Soil macrofauna abundance, biomass and selected soil properties in the home garden and coffee-based agroforestry systems at Wondo Genet, Ethiopia

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Abstract

Background

In Ethiopia, the majority of farmers have limited access to inorganic fertilizers, but agricultural development is largely limited by economic constraints. Agroforestry practices (AFPs) are the typical solutions for such kind of agricultural systems. AFPs play critical roles in the improvement of abundance and biomass of soil invertebrates, which are necessary for long-term improvement of soil properties. The overall objective of the present study was to investigate the spatial and temporal dynamics in macro fauna abundance and biomass in home garden and coffee-based agroforestry systems and to relate it with the dynamics in a range of soil physico-chemical parameters.

Result

The two AF systems did differ in plant species richness and diversity of life forms. For both sampling seasons, higher number of macrofauna was collected from home garden AF than Coffee-based AF plot. Total macrofaunal biomass between the wet and dry season was significant ($p < 0.05$) for samples from home garden AF plot. Depth-wise pattern in macrofauna abundance and biomass showed distinct seasonal variation in the two-agroforestry systems. For both AF plots, marked and significant ($p < 0.001$) seasonal differences were observed in relation to soil moisture, temperature, and pH. On the other hand, dry season samples from home garden AF plot had significantly ($p < 0.001$) higher moisture content and soil pH than coffee-based AF plot.

Conclusion

The abundance and biomass of soil macrofauna including soil properties were improved by AFs. Thus, the results of this study encourage farmers and policy makers about land administration to implement AFs to ensure sustainability of soil fertility for sustainable production and productivity.

1. Introduction

Maintenance of soil fertility and efficient nutrient cycling is a critical factor in the long-term viability of most agricultural systems (Okigbo, 2020). Soil invertebrates (soil fauna) constitute an important biological component that regulates a range of soil processes (Brussaard, 1998). They contribute to the formation of stable aggregates on the soil through mechanical action, which may protect a portion of the soil organic matter from rapid mineralization (à Birang, 2004).

Several previous research results indicated that soil invertebrates involve in decreasing bulk density, increasing soil pore space, soil horizon mixing, increased aeration and drainage, increased water holding capacity of the soil, litter decomposition and improving soil aggregate structure (Lavelle et al., 1994; Rousseau et al., 2013). Despite the fact that soil macrofauna play an important role in soil fertility maintenance, they are negatively affected by agricultural intensification and seasons, (Fragoso et al., 1997; Melman et al., 2019).

Different types of agroforestry systems are recognized and practiced in different parts of Ethiopia. However, many studies conducted on such land use types involve in system description, characterization, and quantification of species diversity, soil conditions and the contribution of products to household livelihood. To date, virtually little or no attempt has been made to investigate the soil macrofauna attributes in agroforestry systems of Ethiopia. Therefore, this work was initiated to generate data on macrofauna abundance and biomass in two agroforestry systems at Wond Genet. It is hoped that the information from this study would shed light on belowground processes and the soil macrofauna and will encourage researchers to undertake similar research in the future.

2. Materials And Methods

2.1 Description of the study site and plot

The study was carried out in the premises of Wondo Genet College of Forestry and Natural Resource (WGCF), Hawassa University Campus, Ethiopia. The campus is located (7° 06' N to 7° 11' N, 38° 5' E to 38° 07' E) ca. 263 Km south of Addis Ababa and about 13 km from Shashemene. The soils of the area are well drained loam or sandy loam, shallow at steep convex slopes but deep at low altitude (Getachew *et al.*, 2012). The study plots were two Agroforestry (AF) land use types within the premises of the College. The first plot is a home-garden AF system established and become operational in January 1999 as an AF Demonstration plot. It has a size of 0.5 ha and is divided into different compartments where different types of crops, fruit trees, vegetables and tree crops are grown. The coffee-based AF plot was established some 30 years ago and has a size of ca. 1 ha. Different species of trees are found interspersed between coffee trees.

