the farmlands in the Ethiopian drylands are devoid of these earthworms, a factor that both directly and negatively impacts soil biodiversity (Hailu et al., 2015; Nederlof and Dangbégnon, 2007).

To date, farming communities in these areas apply chemical fertilizers (e.g. 100 kg ha^{-1} DAP and 50 kg ha^{-1} Urea) and certain organic substances (e.g. farm yard manure, compost and vermicompost) to overcome these challenges. Chemical fertilizer use was based on a blanket recommendation of a limited number of nutrients. Such unbalanced use of plant nutrients could trigger the depletion of other essential nutrient elements in soils (ATA/MoA, 2014). Thus, the use of earthworms (e.g. *Eisenia fetida*) in the composting process has been recently introduced to compensate for the unbalanced plant nutrients in Ethiopia (Sen and Chandra, 2009; Lim et al., 2015). Studies have proved that this method is economically and environmentally appropriate compared to other soil fertility management strategies (Demir, 2019; Teka et al., 2019). Farmers' trials in Tigray (northern Ethiopia) have indicated that vermicompost application has enhanced soil fertility and doubled crop productivity over the use of farm yard manure and chemical fertilizers (Teka et al., 2019).

Despite the benefits described above, the composting processes in the Ethiopian drylands are limited to the use of only one exotic earthworm species, *Esenia fetida* (Teka et al., 2019), despite the existence of a variety of other local earthworm species. To our knowledge, the utilization of local earthworms in the composting process has not been widespread in these areas due to: i) their limited agroecological zone-based characterization and classification and ii) studies on their contribution to plant nutrient addition have been exceptionally scant. Therefore, for their better utilization, it is crucial to explore their characteristics and potential compared to the commonly used exotic earthworm species (*Esenia fetida*) and conventional composting method (without earth worm).

Materials and Methods

Description of the study area

Local earthworms were collected from irrigated surface (0-30 cm) soils in the three agro-ecological zones (highland, midland, and lowland) of Tigray in northern Ethiopia

(Figure 1). The specific sites were Ruba-Feleg in Atsbi-Womberta (highland > 2300 m above sea level), Tahtay-Adikisandid in Kilte-Awulaelo (midland >1500 m above sea level), and Adiha in Keyih-Tekli district (lowland < 1500 m above sea level). The composting materials were collected from the Wukro town municipal waste landfill (13°45′02″ N, 39°35′44″ E, altitude 1960 m), which serves most towns in Tigray; while the experiment was carried out in Mekelle city (13°28′46.46″ N, 39°29′22″ E, altitude 2200 m).

Study method

Local earthworm collection, identification, and classification

Fifteen local earthworm specimens, five from each agroecological zone, were collected for taxonomic classification. From each specimen, five samples of adult earthworms (with clitellum) were taken and washed carefully in a plastic tray. Each earthworm was then transferred to a Petri dish using forceps and investigated under a stereomicroscope. The "Key to common British earthworms" online guide was used for species identification. This key is a widely used approach for the identification of species. Distinguishing features (characteristics) such as the description of body color, body length, number of segments, shape of peristomium, shape and length and position of clitellum, and presence and position of genital pores were used.

Evaluating the role of local earthworms in plant nutrient additions

A compost experiment with four earthworm species (three local and *Esenia fetida*) with three replications was established to evaluate their role in the addition of nutrients

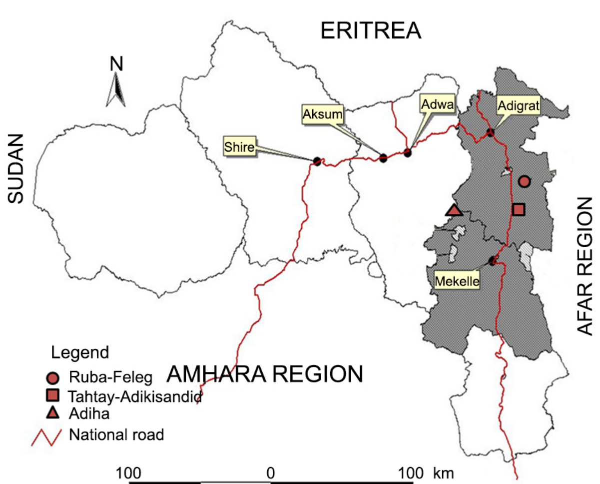

Figure 1 – Location map of the study sites in Eastern Tigray (shaded).

compared to the conventional composting method (with no earthworm). The experiment was carried out at a tree nursery (controlled environment) following a completely randomized design (CRD). Thus, 15 wooden earthworm bins lined with geo-membrane, each being 2 m long, 1 m wide and 30 cm deep, were prepared. Each bin was covered with mesh and plastic to protect earthworms from direct attack by earthworm hunters. An equal weight (200 kg) of freshly prepared composite organic waste based on a pre-defined composition (Table 1) was applied to each earthworm bin and left to stay aerated for approximately ten days before the addition of earthworms.

