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The Influence of Topographic Aspect on Biomass and Soil Carbon Stock in Case of Bale Mountain National Park, Ethiopia

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Abstract
The Bale Mountains of Ethiopia have a global conservation significance which contains a number of unique plants and animal species. The study was conducted to analyze the influence of topographic aspect on biomass and soil carbon stock in case of Bale Mountain national park. Simple random sampling method was used to collect soil and vegetation samples. The sample was laid on two main areas of Bale Mountain (South and North aspect). The total of 20 composite samples were collected from the study area for the year 2017 and 60 soil samples was collected from 2016. During carbon stock measurement the data collection were takes place in to two major activities, (1) Above-ground tree biomass (2) Soil organic carbon measurements. The result showed that, there was a significance difference in soil organic carbon among two aspects. The Northern aspect has 13.12kg/ m^{-2} and Southern aspect was 10.04km/ $^{m-2}$. There was also a significance difference in average diameter of Erica plant species. There is a significant difference in the total N and SOC in both aspects, the Northern aspect has higher total carbon stock (11.4607) than the Southern aspects (11.0116). But the nitrogen of Northern aspect (0.7005) is lower than the Southern aspect (0.8109). Immediate action should be taken on land use conversion and human settlement problems of study area and biodiversity conservation works should be developed and facilitated.
Keywords: Bale Mountain, Biomass, Carbon stock, Topographic aspect, Ethiopia
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Introduction

Background

Ethiopia features extensive high mountain ecosystems, which represent ecological islands in a tropical to subtropical lowland matrix with differing climate and high land use pressure. Mountains cover about 43% of the surface of Ethiopia (Woldemariam 1990, cutoff at a1,500 m asl). These mountains harbor a remarkable diversity of endemic fauna and flora. The mountain climate is more favorable for many species relative to the lowlands where arid to semiarid environments predominate (Hillmann, 1990; Messerli *et al*., 1990). Hence, over 85% of the Ethiopian population and over 75% of livestock are estimated to inhabit the Ethiopian mountains today (Amsalu and de Graaff, 2006).

The Bale Mountains of Ethiopia are of global conservation significance (Hillman, 1986). It used as home to the largest population of the endangered endemic Ethiopian wolf (Canis simensis) and of Mountain Nyala (Sillero-Zubiri *et al*., 1997). The mountains also contains a number of unique plants such as Lobelias (example Lobelia rhynchopetalum, Lobelia scebelii, and Lobelia giberroa) and Senecio species (example, Senecio nanus, Senecio fresenii, Senecio inornatus, Senecio ochrocarpus, Senecio ragazzi, Senecio schultzii, Senecio subsessilis, and Senecio unionis). Besides, the endemic plant populations of mountains are important reservoirs of genetic diversity (Hillman, 1988; NBSAP, 2005). The rainforests located to the South represent the native habitat of wild coffee. Moreover, the mountains support numerous ecosystem services for lowland areas including capture, distribution, and regulation of the water supply (Kidane *et al*., 2012).

Topography is central to the catena concept for soil development (Hook and Burke, 2000), which is characterized by leaching and redistribution of elements and soil material along hill slopes. The effect of topography is more pronounced on young and rolling soils than on old and level soils (Birkeland, 1999; Fisher and Binkley, 2000). The direction of the slope (i.e., the aspect) influences the amount and intensity of solar radiation to which a location is exposed and subsequently the temperature regime, which affects soil biological and chemical processes as well as evaporation. Estimation of the C stocks in soils at regional, national, and global levels is thus of paramount importance in assessing changes in C fluxes (Morisada et al., 2004; Wang et al., 2004).

The overall aim of this study was to analyze the influence of topographic aspect on biomass and soil carbon stock in case of Bale Mountain national park, Ethiopia. Specifically, the objectives of this study were (1) To study the effects of topographic aspect (South & North) on soil physical and chemical properties (2) To estimate the biomass of Erica plants along topographic aspects (South and North aspects).

Materials and methods
Description of study area
Orography

The Bale Mountains are located in Southeast Ethiopia in the Oromia regional state (Figure 1). It is found approximately between $6^{0}40'50.0''$N to $6^{0}15''0''$N latitudes and $39^{0}25'10''$E to $39^{0}60''0'$ E longitude. The mountains comprise one of most extensive high altitude plateaus (above 3,000 m in elevation), the largest contiguous mountain massif of over 2,600 km^{-2} in Africa, and one of the last remaining pristine afro-alpine biodiversity hotspots on the continent (Hillman 1988; Laurenson et al. 1998). The massif exhibits a steep gradient of ecological zones ranging from lowland semi-deserts, savannas and grasslands, and tropical rainforests to afro-alpine vegetation. At the plateau, there are several high peak summits. The highest point mount Tullu Deemtu reaches 4,385 m a s l.