2.2 Plant species association and sampling design

At the start of the study, a complete record of the plant species in each study plot was carried out. Plant species were identified using Bekele-Tesemma *et al.* (1993) and Flora of Ethiopia. Life form and plant characteristics (e.g. nitrogen fixing, deciduousness) were also noted. Soil macrofauna and soil samples were collected seasonally, February 2012 and August 2012, representing dry and wet seasons, respectively. Transect-based soil macrofauna sampling was carried out using the standard Tropical Soil Biology and Fertility Institute (TSBF) manual (Anderson & Ingram, 1993) with some modifications to adapt the sampling design to agroforestry systems as suggested by Schroth and Sinclair (2003). The modified design provides an average estimate of soil macrofauna communities at the scale of a farm or watershed. Spacing between sampling points will depend on the size of the area and the number of samples that can be processed with the available resources (Lavelle *et al.*, 2004). In this sampling procedure, a random transect line will be laid across the study plot and samples will be collected at regularly spaced sample points and this sampling procedure is suitable for the coffee-based AF plot. Accordingly, transects in the coffee-based AF plot were placed along a diagonal line traversing the plot from one randomly selected corner to the other. The origin of transects was located randomly along this line, providing that the entire transect could fit on to the diagonal. Transects were established every 50m. For the home garden AF plot, in view of the apparent compartmentalization of garden units, a combination of sampling procedure was adopted. Larger garden units (e.g. coffee-stand, sugar cane plots) were sampled by the transect method with transects established every 10 m. For smaller garden units (e.g. mixed enset clone stand, vegetable plots), sampling points were identified randomly and a minimum of 3-5 samples were collected per smaller plot. Sampling locations were offset by one meter between the dry season and rainy season sampling periods in order to avoid sampling of a previously disturbed area. A total of 15 samples were collected per season in each land use type and no replication was attempted other than the within-site pseudo-replication inherent in transect.

2.3 Soil macrofauna sampling

At each sampling point, a quadrat of 25 cm by 25 cm was marked out using a wooden frame. The litter layer was carefully collected from within this area and placed in a plastic bag with corresponding label. A soil monolith (25 x 25 x 30 cm) was then dug around the quadrat, starting a few centimetres away from the quadrat, with the wooden frame left in place for reference. Once the monolith had reached a depth of 30 cm, the sides of the monolith were quickly but carefully cut down. Three layers of soil (10cm depth increment) were then cut from the block using a sharp knife and placed in plastic bags and labelled. The soil was later placed on plastic trays (20 cm x 30 cm) and the macrofauna from each layer (depth) were gently sorted out from the soil on the site by hand using pointer as used by Dangerfield (1997). Macrofauna from each soil depth were placed in separate glass-containers and labelled. After sorting, the soil was returned to the sampling sites to minimize site degradation.

2.4 Soil macrofauna preservation and identification

Macrofauna samples were placed in McCartney bottles (150ml) either containing 4% formalin for earthworms (Anderson & Ingram, 1993) or 70% alcohol for arthropods (Baker, 1996) and transported to the laboratory for enumeration and identification. Biological assessment included macrofauna biomass, abundance (number of individuals m⁻²).

Macrofauna fresh weight was determined after rinsing the animals with water and dried them with paper towels on the same day of collection. Taxonomic identification was done at Order/Family level at the Department of Biology, Science Faculty, Hawassa University.

2.5 Soil sampling and analysis

Soil samples (for a range of physical and chemical parameters) were collected at the 0–20 cm depth from all macrofauna sampling locations in both AF land use types. At each sampling point, soil temperature was measured using a mercury thermometer. Soil samples were then processed (weighed and sieved) in the laboratory to determine moisture content (dried overnight at 105 °C) and different physico-chemical parameters. Soil texture was determined using hydrometer after dispersing the soils with solutions of hydrogen peroxide and sodium hexa-metaphosphate. Soil bulk density was determined using the core-volume method by dividing the weight of an oven dried soil in a core (g) to the volume of the core or soil (cm³). Soil pH was determined using electrodes (1M KCl 1:6 V: V) and total carbon was analysed by ignition and total nitrogen was analysed following the Kjeldahl protocol.

2.6 Data analysis

Individual soil macrofauna belonging to each Order/Family from each land use type were counted and recorded. Macrofauna abundance was computed as number of individuals per unit area (No/m²) and macrofauna biomass (FW) was calculated as g m⁻². Absolute abundance, relative abundance and biomass were computed for individual soil depths, seasons and AF plots. Data was subjected to either one-way ANOVA and mean differences between treatments were considered significant at $p < 0.05$. Seasonal and total macrofauna diversity was calculated using Shannon and Simpson diversity indices. Shannon diversity index, given by the formula $H' = -\sum P_i \ln P_i$, where P_i is the number of individuals of one taxa in proportion to the number of individuals in the whole community. The Simpson index was also calculated using the same data to reduce the bias associated with a single diversity index. Simpson index, $D = [n(n-1)] / N(N-1)$, where n is the number of individuals of one group and N is the total number of individuals. The value of $1/D$ is usually used to represent a community's diversity because it allows the index to increase as diversity increases. A possible relationship between earthworm biomass and soil parameters was sought using Pearson's correlation coefficient.