One thousand (1000) earthworms (the equivalent of 0.5 kg) were introduced to each bin after an ideal environment was created for these earthworms. Other management initiatives, such as watering, were applied equally. The experiment was monitored for 90 days. Finally, a mature composite compost sample was taken from each bin (a total of 15 samples) to analyze major chemical parameters following standard laboratory procedure (Table 2).

Data analysis

Collected data were subjected to analysis of variance (ANOVA) using Genstat software version 18, and treatment means were separated by DUNCONs multiple method at 5 % level of significance.

Table 1 – Materials used for experimentation.

Type of waste	Amount	Amount
	kg	%
Household waste	54	27
Fruits	44	22
Leftover food (injera)	10	5
Coffee and tea (daka)	14	7
Animal manure	40	20
Ash	20	10
Green manure	18	9
Total	200	100

Table 2 – Compost quality analysis.

Parameter	Standard procedure	Reference
pH	pH meter	Rhoades (1982)
EC (mS cm^{-1})	EC meter	De Villiers and Jackson (1967)
Organic carbon (%)	Walkley and Black method	Walkley and Black (1934)
Phosphorus (%)	Olsen method	Olsen (1954)
Total nitrogen (%)	Kejeldahl method	Bremner and Mulvaney (1983)
CEC (cmol$_c$ kg^{-1})	Ammonium distillation method	Chapman (1965)
Exchangeable cations (cmol$_c$ kg^{-1})	Ammonium acetate method	Ewulo et al. (2008)
Micronutrients (mg L^{-1})	AAS	Lindsay and Norvell (1978)

EC = electrical conductivity; CEC = cation exchange capacity; AAS = Atomic Absorption Spectrometer.

Results and Discussion

Description and classification of the local earthworms

The description and classification results showed that earthworms in the highland, midland and lowland agroecologies were in the *Dendrobaena veneta* (compost earthworms)*, Esenia andrie* (red earthworm) and *Lumbricus rubellus* (red head earthworms) species category, respectively. *Dendrobaena veneta* is characterized by its: i) typical adult size of 7 cm; ii) stripes on its upper surface when moving; iii) dark red bands on the upper surface with a pale pink or yellowish band in between; iv) saddle usually paler than the rest of the body. The *Eisenia andrei* is characterized by its: i) distinctive yellow banding in the inter segmental grooves; ii) dark red bands on the upper surface with a narrower pale pink or yellowish band in between; iii) stripey on its upper surface; iv) saddle usually having a color similar to the rest of the body; v) typical adult size of 6 cm; vi) its head shape is Epilobic; vii) closely paired setae; viii) the clitellum starts on segments 24-26 and ends at 32-34. The *Lumbricus rubellus* species is also characterized by its: i) typical adult size of 6.5 cm; ii) entirely dark in color (reddish brown) on the upper surface of the body, from the first segment to the saddle; iii) a paddle-shaped tail; iv) invisible male pores; v) the clitellum starts on segments 26 or 27 and the obvious yellow color in the inter segmental grooves is not present.

These earthworms are among the most often used 384 epigeic earthworm types for agricultural purposes due to their high efficiency and easy maintenance (Karuppasamy et al., 2017; Degefe et al., 2018). They are also known as compost earthworms (Podolak et al., 2020). Earthworms inoculated into the soil surface deposit valuable earthworm droppings annually of up to 10 kg m^{-2} or as much as 0.5 cm of the soil layer in fields (Pfiffner, 2022). This author also estimated that the earthworm casts contain, on average, five times as much nitrogen, seven times as much phosphorus, and 11 times as much potassium compared to the surrounding soil. These earthworms are known to affect plant growth through five fundamental mechanisms (Scheu, 2003): (i) enhancing soil organic matter mineralization; (ii) producing plant growth regulators via microbial activity stimulation; (iii) controlling pests and parasites; (iv) stimulating symbionts; (v) modifying soil structure.

Effect of local earthworms on plant nutrient additions

Vermicompost *vs* Conventional compost

Vermicompost, taking the average of the product of the four earthworms, was able to increase compost nutrients ranging from 21.9 % for Sodium (Na) to 3300 % for Boron (B) as compared to the conventional one (Table 3). These results are consistent with experimental study findings in Sivapuri that affirmed that using earthworms in the composting process enhanced plant nutrient content by 1.6 times for Mg to 52 times for Zn (Manivannan et al., 2009). Other studies, such as Nagavallemma et al. (2004), observed that vermicompost contains nearly two fold higher micro- and macro-nutrients than conventional compost. Argentinian farmers have also reported that the nutrient and growth promoting values of vermicompost was seven times richer than that of the conventional compost (Munroe, 2007). Moreover, the pH, EC and CEC increased by 8.7 %, 42.6 % and 12.9 %, respectively. The use of earthworms for composting in the Sivapuri experimental study also showed a 1.2-fold increase in CEC, 1.02-fold in pH and 1.4-fold in EC (Manivannan et al., 2009).

