Journal of Science and Development 1 (1) 2011

The effect of cropland fallowing on soil nutrient restoration in the Bale Mountains, Ethiopia

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Abstract

Fantaw Yimer & Abdu Abdelkadir 2011. The Effect of Cropland Fallowing on Soil Nutrient Restoration in the Bale Mountains, Ethiopia. *Journal of Science and Development* 1(1) 2011, 43-51.

Fallowing is considered an important management practice in maintaining soil productivity. This study investigated the level to which traditional cropland fallowing restored soil fertility in the Bale Mountains of Ethiopia. It included a comparison among a three-year fallow, cropland and natural forest. A total of 36 surface soil samples (3 altitudinal ranges×3 landuse types×4 soil samples from 0–0.20 m depth) were collected and analysed for soil organic carbon, total nitrogen, exchangeable bases, cation exchange capacity (CEC) and percentage base saturation (PBS). Results showed that soil organic carbon content ($p<0.001$) and total N ($p=0.001$) were significantly higher in the fallow land and natural forest than in cropland. Except for exchangeable Mg^{2+} and Ca^{2+}, the differences in exchangeable bases were significant with landuse types. Exchangeable K^{+} was higher in the fallow land than in cropland soils. Cation exchange capacity and PBS also showed significant variation with landuse type ($p<0.001$ and $p=0.004$, respectively) and altitudinal ranges ($p<0.001$ and $p=0.006$, respectively). The overall mean CEC was higher in the natural forest and fallow land than in cropland. The CEC in fallow land was strongly related to the soil organic carbon ($r^2 = 0.84$, $p<0.001$). The nutrient build-up and rise in CEC and PBS in soil within the three-year fallow period could be due to the addition of soil organic matter.

Keywords: Degraded land; Cropland fallowing; Nutrient restoration; Soil fertility recovery

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ISSN 2222-5722.

Introduction

‘Fallow’, the resting state of an agricultural field (Szott *et al.*, 1999), is a soil conservation and soil improvement technique (Grisley & Mwesigwa, 1994), which is important for maintaining and restoring soil fertility over wide areas of the world (Ruthenberg, 1980; Loomis, 1984; Sánchez, 1995; Büttner & Hauser, 2003). Many farmers in the tropics still use fallows as part of their farming system. Fallowing replenishes nutrients removed by crops, reduces erosion and leaching, and maintains better soil physical and biological conditions (Adejuwon & Adesina, 1990; Juo *et al.*, 1995; Sánchez, 1995; Szott & Palm, 1996; Barrios & Cobo, 2004; Tian *et al.*, 2005). However, fallow periods throughout the tropics have become progressively shorter, as a result of pressure on land**,** arising from human population growth (Grisley & Mwesigwa, 1994; Mendazo-Vega & Messing, 2005). A shorter fallow period means that there is less opportunity for the land to restore its fertility status, as well as an increase in net soil nutrient loss; and less crop residue and animal manure remain on the fields (Solomon, 1994). This shortening of traditional fallows, combined with little or no use of fertilisers, has had negative consequences for agricultural productivity and agro-ecosystem functioning in the tropics (Szott *et al.*, 1999).

Despite some reported reservations regarding fallowing (Abubaker, 1996), it has long been seen as one of the systems for maintaining soil fertility (Greenland, 1975). Research information is available for many tropical areas on the extent to which fallowing helps restore soil fertility (Juo & Lal, 1977; Szott *et al.*, 1999; Barrios *et al.*, 2005; Mendazo-Vega & Messing, 2005; Bruun *et al.*, 2006).

Earlier research (Yimer *et al.*, 2007, 2008a) established that cropland soils in the Bale Mountains have shown a decline in organic carbon and total nitrogen (N_{tot}) contents by 30.9 and 32.1%, respectively. There are also reports of a decline in exchangeable cations, CEC, and a reduction in infiltration rate (Yimer *et al.*, 2008a, 2008b) after conversion of native forest into cultivated land. Soil nutrient levels were severely depleted and crop yields declined during the cropping cycle. This was primarily attributed to low nutrient contents, resulting from a negative nutrient budget, *i.e.* when more soil nutrients are removed from the system by leaching, gaseous losses, soil erosion and through crop off-take ('nutrient mining'), than are returned to the soil in the form of crop residues (Sanchez, 1995; Barrios & Cobo, 2004).

On the steep slopes of the Bale Mountains, research into traditional cropland fallowing is lacking, and there is no information on the extent to which fallowing helps protect the land and restore soil nutrients. Effective management of agricultural land for sustained production relies on knowledge of the fluxes and losses of nutrients during cropping and fallowing. Therefore, the aim of this paper is to evaluate the extent to which nutrient-mined sites under cropland are replenished and their fertility restored through traditional cropland fallowing practice.