3. Results And Discussion

3.1 Species richness and plant association

The two AF systems did differ in plant species richness and diversity of life forms (Table 1). Across seasons, 11 plant families were recorded in the home garden plot while there were only five plant families in Coffee-based AF plot. Species richness in home garden AF plot was twice that in the coffee-based AF system. Plant species in home garden AF plot belong to three life forms namely herbs, shrubs and trees and herbaceous plants were absent in coffee-based AF plot. Herbaceous species were the dominant (50%) life form in home garden AF plot while trees constitute ca. 85% of plant species in coffee-based AF plot. Most of the trees (*Cordia africana*, *Milletia ferruginea*, and *Grevillea robusta*) provide shade to coffee plants in the home garden AF plot. Shade trees in coffee-based AF were mainly of *Croton macrostachys*, *Milletia ferruginea* and *Cordia africana* species.

Table 1. *Plant species recorded in home garden and coffee-based AF systems*

Homegarden AF system			
Scientific name	Family Name	Life form	Remark
<i>Cordia africana</i> Lam.	Boraginaceae	Tree	Semi-deciduous, Shade
<i>Coffea arabica</i> L.	Rubiaceae	Shrub	Shade-loving
<i>Grevillea robusta</i>	Proteaceae	Tree	Boundary tree
<i>Enset ventricosum</i> (Welw.) Cheesman	Musaceae	Herb	
<i>Musa paradisiaca</i> L.	Musaceae	Herb	
<i>Persea americana</i> Mill.	Lauraceae	Shrub	
<i>Mangifera indica</i> L.	Ancardiaceae	Shrub	
<i>Solanum tuberosum</i> L.	Solanaceae	Herb	
<i>Milletia ferruginea</i> (Hochst.) Baker	Fabaceae	Tree	Nitrogen fixing, Shade
<i>Acacia abyssinica</i> (Hochst) ex. Benth	Fabaceae	Tree	Nitrogen fixing
<i>Saccharum officinarum</i> L.	Poaceae	Herb	
<i>Brassica oleracea</i> L. var. capitata	Brassicaceae	Herb	
<i>Daucus carota</i>	Apiaceae	Herb	
Coffee-based AF system			
Scientific name	Family Name	Life form	Remark
<i>Croton macrostachys</i>	Euphorbiaceae	Tree	Deciduous
<i>Grevillea robusta</i>	Proteaceae	Tree	Boundary
<i>Milletia ferruginea</i> (Hochst.) Backer	Fabaceae	Tree	Nitrogen fixing, shade
<i>Acacia abyssinica</i> (Hochst) ex. Benth	Fabaceae	Tree	Nitrogen fixing
<i>Coffea arabica</i> L.	Rubiaceae	Shrub	
<i>Cordia africana</i> Lam.	Boraginaceae	Tree	Shade tree

3.2 Soil macrofauna composition, abundance and diversity

The macrofauna community was mainly composed of earthworms and arthropods belonging to 6 (homegarden AF) or 7 (Coffee-based AF) different Orders (Table 2). For both sampling seasons, higher number of macrofauna was collected from home garden AF than Coffee-based AF plot. Total macrofauna abundance (Table 3) in home garden AF was about 48% higher than that in coffee-based AF plot and the mean difference was significant ($p=0.149$). Termites (Isoptera) were the dominant (46% relative abundance) macrofaunal groups in home garden AF while ants (Hymenoptera) being the most abundant (42.2%) in Coffee-based AF plots. Earthworms were the next abundant macrofaunal group with 26% (home garden) and 20% (Coffee-based) contribution to the total macrofaunal abundance in the respective land use types.