The increase in nutrient content upon vermicomposting was related to the presence of enzymes like amylase, lipase, cellulase, and chitinase in the canal of earthworms, which can degrade the organic matter and release the essential nutrients (Sinha et al., 2010). Vermicompost also contains a high proportion of humic substances (40 to 60 % higher), such as humic acids, fulvic acids, and humin, which provide numerous sites for chemical reactions (Nagavallemma et al., 2004). The large surface area of vermicompost provides many micro-sites for microbial activity (a 1.5-fold increase) and retention of nutrients (Manivannan et al., 2009). The difference in temperature and decomposers during the composting process is another factor for the variation in nutrient content. Thermophilic bacteria predominate in conventional composting, while mesophilic bacteria and fungi predominate in the vermi-composting process (Sinha et al., 2010). The earthworm cast contains a higher mesophilic bacterial population (102-106 per gram of vermicompost), which is 10-20 % higher compared to other organic sources (Edwards, 1995). Higher mesophilic microbial populations in vermicomposts hasten the decomposition process by 2-5 times compared to the thermophilic composting method (Atiyeh et al., 2000; Sinha et al., 2010).

Table 3 – Changes in compost properties due to vermi-composting.

Treatment	pH	EC	CEC	OC	Nt	P	K	S
C	6.80	1.03	5.32	5.61	2.14	2.30	2.73	0.56
V	7.39	1.47	6.01	7.45	2.95	3.37	4.63	1.01
Change (%)	8.7	42.7	12.9	32.8	37.6	46.5	69.6	80.4
Treatment	Na	Ca	Mg	Zn	Mn	Cu	B	Fe
C	93.3	363.3	22.0	1.10	0.50	0.23	0.01	27.70
V	113.7	498.2	33.1	1.58	4.75	2.13	0.34	86.09
Change (%)	21.9	37.1	50.5	43.6	850.0	826.1	3300.0	210.8

C = conventional compost; V = vermi-compost; EC = electrical conductivity; Nt = total nitrogen; P = available phosphorus; K = exchangeable potassium; S = sulfur; Na = sodium; Ca = calcium; Mg = magnesium; Zn = zinc; Mn = manganese; Cu = cupper; B = boron; Fe = Iron; CEC = cation exchange capacity; OC = organic carbon.

Effect on OC, pH, EC and CEC

Experimental results (Table 4) showed that the different earthworms had a positive effect ($p < 0.001$) on compost CEC. The highest CEC value (a 19 % increase) was recorded in bins treated with *Esenia fetida* (6.33 $cmol_c\ kg^{-1}$); while the lowest value was recorded in the conventional compost treatment (5.32 $cmol_c\ kg^{-1}$). An increase in CEC (45 %) resulting from the use of exotic earthworms in the composting process compared to manure/compost was also found elsewhere (Yagi et al., 2003). The highest cation exchange capacity (CEC) in the earthworm treated experiments was attributed to the presence of carboxylic and phenolic radicals, which are responsible for the production of surface charges (Jiménez and Garcia, 1992).

The highest soil organic carbon, a 36.4 % increase compared to the conventional compost, was recorded in the *Dendrobaena veneta* species treated bins. This is consistent with the findings of Pattnaik and Reddy (2010) who reported a 51.4 % increase in OC. This indicates lower decomposition of the organic matter and lower carbon loss to energy (Greiner et al., 2011). In such cold agroecological environments, such species contribute to increased carbon accumulation by prompting the formation of micro-aggregates and protecting soil organic matter against microbial decay (Pulleman et al., 2005).

The lowest pH value was recorded in the conventional compost, followed by the *Esenia andrie* species. In contrast, the highest value was observed in the *Esenia fetida* species treated bins, which was 14.7 % higher than the conventional one. These observations corroborated those obtained by Nagavallemma et al. (2004), who found higher pH in earthworm inoculated compost than in the control. The increase in pH was related to the activity of calciferous glands in earthworms containing carbonic anhydrase that catalyzes the fixation of CO_2 as $CaCO_3$, thereby preventing the fall in pH (Pattnaik and Reddy, 2010). It can also be due to increased utilization of organic acids (short-chained fatty acids) and mineralization of waste (Fares et al., 2005).

