Soil Macrofaunal Diversity and Biomass Across Different Land Use Systems in Wondo Genet, Ethiopia

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Abstract
One of the most important roles of soil organisms is breaking up the complex substances in decaying plants and animals so that they can be used again by living plants. The objective of this research work was to assess the biomass, diversity, and abundance of soil macrofauna in four different land use systems: natural forest, mixed stand plantation, agricultural and grazing lands in Wondo Genet, Ethiopia. Moreover, soil carbon and nitrogen were analyzed. In each land use system, three transect lines of 20m by 2m were laid out at 8 meters distance from each other, three quadrants of $1m^2$ were randomly excavated. Hand-sorting of soil was used to extract all fauna greater than 2 mm body length from soils under the four land use systems during the dry season (April to May 2014). Triplicates of soil samples were also collected from 0-30 cm depth for soil physico-chemical analysis. The highest abundance of soil macrofauna was recorded from the natural forest (64.6), while the lowest figure was from plantation forest (45.7). Likewise, the highest biomass and diversity of soil macrofauna was found in the natural forest (6.3857 $gm/m^2$and H' = 2.041, respectively) where it is characterized by higher diversity of plant species whereas the lowest biomass and diversity of soil macrofauna was observed from agricultural land (2.7863 gm/m^2 and H' =1.033, respectively). Generally, the highest biomass and diversity of soil macrofauna in soil under the natural forest was due to the highest diversity of floral composition and high leaf litterfall.
Keywords: land use, soil macrofauna, diversity, biomass, abundance

1. Introduction

According to Swift *et al.* (1979), soil fauna is commonly classified according to their body width into *microfauna* (<100 µm in size), *mesofauna* (100-2000 µm in size) and *macrofauna* (>2000 µm in size). They are among the most conspicuous soil animals with the greatest potential for direct effects on soil properties in the tropics. These include a wide variety of organism such as ants, earthworms, termites, amphipods, centipedes, snails, slugs, and to small extent mole rats that live on the soil surface, in the soil spaces (pores) and in the soil area near roots (Ayuke *et al*., 2009).

Soil macrofauna are among the most important biodiversity components of many ecosystems. They are often described as "soil engineers" in terrestrial ecosystems in that they play an indispensable role in maintaining a healthy soil ecosystem by acting on the soil conditions (physical, chemical and biological properties), and regulating soil microorganisms. They break down and redistribute organic resides in the soil profile, which increases the surface area and availability of organic residues for microbial activity and subsequent deposition (Lavelle *et al*., 1992). Generally, soil macrofauna influence decomposition and bio-degradation of organic residues, soil organic matter dynamics, humification, nutrient release and soil physical parameters (e.g. bulk density, porosity and water availability) (Brussard *et al*., 1993; Tinzara and Tukahirwa, 1995; Black and Okwakol, 1997). As a result, soil macrofauna have been considered to be the best long-term indicator of soil quality (Linden *et al*., 1994). Therefore, a significant component of the below-ground biodiversity, soil macrofauna require proper management of sustainable land use for maximal environmental benefits such as food to man, indicators of habitat quality, link to the above ground biodiversity, and as soil modifiers (Ayuke *et al*., 2009).

Nevertheless, soil macrofauna are affected by various anthropogenic activities. There is an increasing recognition that soil macrofaunal diversity is being threatened by climate change, the introduction of invasive species, genetically modified organisms, bushfires, landslides, and toxic wastes, among others (Ayuke *et al*., 2009). This, in turn, is contributing to the alarming rates of ecological bankrupts. Excessive reduction in soil biodiversity, especially the loss of species with unique functions, may have catastrophic effects, leading to the long-term degradation of soil and the loss of agricultural productive capacity.

Most often, the contribution of soil macrofauna in maintaining the structure and functioning of soil biodiversity, and the associated effects on ecosystem productivity, has been overlooked. For instance, termites are often regarded as serious pests and most of the studies conducted on termite have focused on pest species, yet of the more than 2,500 species, only 10% are agricultural pests (Crossley *et al*., 1992). A relatively more attention has been placed in research and development on the functions of soil micro-organisms; both their positive effects on nutrient cycling and uptake and the negative effects of soil-borne pests, including nematodes (Ruiz and Lavelle, 2008).