Table 2. *Soil macrofauna community in home garden and coffee-based AF plots at Wondo Genet.*

Class	Order	Common name	Habitat
Crustacea	Isopoda	Bugs	Litter
Chilopoda	Juliformia	Millipedes	Litter & soil
Diplopoda	Geophilomorpha	Centipedes	Litter
Oligochaeta	Hepalotaxida	Earthworms	Soil and litter
Insecta	Isoptera	Termites	Soil
Insecta	Hymenoptera*	Ants*	Litter & soil
Insecta	Coleoptera	Beetle larvae	Litter
Total			

*absent in-home garden AF plot

Table 3. *Absolute abundance ($N_0 \text{ m}^{-2}$) and relative abundance (RA) of soil macrofaunal groups sampled in two seasons from two AF land use types at Wondo Genet.*

Soil macrofauna	Home garden AF				Coffee-Tree AF			
	Dry season		Rainy season		Dry season		Rainy season	
	<i>Abundance</i>	<i>RA</i>	<i>Abundance</i>	<i>RA</i>	<i>Abundance</i>	<i>RA</i>	<i>Abundance</i>	<i>RA</i>
Earthworms	60	37.10	44.3	17.97	11.30	10.00	37.90	28.22
Termites	38.40	23.60	150.40	61.01	32.00	28.30	4.80	3.57
Ants	0.00	0.00	0.00	0.00	52.80	46.70	30.40	22.63
Centipedes	43.20	26.60	3.20	1.30	3.20	2.84	19.20	14.31
Beetle larvae	11.20	6.92	24.00	9.74	6.40	5.70	25.60	19.06
Others	9.40	5.78	24.60	9.98	7.30	6.46	16.40	12.21
Total	162.1	100.00	246.50	100.00	113.00	100.00	134.30	100.00

For both AF plots, total number of macrofauna recorded and their abundance (number m^{-2}) was higher (16-32%) for samples collected during the wet season (August 2012) than those collected during the dry (February 2012) season (Table 3). A notable observation was the absence of ants in home garden plot in both seasons. In addition, abundance of earthworms in home garden AF declined with a change from the dry season to wet season. In contrast, for the same seasonal change, a sharp increase in abundance of termite population was observed in the same AF plot whilst the same macrofaunal population showed a sharp decline in the Coffee-based AF plot.

Table 4. *Total and seasonal macrofauna diversity in home garden and coffee-based AF systems.*

AF land use system	Shannon diversity index (H')			Simpson's diversity index (1/D)		
	Sampling seasons			Sampling seasons		
	Dry	Wet	Total	Dry	Wet	Total
Home garden AF	1.45	1.13	1.41	3.75	2.37	3.31
Coffee-based AF	1.42	1.71	1.72	3.24	5.14	4.93

Seasonal and total macrofaunal taxonomic diversity in the two AF systems is presented in Table 4. Total macrofaunal diversity was generally higher for Coffee-based AF than home garden AF. On the other hand, while macrofaunal diversity declined with a change from dry to wet season for home garden AF system the opposite trend was observed for Coffee-based AF system.

3.3 Soil macrofauna biomass

The seasonal dynamics in total macrofauna biomass and biomass of major macrofaunal groups in the two AF plots is shown in Figure 3. Generally, total biomass and biomass of individual macrofaunal groups showed seasonal dynamics. Total biomass (Figure 3, upper right panel) in recorded in the home garden AF plot during the wet season was significantly higher than that coffee-based AF plot. Moreover, the difference in total macrofaunal biomass between the wet and dry season was significant ($p < 0.05$) for samples from home garden AF plot. On the other hand, wet season biomass was generally higher than that for the dry season for most macrofaunal groups except centipede population from home garden soil. When macrofauna biomass was averaged across seasons, the biomass from home garden AF plot was significantly ($p = 0.009$) higher than that from coffee-based AF plot. Proportionally, earthworms (Oligochaete) and beetle larvae (Coleoptera) constitute 75% and 64% of the total macrofaunal biomass in home garden and coffee-based AF plots, respectively. Earthworms had the highest biomass (44%) in home garden AF plots whereas beetle larvae contributed the highest (33%) macrofaunal biomass in coffee-based AF plot with earthworms contributing 31% for the same plot.

3.4 Macrofauna abundance and biomass along soil depth

The seasonal dynamics in macrofauna abundance and biomass along the soil depth is presented in Figure 4 and 5. Depth-wise pattern in macrofauna abundance and biomass showed distinct seasonal variation. For the home garden AF plot, earthworm (Figure 4) and total macrofauna (Figure 5) abundance and biomass increased with depth for the dry season. In contrast, for the same AF plot, there was a decline in earthworm and total macrofauna abundance and biomass during the wet season. For both seasons, the mean differences among the three depths were significant ($p < 0.05$). On the other hand, for samples from coffee-based AF plot, earthworm and total macrofauna abundance and biomass decreased with increasing depth for the wet season but there was no clear pattern for the dry season. The mean difference in abundance and biomass among the three depth classes was significant ($p < 0.05$) only for the wet season.