The EC of all treatments was also between 1.03 $dS\ m^{-1}$ (for conventional compost) and 1.72 $dS\ m^{-1}$ (for *Dendrobaena veneta*), which is considered a range suitable for plant growth (Arancon et al., 2004). The use of *Dendrobaena veneta* species in the composting process yielded a 67 % increase in EC as compared to the control. This is consistent with the findings of Rajendran and Thivyatharsan (2014) found an EC value in the earthworms treated bins 21% higher than that of the conventional one. This increase was attributed to the loss in weight of organic matter and the release of exchangeable ions such as Ca, Mg, K and P during the vermicomposting process (Nath et al., 2009).

Effect on macro-nutrients (N, P, K, S, Ca, Mg and Na)

Experimental results showed a statistical difference in macro-nutrient additions between treatments ($p = 0.03$). The lowest total nitrogen (Nt) value, 44.4 % lower than that of *Eisenia fetida*, was recorded in bins treated with conventional compost. These results are consistent with the findings elsewhere that using *Eisenia fetida* has resulted in 123.3 % (Rajendran and Thivyatharsan, 2014) and 51.8 % (Pattnaik and Reddy, 2010) increases in Nt. The highest Nt content in the earthworm treated bins was related to the difference in N-forms, in which

Table 4 – Nutrient composition of the different treatments.

Treatment	OC	pH	EC	CEC	Nt	P	K	S
C	5.61^{a}	6.80^{a}	1.03^{a}	5.32^{a}	2.14^{a}	2.30^{a}	2.73^{a}	0.56^{a}
E	7.62^{bc}	7.80^{c}	1.58^{a}	6.33^{b}	3.09^{b}	2.63^{a}	3.88^{b}	0.96^{b}
H	7.66^{c}	7.60^{bc}	1.72^{a}	5.41^{a}	2.86^{b}	3.12^{a}	3.93^{b}	1.00^{b}
L	7.40^{bc}	7.27^{abc}	1.32^{a}	6.25^{b}	2.94^{b}	3.22^{a}	4.57^{b}	1.04^{b}
M	7.12^{b}	6.90^{ab}	1.26^{a}	6.03^{b}	2.89^{b}	4.51^{b}	6.14^{c}	1.04^{b}
p-value	< 0.001	….	….	< 0.001	0.026	0.004	< 0.001	0.024
LSD	0.5039	….	….	0.3596	0.5409	0.902	0.908	0.29
CV (%)	3.8	….	….	3.3	10.3	15.2	11.3	16.8
Treatment	Ca	Mg	Na	Zn	Cu	Mn	B	Fe
C	363.3^{a}	22.0^{a}	93.3^{a}	1.1^{a}	0.2^{a}	0.5^{a}	0.01^{a}	27.7^{a}
E	418.3^{b}	26.3^{a}	101.3^{ab}	1.1^{a}	0.7^{ab}	2.7^{b}	0.24^{a}	43.0^{a}
H	465.3^{b}	32.3^{b}	105.3^{ab}	1.4^{ab}	1.4^{bc}	4.2^{c}	0.28^{a}	84.67^{b}
L	537.3^{c}	33.3^{b}	118.3^{ab}	1.7^{bc}	2.1^{c}	4.6^{c}	0.40^{a}	89.00^{b}
M	571.7^{c}	40.3^{c}	130.0^{b}	2.1^{c}	4.3^{d}	7.5^{d}	0.45^{a}	127.67^{c}
p-value	< 0.001	< 0.001	0.152	0.004	< 0.001	< 0.001	0.395	< 0.001
LSD	53.02	9.6	31.54	0.4329	1.020	7	0.5150	23.34
CV (%)	6	5.6	15.3	15.5	30.7	0.5	9.9	16.7

Means followed by the same letters are not significantly different ($p \leq 0.05$); CV = coefficient of variation; C = Conventional compost; H = highland earthworm species; M = midland earthworm species; L = lowland earthworm species; E = *Esenia fetida*; EC = electrical conductivity; Nt = total nitrogen; P = available phosphorus; K = exchangeable potassium; S = sulfur; Na = sodium; Ca = calcium; Mg = magnesium; Zn = zinc; Mn = manganese; Cu = cupper; B = boron; Fe = Iron; OC = organic carbon; CEC = cation exchange capacity; LSD = least significant difference.

conventional compost contains higher 'ammonium-N', while vermicompost tended to contain higher 'nitrates-N, the most available nitrogen form' (Atiyeh et al., 2000; Suthar and Singh, 2008). Earthworms facilitate nitrogen-fixing bacteria and mycorrhizal fungi (Bin Dohaish, 2019). The pre-dominance of thermophilic bacteria in conventional composting can also lead to the nitrogen loss through volatilization (Sinha et al., 2010; Barthod et al., 2018).