Materials and methods

Study site

The study was carried out on the southern slope of the Bale Mountains National Park (BMNP), 60 km south of Goba town, Ethiopia (Figure 1). The BMNP is situated between 6º29´–7º10´ N lat., and between 39º28´–39º58´ E long. The altitudinal range of the study site is 3000–3200 m above sea level (m asl). The mean annual precipitation is 1064 mm, of which 66% falls partly during summer and partly during autumn. The mean annual temperature ranges between 13.3 °C–14.1 °C.

Geologically, the area consists of rocks of

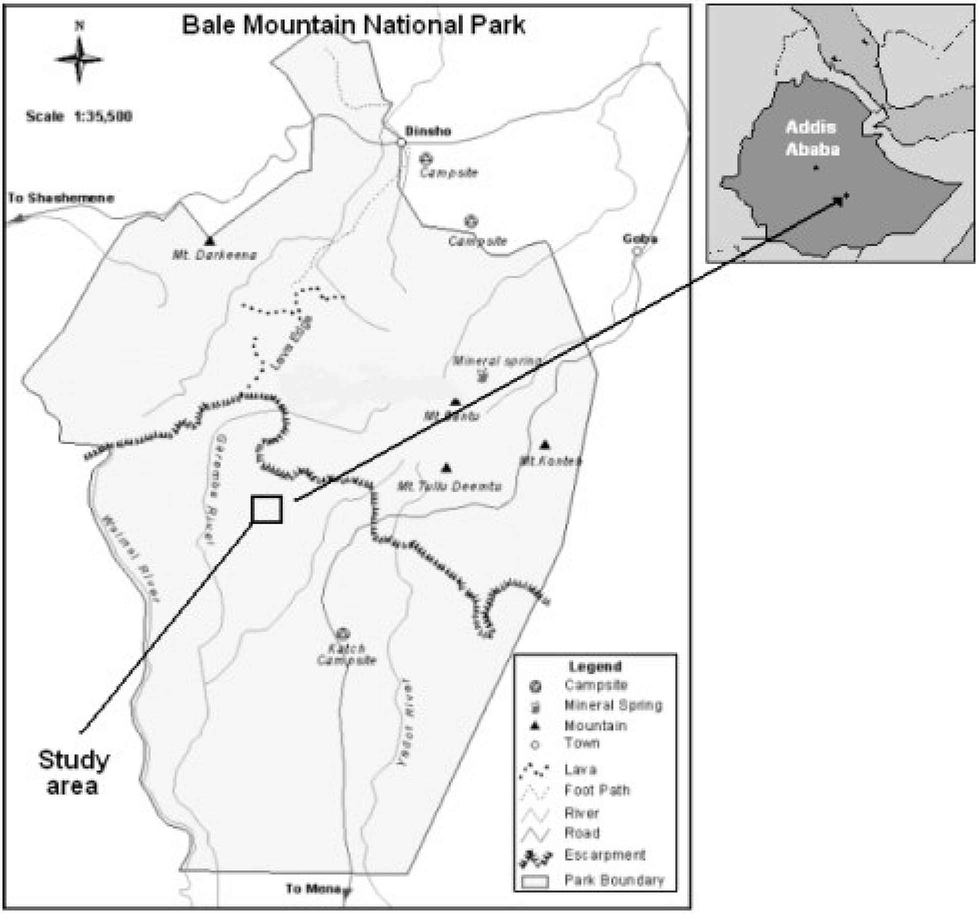

Figure 1. Map showing location of the study area.

Table 1. *Soil textural fractions (%) and bulk density (B.d., cm^{-3}) in relation to altitudinal range and landuse type (mean ± SE) at 5% probability level*

Treatment	**Soil property**			
	Sand	Silt	Clay	B.d.
Altitudinal range				
Lower	53.8 (± 1.3)	38.5 (± 0.7)	7.7 (± 1.3)	0.9 (± 0.04)
Middle	53.7 (± 2.2)	38.5 (± 1.6)	7.8 (± 1.1)	0.9 (± 0.03)
Upper	53.7 (± 2.0)	42.2 (± 1.4)	4.2 (± 0.6)	0.7 (± 0.03)
Landuse type				
Cropland	50.3 (± 1.8)	41.8 (± 1.4)	7.8 (± 0.9)	0.92 (± 0.03)
Cropland-fallow	54.0 (± 1.1)	41.3 (± 1.0)	4.7 (± 0.5)	0.88 (± 0.04)
Native forest	56.8 (± 2.0)	36.0 (± 1.1)	7.2 (± 1.6)	0.80 (± 0.05)