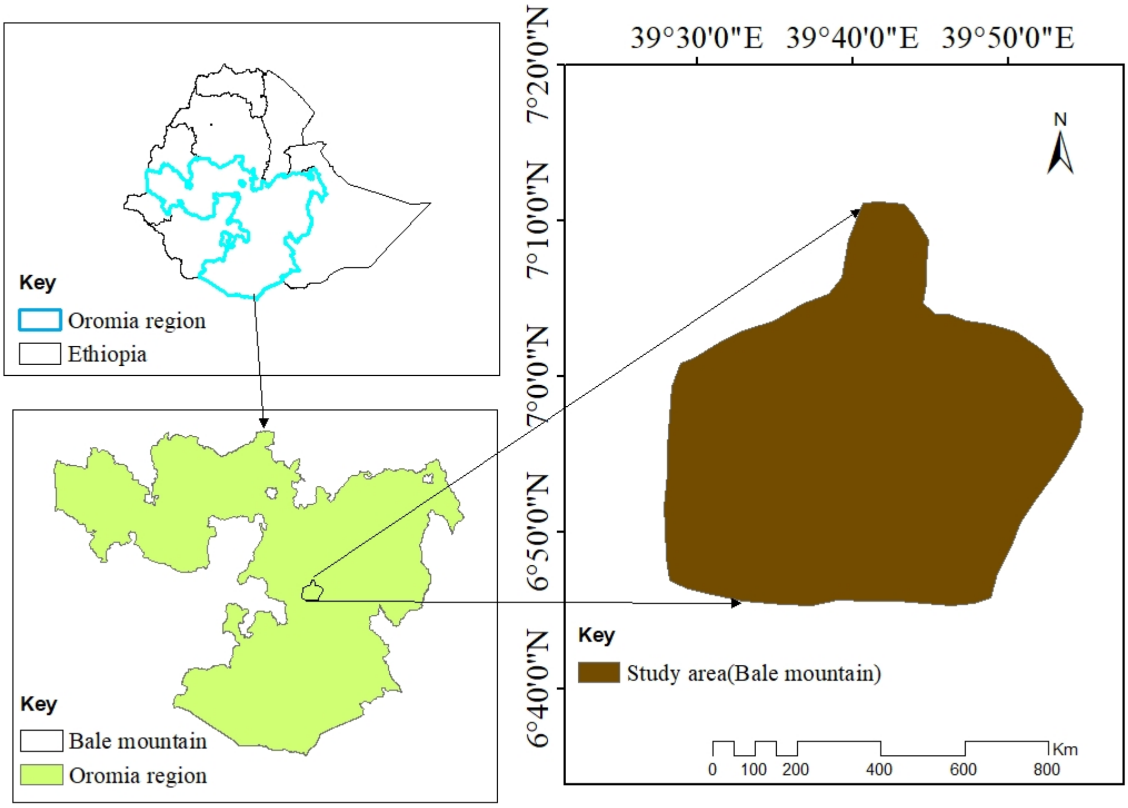

Figure: Location of study area

Climate

According to Uhlig (1990), Bale Mountains are located at the convergence of the wet east African and dry Northeast African mountains of Southeast Ethiopia. The climate of the mountains varies from North to South mainly due the differences in elevation, aspect, and the influences of lowland hot air masses. Historically, the area has experienced a high degree of climate variability and change (Umer et al., 2007). The current climate is categorized by a short dry season (November to February) and a long period of rainfall and high moisture (March to October). The wet season rainfall pattern is slightly bimodal, with a peak from April to May followed by a second peak from September to October (Woldu *et al*., 1989). Recently, the area has also witnessed an increase in the frequency and severity of exceptional droughts (Wesche, 2003).

As indicated by different studies (Uhlig, 1990; Miehe and Miehe, 1994) rain comes to the Bale Mountains from two different sources: the equatorial westerly and the Indian Ocean monsoon. Along altitude, precipitation increases up to an elevation of 3,850 m asl, but decreases then again towards the summits (Hillman, 1986). The Northern part of the mountain range exhibits 800–1,000 mm of annual rainfall and a wet season from June to September. The southern part is more humid, with a subtropical climate and 1,000–1,500 mm of annual rainfall (Woldu *et al*., 1989).

Geology and geomorphology

The Bale Mountains are fragmented due to numerous volcanic plugs, peaks, alpine lakes, and rushing mountain streams that descend into deep rocky gorges on their way to the lowlands. The uppermost part, the Senetti plateau, is an isolated area covering 211 km^2 at an altitude of about 4,000 m bordered by abrupt escarpments to the south. The North and Northeast are deeply dissected valleys descending to the Northern slope, while to the west lava flows form spectacular bluffs (Osmaston *et al*., 2005).