Table 6. *Seasonal changes in soil physico-chemical characteristics in home garden and coffee-based AF land use systems. Values are mean and S.E. $n = 15$. For a given land use type, means in the same column followed by same lower-case letter and for a given season*

AF practices and seasons	Soil physico-chemical parameters						
	Moisture	Temp (°C)	pH	Bulk density	Total N	Org. C	C/N
Home garden							
<i>Dry</i>	15.0±1.3aA	2.4±0.1aA	7.2±0.1aB	0.9±0.0a A	0.2±0.0aA	0.4±0.0a A	1.7±0.2aA
<i>Wet</i>	54.4±1.8bB	1.8±0.0bB	7.8±0.0bB	0.9±0.0a A	0.3±0.0aA	0.4±0.0a A	1.7±0.3aA
Mean	31.3	2.1	7.5	0.9	0.3	0.4	1.7
Coffee-based							
<i>Dry</i>	8.9±0.5bB	2.7±0.1aB	6.7±0.1aA	0.9±0.0aA	0.3±0.0aA	0.4±0.0aA	1.5±0.1aA
<i>Wet</i>	53.6±1.6aB	1.9±0.0bB	7.2±0.1bA	0.9±0.0aA	0.3±0.0aA	0.6±0.1bA	2.2±0.3bA
Mean	34.7	2.3	6.9	0.9	0.3	0.5	1.85

3.5 Soil conditions and litter quantity

Soil physico-chemical characteristics in the two AF plots during the study period are presented in Table 5. Generally, for both AF plots, marked and significant ($p<0.001$) seasonal differences were observed in relation to soil moisture, temperature, and pH. On the other hand, dry season samples from home garden AF plot had significantly ($p<0.001$) higher moisture content and soil pH than coffee-based AF plot. In contrast, dry season samples from coffee-based AF plot had a significantly higher soil temperature than that from home garden AF plot. None of the seasonal differences in soil bulk density and total nitrogen were significant. Moreover, there was no significant difference in the quantity of litter between the two AF plots (Figure 6). However, for both AF plots, litter quantity from the wet season was significantly ($p<0.01$) higher than that from the dry season.

To find out the relationship between soil parameters and soil macrofauna attributes, Pearson correlation (r) coefficient was calculated. There was no clear pattern of relationship between total macrofauna biomass/abundance and soil parameters for both AF systems. Moreover, attempts to find out the relationship between individual taxa and soil parameters gave no clear results owing to high variability between samples. Finally, the relationship between earthworm biomass and selected soil parameters were sought and the results are shown in Table 6. Accordingly, earthworm biomass was positively correlated with soil moisture and negatively correlated with soil temperature in both AF plots. Interestingly, soil pH was significantly and positively correlated with earthworm biomass collected in the home garden AF plot. The correlation between earthworm biomass and soil organic carbon is positive but weak and not significant.

Table 7. *Pearson's correlation coefficient (r) of earthworm biomass ($g\ m^{-2}$) with soil physico-chemical variables. * Significant (2-tailed) at $p<0.05$*

Soil parameters	Pearson Correlation coefficient values (r)	
	Home garden AF	Coffee-based AF
Soil moisture	0.37*	0.63*
Soil temperature	-0.49*	-0.57*
Soil pH	0.55*	0.17
Soil organic C	0.21	0.26
Soil nitrogen	0.34	0.11