The ultimate fate of overlooking the beneficial functions performed by soil organisms in agricultural ecosystems is increased rates of land degradation, nutrient depletion, fertility decline, water scarcity, and yield reductions. All these factors have a negative impact on the livelihoods of people who depend directly on agriculture for their subsistence. One of the main gaps in most agricultural management systems is their failure to consider the option of managing soil biological processes and, in particular, using practices that favor the activity of soil macrofauna as a means to maintain and improve soil fertility.

Soil management practices, such as the use of agri-chemicals, frequent and/or deep tillage, and the lack of adequate organic matter management and protection of the soil from physical degradation (erosion, compaction), contamination and pollution, are generally associated with negative effects on the soil fauna community (Hendrix *et al*., 1990). The effect of various management activities on the population of soil macrofauna and their potential contributions are not known in the study area. This urges for further integrated research and development endeavors, through the development of baseline information on the sector to serve as an entry point and opportunity for managing the populations of soil macrofauna, enhancing their beneficial activities on soil fertility and agricultural production. The study is, therefore, initiated with an objective of addressing the effect of various land use systems on soil macrofaunal community (diversity and biomass) and the associated implications on soil health.

2. Materials and methods

2.1. Description of the study area

The study was conducted in Wondo Genet catchment, Ethiopia. Wondo Genet is situated 263 km from the capital Addis Ababa, 38 km from the regional capital Hawassa and 13 km from the nearby town of Shashemene, West Arsi zone in Oromia Regional State. It is located between 7^{0}02'-7^{0}07'N latitude and 38^{0}37' and 38^{0} 42' E longitudes. The area falls within an altitudinal range of 1600 and 2500 m.a.s.l. The area comprises a series of hills that are the south-western spur of the Bale Mountains. The agro-climatic zone of the district is traditionally categorized under Woyna-Dega (mid highland). The area receives a bimodal rainfall pattern (short rains between February and April, and long rains between June and September) with a total annual rainfall ranging between 700 and 1400mm (http://www.wgcfnr.org/resource/land.html).

The vegetation resource of Wondo Genet district includes both natural and plantation forests. The natural forest constitutes an important pocket of disturbed but still in good condition with its plant and animal species protected from the impacts of human beings in relation to many of the remaining natural forests in the country. The natural forest accounts for the greatest number of species and individuals of wild animals. Some of the major tree species in the natural forest include *Albizia gummifera, Celtis africana, Cordia africana, Croton macrostachyus, Prunus africana and Afrocarpus falcatus (Podocarpus falcatus syn.), Aningeria adolfi-friederici*, scattered Acacia trees and other tall grasses.

2.2. Sampling design and data collection

Soil and macrofaunal data were collected from four different land use systems in the watershed: (i) natural forest (ii) mixed plantation forest (iii) agricultural land and (iv) grassland. Transect sampling method was employed for the macrofaunal collection. In each land use type, three transect lines of size 20m x 2m was laid out about 8 meters from the monolith (Figure 1). Within each transect line, three quadrants, each measuring 1m^{2}, were randomly excavated using a digging tool. Sample plots were excavated to a depth of 0 to 30 cm for macrofauna collection. Similar methods were reported by various researchers elsewhere (e.g. Ayuke *et al*., 2009, Moriera *et al*., 2008 and Brown *et al*., 2001). Similar measurements were conducted in three different sites (replicated three times) for each land use type.

The collected soil and organic materials were placed in a plastic sheet for the macrofaunal count, in which each macrofauna obtained was picked up using clean forceps, and transferred into a collection jar containing 70% ethanol and immediately brought to the laboratory for analysis of soil macrofaunal diversity and biomass. Identification of the soil macrofauna was based on different standard identification manuals (Ayuke *et al*., 2009).