Bale Mountain geology is characterized by a high altitude volcanic plateau over much older volcanic material formed during the spreading of the East African Rift Valley system. The petrography is dominated by alkali basalt and tuffs, with occasional rhyolites (Uhlig and Uhlig, 1991). The mountains were locally glaciated, which shaped their recent geomorphology (Osmaston et al., 2005).

Soils in the area tend to be shallow, gravelly, and recently derived from volcanic rock exposed since glacial retreat (Sillero-Zubiri and Macdonald, 1997). In an earlier reconnaissance study, Andosols is considered as the most predominant soil in the higher parts of the Bale Mountains (Weinert and Mazurek, 1984). Soils consist of a relatively silty loam of reddish brown to black color (Woldu et al., 1989). Soils located on top of stratigraphically youngest units derive mainly from the Miocene basalt and trachyte lavas that lay over Mesozoic sediments (Umer et al., 2007).

Data collection

The sample was laid on two main areas of Bale Mountain (South and North aspect). Simple random sampling technique was used and transect line was laid on two aspects. Soil and biomass sample was taken and recorded approximately at about 10mx10m distance. To reveal the vegetation composition and biomass, all live vegetation were recorded as indicated by (Pearson et al., 2007). The DBH was measured at knee height to estimate biomass and the size class distribution in a sampling plot using measuring tape. The methodology and procedures used to estimate carbon stocks were simple step by step procedures using standard carbon inventory principles and techniques (Pearson et al., 2007). Procedures were based on data collection and analysis of carbon accumulating in the above ground biomass only. The following two image shows sampling area of Bale Mountain of Erica plants on two aspects.

Figure 2: Erica plants at Northern side of Bale Mountain.

Figure 3: Shows Erica plants at Southern side of Bale Mountain

Carbon stock measurement at a field

During carbon measurement at the field, the data collection was takes place in to two major activities, (1) Above-ground tree biomass (2) Soil organic carbon measurements.

Above ground biomass measurement

E. arborea vegetation community was divided as a distinct vegetation zone. At each stratified vegetation zone and in each of the two aspects, sample plots of 10×10 m^2 were randomly located, giving a total of 20 sample plots. The DBH was measured in each sampling plots

- ✓ The carbon pool in this resource was calculated using the following formula
  AGB= 34.4703 - 8.0671(DBH) + 0.6589 (DBH2) (Simegn and Soromessa, 2015).

Soil sampling and laboratory analysis techniques

Soil samples was taken in each vegetation zone (Hypericum revoltum, Erica arborea and Schefflera volkensii) and bulked similar soil depths. These depths are commonly used in studies of soil organic carbon and total nitrogen pools (Yimer, Ledin and Abdelkadir, 2007). The soil was dried for 24 hours before laboratory analysis. Samples for chemical and physical analyses were passed through a 2mm soil sieve. SOC was determined according to the Walkley and Black method (Yimer, Ledin and Abdelkadir, 2007), While total N was measured following the Kjeldahl method (Bremner and Mulvaney, 1982).

Soil sample was taken from two aspects, total of 20 composite samples were collected from the study area for the year 2017 and 60 soil samples was collected from 2016, then the laboratory analysis were done for the two consecutive years. The results from 10 core samples were taken to obtain representative bulk density. The data were then grouped according to Southern and Northern aspects of study area where each vegetation communities were located. Total N content of the soil was determined by wet-digestion, distillation and titration procedures of the Kjeldahl method as described by Black (1965). The pH (H_2O) of the soil was measured potentio-metrically in the supernatant suspension of 1:2.5 in soil: water ratio using digital pH meter following the procedure outlined by Sahlemedhin and Taye (2000).

Statistical analysis

Statistical differences were tested using independent t test procedure for comparing means of SPSS version 16.0 and ANOVA was used to test differences in mean soil physical and chemical properties across the different aspects of the study site. Significance level (95% confidence interval with $\alpha = 5\%$) was generated among the two aspects study sites.

Result

Soil Carbone stock and Erika plant biomass

There was a significance difference in soil organic carbon among two aspects. The Northern aspect has 13.12kg/ m^{-2} and Southern aspect was 10.04km/ $^{m-2}$. There was also a significance difference in average diameter of Erica plant species. That means the Northern aspect has more diameter than the Southern aspects (Northern aspect=3.89 cm and Southern aspect= 2.93cm). But there was no a significant difference in total count of Erica plant species and nitrogen content among two aspects. There was a significant difference in quadrant coverage and above ground Carbone stock. Table 1 shows the detail of those results.