The highest available phosphorus (P) content ($p < 0.05$) was recorded in bins treated with the *Eisenia andrie* species compared to the other treatments, and a twofold increase compared to conventional composting. An increase in P (4.5-264 %) when using earthworms in the composting process was also found elsewhere (Pattnaik and Reddy, 2010; Rajendran and Thivyatharsan, 2014). Mineralization and mobilization of phosphorus resulting from the enhanced phosphatase activity by microorganisms in the earthworm's gut epithelium might possibly be the reason for this (Garg et al., 2006; Suthar and Singh, 2008; Bin Dohaish, 2019). Earthworms convert insoluble P into soluble forms with the help of P-solubilizing microorganisms, making it more available to plants (Padmavathiamma et al., 2008; Suthar and Singh, 2008; Ramnarain et al., 2019).

Comparisons between treatments showed that the highest exchangeable potassium (a 125 % increase as compared to the control) was recorded in the *Eisenia andrei* treated bins. This is on par with the findings of Pattnaik and Reddy (2010), and Rajendran and Thivyatharsan (2014), who, respectively, reported a 172.4 and 155 % increase in K when composting including earthworms. This increase supports the findings of others elsewhere who have reported 1.55-95 % more exchangeable potassium in earthworm treated bins compared to the conventional one (Sinha et al., 2010). This was mainly related to the sizeable number of symbiotic microflora present in the earthworm gut and the cast, and secreted mucus and water which can trigger the release of available metabolites to enhance the mineralization rate (Kaviraj and Sharma, 2003; Suthar and Singh, 2008).

Experimental results for exchangeable calcium (Ca) and exchangeable magnesium (Mg) showed statistically different effects on treatments ($p = 0.001$). The *Eisenia andrie* and *Lumbricus rubellus* species treated bins had higher Ca (an increase of 57 and 48 %, respectively) compared to the control. The use of *Eisenia andrie* species in the composting process also yielded a higher Mg (an increase of 83 %) compared to the control. The increase in Ca and Mg content in the study area supports the findings of others who have reported increases of 131.5 and 155.6 %, respectively, when earthworms are included in the composting process (Teka et al., 2014). Increases in Ca (155.6 %) and Mg (50.0 %) content compared to the conventional compost were also noted by Pattnaik and Reddy (2010). The gut processes associated with calcium metabolism were primarily responsible for the enhanced of calcium and magnesium content in the earthworm treated bins (Garg et al., 2006).

There was no statistical variation ($p = 0.15$) in the contents of sodium (Na) and sulfur (S) in the earthworm treatments. However, there was a striking difference compared with the control, which reached 85.7 % of S and 27-39 % of Na increases in utilization in the *Eisenia andrie* and *Lumbricus rubellus* species.

Effect on micro-nutrients (Cu, Mn, Zn, Fe and B)

The experimental results of the effect of the different treatments on micro-nutrients showed statistical differences ($p = 0.001$) between treatments, except in the case of boron (B). The *Eisenia andrie* species was the top contributor with increases in Zn, Cu, Mn, B and Fe of 91 %, 1770 %, 1400 %, 4400 % and 361 %, respectively. These results indicate an accumulation of these micro-elements in the earthworm treated compost due to enhanced microbial activity in the earthworm's gut and the cast (Dey et al., 2019; Ramnarain et al., 2019). These can prompt the release of available metabolites to enhance the rate of mineralization (Kaviraj and Sharma, 2003; Suthar and Singh, 2008).

Conclusions

Our findings showed that the highland, midland, and lowland earthworms were those taxonomically classified as *Dendrobaena veneta*, *Eisenia andrie* and *Lumbricus rubellus*, respectively. Vermicomposting, taking the average of the product of the four earthworm species, resulted in increased nutrient contents, ranged from 21.9 % for Na to 3300 % for B, compared to conventional compost. It also increased the compost conditions such as pH, EC, and CEC by 8.7 %, 42.6 % and 12.9 %, respectively.

When the different earthworm species were compared, the highest increase in CEC (19 %) and Nt (44.4 %) was recorded in the *Eisenia fetida* treated bins compared to the control. The highest content for OC (a 33.4 % increase) and EC (a 67 % increase) was reported from the *Dendrobaena veneta* treated bins. Composting with *Eisenia andrie* also resulted in an increase in P (96.1 %), K (125 %), Mg (83 %) and all micro-nutrients (91 % for Zn to 4400 % for B). Furthermore, *Eisenia andrie* and *Lumbricus rubellus* species contributed to the increased additions of Ca (57 and 48 %, respectively), Na (39 %) and S (85.7 %) compared to the control.