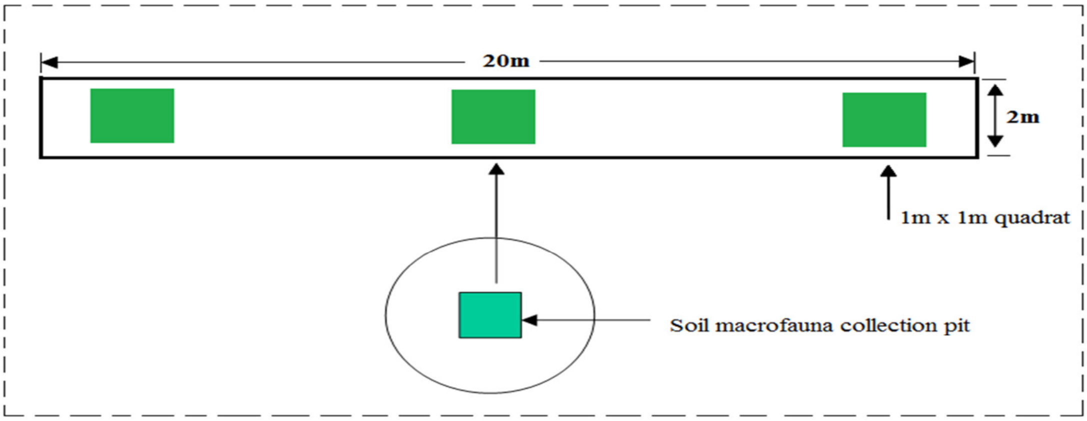

Figure 1: Transect layout and sampling scheme for macrofauna

Soil samples were also collected from 0-30cm depth, thoroughly mixed, homogenized and composited representing each sample plot for analysis of soil organic matter, pH, soil organic matter, soil organic carbon and nitrogen and moisture content (%). The soil organic matter was determined with a loss on ignition and the soil organic carbon following the Walkely and Black (1934) methods while nitrogen was analyzed following Kjeldahl procedure (Bremner and Mulvaney,1982), and moisture content (Ayuke *et al.*, 2009 and Brown *et al.,* 2001).

2.3. Data analysis and interpretation

The soil and macrofaunal data collected were organized and analyzed using descriptive statistics and presented in the form of tables, percentages, and graphs. The data obtained from soil characteristics, plants species diversity and land use systems were related to soil macrofaunal biomass and diversity. The species diversity of soil macrofaunal community recovered from the soil of different land uses and management practices were estimated using Shannon diversity index (Pielou, 1975) as indicated below.

$$H' = -\sum_{i=1}^{S}(p_i \ln p_i)$$

3. Results

3.1. Soil physico-chemical properties

The soil physico-chemical properties of the four land use types were analyzed; organic matter, organic carbon and nitrogen, pH, bulk density and moisture content (Table 1). The study found that very high amount of organic matter was recorded in the natural forest (26.05%), followed by plantation forest (15%), grassland (9.06%) and agricultural land (4.12%). Overall, the results showed significant differences in most of the soil physico-chemical properties determined among the different land use types. Highest values were generally obtained from the natural forest. Comparisons of these values is presented in Table 1.

The highest level of organic carbon (%) was obtained in the natural forest (15.11), followed by plantation forest (8.70); while the least was observed in agricultural land (2.39). Organic carbon was also significantly affected when the land use type was changed (Table 1). The natural forest has shown the highest organic carbon compared to the other land use types. Even though nitrogen was highest in the natural forest, it did not show significant differences among the land use types. Ranging between 6.59 and 7.35, the soil pH level was found to be close to the neutral. It was highest in the natural forest (7.35), but lowest in the grassland (6.59) (Table 1). However, no significant differences were found among the different land use types. Bulk density was highest in grassland, but lowest in natural forest and showed no significant difference among the land use types. The study also determined the moisture content of the land use types; the highest level of moisture content was recorded in the natural forest (35.76), while the least amount of moisture content was obtained in the grassland (20.92).