Table 1. Biomass and soil carbon stock vegetation on North and South aspects (2017)

	Biomass and soil carbon stock vegetation on North and South aspects			
	Location	N	Mean	Std. Error Mean
SOC	South	10	11.04^{a}	1.15
	North	10	13.12^{b}	0.42
Average Diameter	South	10	2.93^{a}	0.445
	North	10	3.89^{b}	0.57
Total count	South	10	132^{a}	26.46
	North	10	112^{a}	27.03
Quadrant Coverage (%)	South	10	85^{b}	5.65
	North	10	69.8^{a}	6.4
Nitrogen	South	10	0.41^{a}	0.12
	North	10	0.51^{a}	0.15
Above ground Carbon	South	10	14.67^{a}	3.03
	North	10	8.22^{b}	3.79

*** Means with similar letters are significantly different at α=0.05*

Soil organic carbon stock and nitrogen contents

As shown on the following table (table 2), there is a significant difference in the total N and SOC in both aspects, the Northern aspect has higher total carbon stock (11.4607) than the Southern aspects (11.0116). But, the nitrogen of Northern aspect (0.7005) is lower than the Southern aspect (0.8109).

Table 2. Mean nitrogen and Soil organic carbon (Year 2016-2017)

Aspect	Soil parameter			
	SOC	N	AGC Total C	AGC Total C
South Rira	11.0116	0.8109	14.67	25.6816
North Rira	11.4607	0.7005	8.22	19.6807
SE	0.45395	0.7583		
P-value at =0.05	**	**	**	**

Different soil parameters at Southern and Northern aspects

All the selected soil parameters varied significantly in the two aspects. Southern aspect has higher pH (5.588), total nitrogen (0.8109) and bulk density while the Northern aspect has a higher soil organic carbon (11.4607) (Table 3).

Table 3. Effect of aspect on selected soil properties

Aspect	Soil parameter			
	PH (H_2O)	OC (%)	TN (%)	BD
South Rira	5.5880	11.0116	0.8109	0.651
North Rira	5.1470	11.4607	0.7005	0.570
SE (±)	0.1106	0.45395	0.7583	0.061
P-Value (0.05)	**	**	**	**

As explained in the following table (table 4), there is a significant negative correlation between the soil organic carbon and pH (-0.425).

Table 4. Pearson's correlation matrix for soil physicochemical properties (2017).

	BD	PH	OC	N
BD	1	0.320	0.258	-0.166
PH	0.320	1	-.425**	0.164
OC	0.258	-.425**	1	0.195
N	-0.166	0.164	0.195	1

**. Correlation is significant at the 0.05 level (1-tailed).

The following table (table 5) explain both the total nitrogen and soil organic carbon are found to be very high in the study site.

Table 5. Ratings considered for some soil parameters

Parameters	Categories or ratings				Source
	V. low	Low	Medium	High	
OC	<0.86	0.86-2.59	2.59-5.17	>5.17	Tekalegn, 1991
TN	<0.05	0.05-0.12	0.12-0.25	>0.25	

Discussion

Soil organic carbon and total nitrogen stock were significantly different among two aspects (Southern and Northern aspect) on Bale Mountain. The mean SOC stocks were higher among the vegetation communities in the Northern than in the Southern aspects. This finding is in contrary with the findings of Yimer *et al*. (2007) who stated that the mean soil organic carbon stocks, According to Yimer *et al*. (2007) the vegetation communities was higher in the Southern aspect than in the Northern aspects both in the upper and sub surface soil layer. The mean total nitrogen stock also higher in the Southern aspect than the Northern aspect and is in line with Yimer et al. (2007). This phenomenon may be explained by the pressure of climate on the biomass and also the action of microbes on decomposing litter.

This study also found that, soil pH and bulk density were affected by aspect. The Southern aspect have higher bulk density than the Northern aspect. This finding is in contrary with Yimer et al. (2006) who found that there was no significant difference in bulk density in Southern and Northern aspects of Bale Mountain. The finding of the pH also dis agrees with the findings of Yimer *et al*. (2006) who found that the average pH was relatively low for the Southern aspect. Output of the correlation matrix showed that soil organic carbon has significant and negative correlation with pH. This may due to clay particles and organic matter have the capability of absorbing soil cations on sites on their surfaces that carry unsatisfied negative charges.

Conclusion

This study approved that, Southern aspects have relatively higher concentration of SOC, pH and bulk density and the Northern aspect have higher total N. It is mainly regulated by the climate and the vegetation community which contributes to the organic residue. Identifying the differences in the SOC and total N concentrations affected by aspects is an important aspect for a better management of the ecosystem and helps improve carbon sequestration. Generally, the Soils of Bale Mountain are good in the concentration of SOC and total N accumulation. So, this study approved the study area contributes to the adaptation and mitigation of climate change. Immediate action should be taken on land use conversion and human settlement problems of study area and biodiversity conservation works should be developed and facilitated.

Availability of data and materials

The raw data supporting the conclusions of this study has attached without any reservation.

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