It can be concluded that the use of local earthworms (particularly *Eisenia andrie)* in the composing process can play an exceptionally significant role in plant nutrient additions. Moreover, the different earthworms used in this study have their specific contributions in terms of increasing the availability of nutrients for soil fertility improvement.

Acknowledgments

The author acknowledges Mekelle University for the financial support.

References

Arancon, N.Q.; Edwards, C.A.; Atiyeh, R.; Metzger, J.D. 2004. Effects of vermicomposts produced from food waste on the growth and yields of greenhouse peppers. Bioresource Technolology 93: 139-144. https://doi.org/10.1016/j.biortech.2003.10.015

Atiyeh, R.M.; Dominguez, J.; Sobler, S.; Edwards, C.A. 2000. Changes in biochemical properties of cow manure during processing by earthworms (*Eisenia andrei*, Bouché) and the effects on seedling growth. Pedobiologia 44: 709-724. https://doi.org/10.1078/S0031-4056(04)70084-0

Barthod, J.; Rumpel, C.; Dignac, M.F. 2018. Composting with additives to improve organic amendments. A review. Agronomy for Sustainable Development 38: 17. https//doi.org/10.1007/s13593-018-0491-9.hal-01731152

Bin Dohaish, E.A. 2019. Black Gold: The best alternative in waste management via agriculture. Agricultural Research Technology 21: 556153. https//doi.org/10.19080/ARTOAJ.2019.21.556153

Bremner, J.M.; Mulvaney, C.S. 1983. Nitrogen Total. p. 595-624. In: Page, A.L., eds. Methods of Soil Analysis: Part 2 Chemical and Microbiological Properties. American Society of America, WI, USA. (Agronomy Monographs). https://doi.org/10.2134/agronmonogr9.2.2ed.c31

Chapman, H.D. 1965. Cation-exchange capacity. p. 891-901. In: Norman, A.G. eds. Methods of Soil Analysis. Part 2. Chemical and microbiological properties. Madison, Wisconsin. (Agronomy Monographs). https://doi.org/10.2134/agronmonogr9.2.c6

De Villiers, J.M.; Jackson, M.L. 1967. Aluminous chlorite origin of pH-dependent cation exchange capacity variations. Soil Science Society of America Journal 31: 614-619. https://doi.org/10.2136/sssaj1967.03615995003100050005x

Degefe, G.; Tamire, G.; Mohammed, S. 2018. Biomanagement of Rose and carnation wastes in flower industries with three epigeic earthworm species: *Eisenia fetida, Eisenia andrie* and *Dendrobanae veneta*. African Journal of Biotechnology 17: 1015-1020. https://doi.org/10.5897/AJB2018.16556

Delelegn, Y.T.; Purahong, W.; Sandén, H.; Yitaferu, B.; Godbold, D.L.; Wubet, T. 2018. Transition of Ethiopian highland forests to agriculture-dominated landscapes shifts the soil microbial community composition. BMC Ecology 18: 58. https://doi.org/10.1186/s12898-018-0214-8

Demir, Z. 2019. Effects of vermicompost on soil physicochemical properties and lettuce (*Lactuca sativa* Var. Crispa) yield in greenhouse under different soil water regimes. Communications in Soil Science and Plant Analysis 50: 2151-2168. https://doi.org/10.1080/00103624.2019.1654508

Dey, M.; Mohilal, N.; Mongjam, S. 2019. Effect of compost and vermicompost prepared from different biodegradable wastes on the growth of king chilli *Capsicum chinense*. International Journal of Plant, Animal and Environmental Sciences 9: 74-82. http://dx.doi.org/10.21276/ijpaes

Drenovsky, R.E.; Steenwerth, K.L.; Jackson, L.E.; Scow, K.M. 2010. Land use and climatic factors structure regional patterns in soil microbial communities. Global Ecology Biogeography 19: 27-39. https://doi.org/10.1111/j.1466-8238.2009.00486.x

Edwards, C.A. 1995. Historical overview of vermicomposting. Biocycle 36: 56-58.

Ewulo, B.S.; Ojeniyi, S.O.; Akanni, D.A. 2008. Effect of poultry manure on selected soil physical and chemical properties, growth, yield and nutrient status of tomato. African Journal of Agricultural Research 3: 612-616.