Table 1: Soil physico-chemical properties at different land use types

No.	Land use type	% Organic Matter	% Organic Carbon	% Nitrogen	pH	Bulk Density (g/cm^3)	%Moisture
1	NF	26.05 ± 2.29^{a}	15.1 ± 1.74^{a}	0.89 ± 0.53^{a}	7.35 ± 0.76^{a}	0.82 ± 0.367^{a}	35.76 ± 2.39^{a}
2	PL	15.0 ± 0.707^{b}	8.70 ± 0.54^{b}	0.50 ± 0.27^{ab}	7.38 ± 0.38^{a}	0.85 ± 0.22^{ab}	29.17 ± 1.98^{ab}
3	AL	4.13 ± 0.64^{cd}	2.39 ± 0.49^{cd}	0.20 ± 0.22^{b}	6.85 ± 0.26^{a}	1.01 ± 0.29^{ab}	21.56 ± 1.15^{b}
4	GL	9.07 ± 1.1^{bc}	5.26 ± 0.84^{cb}	0.23 ± 0.29^{b}	6.59 ± 0.28^{a}	1.04 ± 0.13^{b}	20.92 ± 1.47^{b}

NF= natural forest; PL= plantation forest; AL = agricultural land; GL= grassland

NB: Values followed by the same letters across column are not significantly different at $P<0.05$

3.2. Biomass of soil macrofauna

Results of the biomass of macrofauna from different land use types (natural forest, mixed plantation forest, grassland and agricultural land) are illustrated in Table 2. The highest biomass of soil macrofauna was obtained from the natural forest (6.38 gm/m^2), followed by mixed plantation forest (6.27 gm/m^2); while the smallest biomass of soil macrofauna was recorded from agricultural land (2.78 gm/m^2). On average, the most dominant soil macrofauna across all land use systems was found to be earthworm (2.2746 gm/m2), followed by millipedes (0.8070 gm/m2), and centipedes (0.4442 gm/m2). The biomass of earthworm was very high in plantation forest followed by agricultural land, while the smallest biomass of earthworm was found in the grassland. Even though the macrofaunal biomass was not statistically different across the different land use types, results of the study are indicative for the fact that biomass and types of macrofauna are dependent on the land use types. The biomass of cockroach, millipedes, larvae, snail, and spider was very high in the natural forest; earthworm was very high in plantation forest; ants were very high in agricultural land; and beetles, grasshopper, soil bugs, termite and tick were very high in grassland.

Table 2: Biomass of soil macrofauna under different land use systems

No.	Soil organism	Biomass of soil macrofauna in each land use type (gm/m^2)			
		Natural Forest	Plantation Forest	Agricultural Land	Grass Land
1	Ants	0.0043	0.00	0.11802	0.1110
2	Centipedes	0.00	0.09816	0.00	0.00
3	Beetles	0.2986	0.21793	0.31368	0.9468
4	Cockroach	0.0778	0.03239	0.01008	0.0099
5	Earthworm	1.5287	4.64727	1.80899	1.1138
6	Grasshopper	0.2792	0.01426	0.13866	0.3866
7	Millipedes	1.9846	0.85327	0.00787	0.3823
8	Other larvae	0.4612	0.00306	0.24248	0.00
9	Snail	1.4097	0.30252	0.00	0.00
10	Soil bugs	0.0170	0.00109	0.02618	0.0659
11	Spider	0.1127	0.05021	0.11024	0.0272
12	Termite	0.0357	0.00870	0.00	0.0701
13	Tick	0.00	0.00	0.00	0.0044
14	Unidentified	0.1762	0.04459	0.01014	0.1721
Total Biomass (per m^2)		**6.3857**	**6.2734**	**2.7863**	**3.2901**

3.3. Abundance of soil macrofauna

Results concerning population density with respect to land uses are presented in Table 3. A total of 2015 specimens representing 12 species were recorded. The major groups recorded in the study site included: Ants, Centipedes, Beetles, Cockroach, Earthworm, Grasshopper, Millipedes, Snail, Soil bugs, Spider, Termite, and Tick. Macrofauna density (number of individuals) was highly variable across the land use systems although the ANOVA results revealed no significant differences among the land use types. The highest mean number of soil macrofauna was recorded in the natural forest (64.6) followed by agricultural land (62.7), grassland (51), while the smallest number was found in the plantation forest (45.7). A relatively higher number of earthworms was recorded across the land uses. The highest density of earthworm was observed in agricultural land (46.1), followed by plantation forest (31.2). Millipedes were the next most abundant individuals in the natural forest. Beetles were the most abundance macrofauna in grassland. However, it was observed that the abundance of macrofauna across the land use was not significantly different from each other.