4. Discussion

4.1 Soil macrofauna community and diversity

The present study showed that the two AF systems have comparable macrofauna composition. It should be noted that this study is probably the first of its kind on Ethiopian soils as far as our literature search is concerned. Consequently, it was not possible to make a reasonable comparison between the findings of this study and similar local studies. However, the number of macrofauna taxa (Orders) in this study are far lower than those reported for different agroforestry and crop monocultures in tropical and sub-tropical countries like in 19 orders by Vohland and Schroth (1999) and 13 orders by da Silva Moço *et al.* (2009) in Brazil, 19 orders in Zambia by Sileshi and Mafongoya (2006), 16 orders in Kenya by Karanja *et al.* (2009) but comparable with the report from Kenya (Tabu *et al.*, 2004). Soil macrofauna community composition, abundance and biomass are characteristic of soil type, vegetation cover, climate and management activities (Lavelle *et al.*, 2004). A higher macrofaunal abundance and biomass in the home garden AF than in the coffee-based AF system in this study may be related to the difference in litter quality, quantity and microclimate of the two land use types. A consistent presence of a rich organic layer of soil provides a more stable place for invertebrates to live (Chauvat *et al.*, 2007). The soil invertebrates encountered in the two AF systems are common to different agro-ecosystems and other land use types elsewhere in the tropics (Araújo *et al.*, 2010). In terms of function, the macrofauna in this study can generally be grouped into two major functional categories. The first being earthworms, ants and termites which are ecosystem engineers whose activity modulates the availability substrates to other organisms and greatly influences soil physical and chemical properties (Jouquet *et al.*, 2006). The second group includes bugs, millipedes, centipedes and beetle larvae. These arthropods directly influence the formation and stabilization of soil structure and indirectly influence decomposition processes through strong participation in litter fragmentation and mixing and predation on soil microfauna (Lavelle *et al.*, 1993; Lavelle *et al.*, 1994). Accordingly, the relative abundance and biomass of these functional groups in the two agroforestry systems determines a variety of soil processes including litter decomposition, mineralization and influence soil physical parameters.

The Shannon and Simpson indices in the two AF systems are indicative of the functional diversity of soil macrofauna rather than species diversity as it was very difficult to identify individual species of macrofauna in this study. Generally, soil macrofaunal diversity is expected to be higher in forests (1.5-3.5) and decreases in mono-cropping systems. Agroforestry systems display variable soil macrofaunal diversity values that range between monocropping systems and natural forests. The Shannon diversity index of 1.41 - 1.75 in this study is higher than those reported for home garden and other agroforestry systems (Karanja *et al.*, 2009) but comparable with the reports of Vohland and Schroth (1999) for different agroforestry systems.

4.2 Soil macrofauna, soil conditions and seasonal dynamics

There was a pronounced difference in soil macrofauna abundance and biomass on one hand and in selected soil parameters on the other for both AF systems. Seasonal variation in abundance and biomass of soil macrofauna in the tropics is a common phenomenon (Anu *et al.*, 2009). The observed seasonal variation in soil macrofauna abundance and biomass is possibly related to the change in food availability, site climatic factors and soil physico-chemical parameters. More importantly, the seasonal change in rainfall and to a lesser extent in temperature control plant growth and litter production particularly in deciduous tree and shrub species in the two AF plots. The observation that total soil macrofauna abundance and biomass was higher during the wet season than in the dry season imply that macrofauna attributes (abundance and biomass) may partly influenced by litter production (food availability). Different studies reported that population numbers of soil invertebrates vary in accordance with natural changes in season, temperature, amount of rainfall, altitude and other environmental gradients (Wiwatwitaya & Takeda, 2005). Apart from high litter availability, the wet season is also characterized by high soil moisture which may have contributed positively for the increased abundance and biomass of either earthworms and/or litter dwelling microarthropods. A similar seasonal dynamics in macrofauna abundance and biomass has been observed in different land use systems in the tropics (Vasconcellos *et al.*, 2010; Pauli *et al.*, 2011).

The role of soil moisture in determining earthworm abundance and biomass is well documented (Dewi & Senge, 2015). Earthworms can live in the soil with moisture ranging from 30 to 50% (Curry & Schmidt, 2007; Kale & Karmegam, 2010). In the present study, an increase in earthworm abundance (ca. 70% increase) with increase in soil moisture (from dry to wet season) was observed for the coffee-based AF system. In contrast, for the home garden AF system, there was a 27% decline in earthworm abundance for the same change in season whilst their biomass increased almost 3-fold. It was observed that there was a higher variation in earthworm count among sample points during the dry season as compared to the count in the wet season. The presence of different compartments with different ground cover and possibly soil moisture in home garden AF might have created patches of isolated niches with suitable environment (at least in terms of litter, soil moisture and possibly temperature) for earthworm proliferation during the dry season.