Fares, F.; Albalkhi, A.; Dec, J.; Bruns, M.A.; Bollag, J.M. 2005. Physicochemical characteristics of animal and municipal wastes decomposed in arid soils. Journal of Environmental Quality 34: 1392-1403. https://doi.org/10.2134/jeq2004.0257

Garg, P; Gupta, A.; Satya, S. 2006. Vermicomposting of different types of waste using *Eisenia foetida*: a comparative study. Bioresource Technology 97: 391-395. https://doi.org/10.1016/j.biortech.2005.03.009

Greiner, H.G.; Stonehouse, A.M.T.; Tiegs, S.D. 2011. Cold tolerance among composting earthworm species to evaluate invasion potential. American Midland Naturalist Journal 166: 349-357. https://doi.org/10.1674/0003-0031-166.2.349

Haileselassie, A.; Priess, J.; Veldkamp, E.; Teketay, D.; Lesschen, J.P. 2005. Assessment of soil nutrient depletion and its spatial variability on smallholders' mixed farming systems in Ethiopia using partial versus full nutrient balances. Agriculture Ecosystems & Environment 108: 1-16. https://doi.org/10.1016/j.agee.2004.12.010

Hailu, H.; Mamo, T.; Keskinen, R.; Karltun, E.; Gebrekidan, H.; Bekele, T. 2015. Soil fertility status and wheat nutrient content in Vertisol cropping systems of central highlands of Ethiopia. Agriculture & Food Security 4: 19. https://doi.org/10.1186/s40066-015-0038-0

Henao, J.; Baanante, C. 2006. Agricultural Production and Soil Nutrient Mining in Africa: Implications For Resource Conservation And Policy Development. International Fertilizer Development Center. Ames, AI, USA. (IFDC Technical Bulletin).

Jiménez, E.I.; García, V.P. 1992. Determination of maturity indices for city refuse composts. Agriculture, Ecosystems and Environment 38: 331-343. https://doi.org/10.1016/0167-8809(92)90154-4

Karuppasamy, G.; D'Couto, M.A.; Baskaran, S.; Achary, A. 2017. Biotransformation of various wastes into a nutrient rich organic biofertilizer: a sustainable approach towards cleaner environment. p. 212. In: Bhore, S.; Marimuthu, K.; Ravichandran, M., eds. Biotech Sustainability: Achievements, Challenges and Perspectives.

Kaviraj; Sharma, S. 2003. Municipal solid waste management through vermicomposting employing exotic and local species of earthworms. Bioresource Technology 90: 169-173. https://doi.org/10.1016/S0960-8524(03)00123-8

Lauber, C.L.; Strickland, M.S.; Bradford, M.A.; Fierer, N. 2008. The influence of soil properties on the structure of bacterial and fungal communities across land-use types. Soil Biology & Biochemistry 40: 2407-15. https://doi.org/10.1016/j.soilbio.2008.05.021

Lim, S.L.; Wu, T.Y.; Lim, P.N.; Shak, K.P.Y. 2015. The use of vermicompost in organic farming: overview, effects on soil and economics. Journal of Science and Food Agriculture 95: 1143-1156. https://doi.org/10.1002/jsfa.6849

Lindsay, W.L.; Norvell, W.A. 1978. Development of a DTPA soil test for zinc, iron, manganese, and copper. Soil Science Society of America Journal 42: 421-428. https://doi.org/10.2136/sssaj1978.03615995004200030009x

Manivannan, S.; Balamurugan, M.; Parthasarathi, K.; Gunasekaran, G.; Ranganathan, L.S. 2009. Effect of vermicompost on soil fertility and crop productivity-beans (*Phaseolus vulgaris*). Journal of Environmental Biology 30: 275-281.

Melese, A.; Gebrekidan, H.; Yli-Halla, M.; Yitaferu, B. 2015. Phosphorus status, inorganic phosphorus forms, and other physicochemical properties of acid soils of Farta District, northwestern highlands of Ethiopia. Applied and Environmental Soil Science 2015: 1-11. https://doi.org/10.1155/2015/748390

Munroe, G. 2007. Manual of On-farm Vermicomposting and Vermiculture. Organic Agriculture Centre of Canada, Halifax, Canada.

Nagavallemma, K.P.; Wani, S.P.; Lacroix, S.; Padmaja, V.V.; Vineela, C.; Babu Rao, M.; Sahrawat, K.L. 2004. Vermicomposting: Recycling wastes into valuable organic Fertilizer. Global Theme on Agroecosystems Patancheru. International Crops Research Institute for the Semi-Arid Tropics, Andhra Pradesh, India (Report no. 8).

Nath, G.; Singh, K.; Singh, D.K. 2009. Chemical analysis of vermicomposts/vermiwash of different combinations of animal, agro and kitchen wastes. Australian Journal of Basic and Applied Sciences 3: 3671-3676.

Nederlof, E.S.; Dangbégnon, C. 2007. Lessons for farmer-oriented research: experiences from a west African soil fertility management project. Agriculture and Human Values 24: 369-387. https://doi.org/10.1007/s10460-007-9066-0

Olsen, S.R. 1954. Estimation of Available Phosphorus in Soils By Extraction with Sodium Bicarbonate. U.S. Department of Agriculture, Washington, DC, USA.