Table 3: Average abundance of soil macrofauna under different land use systems

No	Soil macrofauna	Average abundance of soil macrofauna in each land use type			
		Natural Forest	Plantation Forest	Agricultural Land	Grassland
1	Ants	0.333	0.00	6.222	7.444
2	Centipedes	0.00	2.000	0.000	0.000
3	Beetles	**7.222**	2.555	4.000	**16.333**
4	Cockroach	1.666	0.555	0.222	0.111
5	Earthworm	**18.444**	**31.222**	**46.111**	**12.000**
6	Grasshopper	1.000	0.222	0.444	2.000
7	Millipedes	**15.222**	4.555	0.333	0.333
8	Other larvae	1.888	0.111	1.222	0.000
9	Snail	**5.777**	0.888	0.000	0.000
10	Soil bugs	1.666	0.111	1.111	2.666
11	Spider	3.888	1.222	2.333	1.222
12	Termite	3.333	1.111	0.000	6.333
13	Tick	0.00	0.00	0.000	0.444
13	Unidentified	4.111	1.111	0.666	2.111
Total count		**64.6**	**45.7**	**62.7**	**51**

3.4. Diversity of soil macrofauna

Results on the diversity of macrofauna from the different land use types is illustrated in Figure 2. The highest diversity index was recorded in the natural forest (2.041), followed by grassland (1.835), whereas the smallest diversity index was observed in agricultural land (1.033).

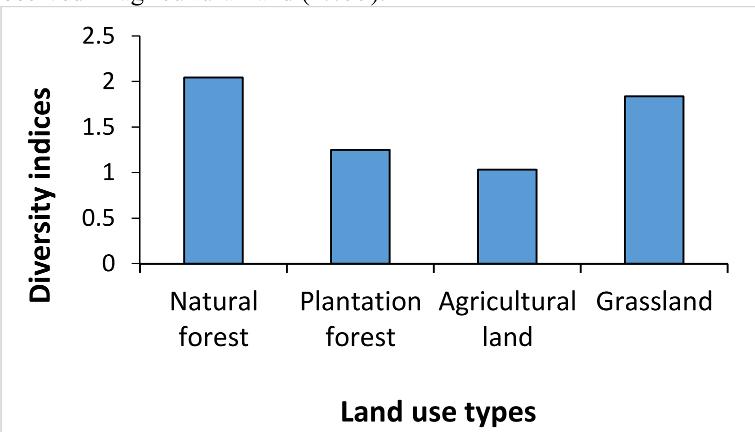

Figure 2: Diversity of soil macrofauna under different land use system

4. Discussion

Land use change may lead to changes in soil physical, biological and chemical properties through their influence on various ecological processes (Chen *et al*., 2010). Results of this study confirmed that changes in tree species and composition affect the physical, chemical and biological activity of the soil. Natural forest was higher in moisture content followed by plantation forest, agricultural land and grassland (Table 1). This result is in line with an earlier report by Pereira *et al.* (2013), which showed higher soil moisture content in forested areas compared to cropland. The reason for decreased soil moisture level in the cropland compared to forest ecosystems may be due to the decrease in organic matter and aeration following cultivation, which may promote drying (Singh *et al*, 2009). Moreover, Singh *et al.* (2009) reported about 17% decline of soil moisture in cultivated soils following cultivation and stated that evaporation, a moisture-loss mechanism in the 0–10 cm soil layer, is responsible for such changes.

Bulk density was highest in grassland (1.04±0.13 g/cm^3) whereas lowest in the natural forest (0.82±0.367 g/cm^3). The Bulk densities of plantation forest and agricultural land were 0.85±0.22 g/cm^3 and 1.01±0.29 g/cm^3, respectively (Table 1). Similarly, Iqbal and Goni (2015) reported higher bulk density in wasted land and followed in decreasing order by grassland, agricultural land, and forest land. Zhang *et al* (1988) and Singh *et al* (1989) have also reported higher soil bulk density due to cultivation. This may be attributed to the decreased soil organic carbon (SOC) and soil aggregation (Iqbal and Goni, 2015) as a result of repeated events of sowing and harvesting. Bot and Benites (2005) also revealed that bulk density is lower in soils with high organic matter content.