Regarding soil conditions, the seasonal variation in soil moisture and temperature observed in the two AF systems are a function of the variation in rainfall and air temperature of the site. However, the high pH during the wet season may be related to the activity of soil macrofauna most importantly earthworms whose biomass increased almost 3-fold and 4-fold in home garden and coffee-based AF plots. Deposition of casts (excreta) by earthworms may have increased the pH of the soil in the wet season. In fact, a positive and significant correlation was observed between earthworm biomass and soil pH particularly for the home garden AF. This observation disagrees with the reports of Edwards and Bohlen (1996) where the authors identified soil pH as a limiting factor on earthworm distribution and that most earthworms are neutrophilic, preferring a pH of 6.0-7.0 and the species diversity is drastically reduced at pH>7.0. There were no seasonal differences in other soil parameters except soil organic carbon increase in the coffee-based AF plot. However, increased mineralization accompanied by an increase in total soil N during the wet season has been reported in two enset plots in South Ethiopia (Zewdie *et al.*, 2008).

4.3 Depth-wise variation in soil macrofauna

Abundance and biomass of total soil macrofauna varied along the soil depth. The variation in abundance and biomass along the soil depth could be related to the presence of different functional groups of soil macrofauna (epigeic, anecic and endogeic) with different feeding habit and distribution in the soil profile (Anderson & Ingram, 1993). On the other hand, a reversal in abundance pattern along the soil depth with a change in season (dry to wet) may indicate the dynamics in the proportion of the three functional groups inhabiting different soil layers, their habitat preference and possibly the change in availability of substrates. Accordingly, epigeic soil macrofauna (largely represented by epigeic earthworms) which usually inhabit the litter layer predominate the upper soil layer during the wet season while endogeic macrofauna which form vertical burrows in the soil layer could dominate the macrofauna population during the dry

season. A seasonal dynamics in depth-wise soil microarthropods has been observed in forest soils in Brazil (Araújo *et al.*, 2010) and earthworms (Lalthanzara *et al.*, 2011) in agroforestry systems in India. According to Lalthanzara *et al.* (2011), earthworm abundance in two agroforestry systems showed a positive and significant correlation with soil moisture ($r = 0.562-0.630$).

5. Conclusions

Home garden and Coffee-based AF systems have comparable macrofauna composition. The macrofauna community dominated by ecosystem engineers is indicative of the biological quality of the soils with little or no disturbance under the two AF systems. Home garden AF system provides better living environment than coffee-based AF system for soil macrofauna proliferation and activity. Plant species richness and compartmented garden units with different life forms provide diverse living environment for macrofauna in home garden AF. Litter availability and moisture are important factors that determine the seasonal dynamics in soil macrofauna abundance and biomass. The depth-wise variation in macrofauna abundance and biomass across seasons is a function of the habitat preference of soil animals. The result of this study shed light on belowground processes and the soil macrofauna and farmers will be encouraged to maintain their farm production and productivity with agroforestry.

Declarations

Ethics and consent participant

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

All data and materials used in the study are presented in the main paper.

Competing interest

The authors declare that they have no competing interests.

Funding

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Authors' contributions

AA (main author) collected, analysed, and interpreted the data and wrote the manuscript. SZ edited, commented, and suggested ideas in the manuscript preparation process. All authors read and approved the final manuscript.

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Table 5

Table 5 is not available in this version.

Figures

Figure 1

Seasonal changes in major macrofauna biomass and total biomass in Home garden and Coffee-based AF plots. Bars are mean and S.E. $n=15$. Bars with same lower-case letter for a given AF plot and bars bearing same upper-case letter for a given season do not differ significantly at $P<0.05$.

Figure 2

Seasonal dynamics in earthworm abundance and biomass along the soil depth (0-30cm) in home garden (A and C) and coffee-based (B and D) AF plots. Bars represent mean and S.E. $n=15$. Bars (for a given season and different depths) bearing same lower-case letter and bars (for a given depth and different seasons) bearing same upper-case letter don not differ significantly at $p<0.05$.

Figure 3

Seasonal dynamics in total macrofauna abundance and biomass along the soil depth (0-30cm) in home garden (A and C) and coffee-based (B and D) AF plots. Bars represent mean and S.E. n=15. Bars (for a given season and different depths) bearing same lower-case letter and bars (for a given depth and different seasons) bearing same upper-case letter don not differ significantly at p<0.05.

Figure 4

Seasonal dynamics in litter production under home garden and coffee-based AF practices. Bars represent mean and S.E. n= 15. Bars for a given land use system bearing different letters differ significantly at $p < 0.05$.