Padmavathiamma, P.K.; Li, L.Y.; Kumari, U.R. 2008. An experimental study of vermi-biowaste composting for agricultural soil improvement. Bioresource Technology 99: 1672-1681. https://doi.org/10.1016/j.biortech.2007.04.028

Pattnaik, S.; Reddy, M.V. 2010. Nutrient status of vermicompost of urban green waste processed by three earthworm species: *Eisenia fetida*, *Eudrilus eugeniae*, and *Perionyx excavatus*. Applied and Environmental Soil Science 2010: 13. https://doi.org/10.1155/2010/967526

Pfiffner, L. 2022. Earthworms – architects of fertile soils: their significance and recommendations for their promotion in agriculture. FiBL technical guide No. 1629. https://doi.org/10.5281/zenodo.6670157

Podolak, A.; Kostecka, J.; Mazur-Pączka, A.; Garczyńska, M.; Pączka, G.; Szura, R. 2020. Life Cycle of the *Eisenia fetida* and *Dendrobaena veneta* Earthworms (Oligohaeta, Lumbricidae). Journal of Ecological Engineering 21: 40-45. https://doi.org/10.12911/22998993/113410

Pulleman, M.M.; Six, J.; Uyl, A.; Marinissen, J.C.Y.; Jongmans, A.G. 2005. Earthworms and management affect organic matter incorporation and microaggregate formation in agricultural soils. Applied Soil Ecology 29: 1-15. https://doi.org/10.1016/j.apsoil.2004.10.003

Rajendran, M.; Thivyatharsan, R. 2014. Performance of different species of earthworms on vermicomposting. International Journal of Research in Agriculture and Food Sciences 2: 1-6.

Ramnarain, Y.I.; Ansari, A.A.; Ori, L. 2019. Vermicomposting of different organic materials using the epigeic earthworm *Eisenia foetida*. International Journal of Recycling of Organic Waste in Agriculture 8: 23-36. https://doi.org/10.1007/s40093-018-0225-7

Rhoades, J. 1982. Cation exchange capacity. p. 149-157. In: Page, A.L., eds. Methods of soil analysis: Part 2 Chemical and microbiological properties. American Society of America, WI, USA. (Agronomy Monographs). https://doi.org/10.2134/agronmonogr9.2.2ed.c8

Scheu, S. 2003. Effects of earthworms on plant growth: patterns and perspectives. Pedobiologia 47: 846-856. https://doi.org/10.1078/0031-4056-00270

Sen, B.; Chandra, T.S. 2009. Do earthworms affect dynamics of functional response and genetic structure of microbial community in a lab-scale composting system? Bioresource Technology 100: 804-811. https://doi.org/10.1016/j.biortech.2008.07.047

Sinha, R.K.; Agarwal, S.; Chauhan, K.; Valani, D. 2010. The wonders of earthworms and its vermicompost in farm production: Charles Darwin's 'friends of farmers', with potential to replace destructive chemical fertilizers from agriculture. Agricultural Sciences 1: 76-94. https://doi.org/10.4236/as.2010.12011

Suthar, S.; Singh, S. 2008. Vermicomposting of domestic waste by using two epigeic earthworms (*Perionyx excavatus* and *Perionyx sansibaricus).* International Journal of Environment Science and Technology 5: 99-106. https://doi.org/10.1007/BF03326002

Teka, K.; Berihu, T.; Amdu, H.; Araya, T.; Nigussie, S. 2014. Assessing soil nutrient additions through different composting techniques in northern Ethiopia. Momona Ethiopian Journal of Science 6: 110-126. https://doi.org/10.4314/mejs.v6i2.109713

Teka, K.; Githae, E.; Welday, Y.; Gidey, E. 2019. Vermi-composting for increased agricultural productivity, women empowerment and environmental sanitation in northern Ethiopia. AgriFoSe2030, Tigray, Ethiopia. (Report 23).

The Agricultural Transformation Agency [ATA/MoA]. 2014. Soil Fertility Status and Fertilizer Recommendation Atlas for Tigray Regional State, Ethiopia. Addis Ababa, Ethiopia.

Walkley, A.; Black, I.A. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science 37: 29-38. https://doi.org/10.1097/00010694-193401000-00003

Yagi, R.; Ferreira, M.E.; Cruz, M.C.P.; Barbosa, J.C. 2003. Organic mater fractions and soil fertility under the influence of liming, vermicompost and cattle manure. Scientia Agricola 60: 549-557. https://doi.org/10.1590/S0103-90162003000300021