Our study also showed very high amount of organic matter in the natural forest (26.05%), followed by plantation forest (15 %), grassland (9.06%) and agricultural land (4.12%). This is comparable with other similar studies elsewhere. For instance, Singh and Ghoshal (2011) and Pereira *et al*. (2013) reported forest had higher inorganic carbon and nitrogen than Jatropha plantation/reforested area, degraded forest and lowest in agro-ecosystem; while others reported higher soil organic carbon content in natural forest than in croplands (Gol, 2009). Similarly, Iqbal*et al*. (2015) also reported that highest soil organic carbon was obtained in agroforestry, followed by grassland and fallow land. Such higher values of soil organic carbon concentrations in the natural forest are associated to the regular addition of plant litter including above and below ground plant parts, and limited disturbances like grazing, logging, lack of tillage, high plant biodiversity, and root exudates (Iqbal and Goni, 2015). Moreover, an increased return of residues from high root biomass contributes to the storage and stabilization of SOC in aggregates (Srivatava and Singh 1991; Iqbal and Goni, 2015).

The macrofaunal diversity, biomass, and abundance in the study area varied with land use types. Results of this study have shown that natural forest was highest in biomass (Table 2), abundance /density (Table 3) and diversity of soil macrofauna (Figure 2). The main reason for variation in macrofauna diversity and density is associated with management practices such as use of agrochemicals, consequent destruction of nesting habitats, modification of soil microclimate within these habitat and removal of substrate, low diversity and availability of food sources for the associated macrofauna groups (Warren et al., 1987; Dangerfield, 1993; Roper and Gupta, 1995; Brown *et al*., 1996). Management practices such as mechanized land clearing and burning, continuous tillage, monoculture, crop rotation, organic residue inputs, retention and removal and use of agrochemicals have been shown to be among the causes of the alterations of soil fauna population structure, disappearance or reduction of key species and in some cases extremely low abundances or biomass.

The higher organic matter (organic carbon) and nitrogen content might have favored their presence in the natural forest than the rest land use systems (Table 2). In addition, soil organisms' activity and population proliferate best in the moisture range of 20% to 60% (Agriculture Information Bank, 2015), in which the natural forest is characterized by having the highest moisture content as compared to the rest of land use systems. The decrease in vegetation diversity, the quantity of leaf litter and density of root system affect the abundance and diversity of soil organisms in a given ecosystem (Decaens *et al.,* 1994). On the other hand, the lowest diversity index was recorded in the agricultural land (Figure 2) due to lower soil organic matter and nitrogen content (Table 2) resulted from human disturbances through frequent pulverization of the soil. This reaffirms the existence of considerable diversity in the different macrofaunal community across the various land use systems.

Different land use and management practices have an important impact on soil macrofauna biomass, abundance, and diversity which, in turn, affect their functional role in maintaining soil ecosystem processes resulting in differing soil chemical and physical properties. Soil organisms play an indispensable role in maintaining a healthy soil ecosystem by acting on the process of cycling of nutrients and are described as engineers of a soil ecosystem. Therefore, proper implementation of land use management practices in a given area will increase the number and activity of soil organisms. The uses of agro-chemicals to improve soil conditions have their own effect on the long-term use of land by directly or indirectly affecting soil organisms. Thus, implementing a suitable land management practice possibly improves their roles in decomposition, immobilization, mineralization, and bio-control of pest and pathogen of soil organisms in a given ecosystem.

Declaration

We declare that this research is originally our own and it has not been submitted before for any other journal for publication.

- **Ethics approval and consent to participate**

This research work is conducted by five academic staffs working in the same university. There is no one who is missed or neglected from being listed in this research work. Therefore, I (as a corresponding author) confidentially affirm the editorial board that all participants are listed in this manuscript.

- **Consent of publication**

This research work is the sole property of all the authors listed in the manuscript and we confidentially allow the manuscript to be published by your journal.

- **Competing interest**

No competing of interest

- **Authors' contribution**

Initially the idea of conducting the research work was raised while we are in a research forum and developed in to a full fledged proposal through the contribution of all the members. Data collectin, data analysis, data interpretation, reviewing of literatures and writing the research work is also made in collaboration.

- **Acknowledgment**

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