volcanic origin, welded with volcanic ash materials (Mohr, 1971; Berhe *et al.*, 1987), weathered to mainly black to very dark brown sandy loam to loam in the surface soil, and sandy loam to loam–clay loam in the subsurface soils (Yimer *et al.*, 2006b). In an earlier reconnaissance study, Andisols were considered to be the most prevalent soil in the higher parts of the Bale Mountains (Weinert & Mazurek, 1984). Andisols have a unique combination of physical and chemical properties (*e.g.* low bulk density, large variable charge, large water storage capacity, high phosphate retention and high accumulation of organic matter (Shoji *et al.*, 1993; Delvaux *et al.*, 2004; Yimer *et al.*, 2006a). Both the surface and subsurface horizons are very friable to friable at moist moisture content; not sticky to slightly sticky and slightly plastic (wet) (Yimer *et al.*, 2006b). Selected surface-soil properties are presented in Table 1. The natural vegetation is dominated by *Schefflera abyssinica* and *Hagenia abyssinica,* and the understorey consists of small trees and shrubs such as *Brucea antidysenterica, Cassipoourea malosana, Rubus apetalus, Dombeya torrida, Allophyllus abyssinicus, Rapanea simensis, Euphorbia dumalis, Vernonia urticifolica* and *Echinops macrochaltus* (Nigatu & Tadesse 1989).

The traditional farming system in the higher areas of the Bale Mountains is mainly based on continuous cultivation, followed by three to four years of fallowing to restore soil nutrients. Barley, the major food crop, is cultivated below 3300 m asl and may extend far above that level, depending on the soil and slope. Grazing is carried out mainly on the communal pastures.

Soil sampling & laboratory analyses

Three elevation ranges: lower, middle and upper, with an interval of 50 m between 3000 and 3150 m asl altitude, were designated. In each elevation range, three landuse types were selected: natural forest, cropland (cultivated for three consecutive years, and at the time of sampling, covered with barley), and fallow land (abandoned for three years). Four soil pits were sited in each landuse type, taking into account similarities in the physiographic conditions, such as landscape position and slope. A total of 36 surface soil samples (3 altitudinal ranges×3 treatments×4 soil samples from 0–0.2 m soil depth) were collected for laboratory analysis.

Samples for chemical analysis were passed through a 2-mm soil sieve. SOC was determined according to the Walkley and Black method (Schnitzer, 1982). N_{tot} was measured following the Kjeldahl method (Bremner & Mulvaney, 1982). Soil pH was measured with combined electrodes in a 1:2.5 soil to water suspension. Exchangeable base cations were extracted with 1*N* ammonium acetate at pH 7. Ca and Mg were determined by atomic-absorption spectrophotometry, while Na and K were analysed by flame-emission spectrophotometry (Black *et al.*, 1965). Cation exchange capacity (CEC) was estimated titrimetrically by distillation of ammonium displaced by Na (Chapman, 1965). Percentage base saturation (PBS) was calculated by dividing the sum of the charge equivalents of the exchangeable base cations (Ca^{2+}, Mg^{2+}, K^+ and Na^+) by the CEC of the soil, and multiplying by 100. The data were then grouped according to the landuse and elevation ranges. Statistical differences were tested using two-way analysis of variance (ANOVA), following the General Linear Model (GLM) procedure of SPSS version 12.0.1 for Windows (Julie, 2001). Tukey's Honest Significance Difference (HSD) test was used for mean separation, when the analysis of variance showed statistically significant differences ($p<0.05$).

Results

Soil organic carbon & total nitrogen

Soil organic carbon and N_{tot} (p=0.001) concentrations varied significantly with landuse types and altitudinal ranges (p<0.001, Table 2). The significantly lowest SOC occurred in cropland, while N_{tot} showed the highest increase in the native forest (Table 3). Irrespective of the landuse types, SOC and N_{tot} contents were significantly higher in the upper than in the middle and lower elevation ranges (Table 3). The C/N ratios varied greatly with respect to landuse type (p=0.042) and altitudinal range (p=0.010).

Exchangeable cations

Except for exchangeable Mg^{2+} and Ca^{2+}, the differences were significant with landuse type (Tables 3 and 4). However, the combined interaction effects were significant for all base cations in relation to landuse type (Table 4). Exchangeable Na^+ was low in cropland and high in natural forest, followed by the fallow land. Irrespective of landuse, significantly higher concentrations of Na^+ and Ca^{2+} were observed in the middle than in the lower and upper altitudinal ranges. Exchangeable K^+ was higher in the fallow land than in cropland soils (Table 3).

Cation exchange capacity (CEC) & percentage base saturation (PBS)

CEC and PBS varied significantly with landuse type (p<0.001 and p=0.004, respectively) and altitudinal range (p<0.001 and p=0.006, respectively (Tables 3, 4 overleaf). The overall mean CEC was higher in the natural forest and fallow land than in cropland (Table 3). Irrespective of land use, CEC was significantly higher in the upper than in the middle and lower altitudinal ranges. CEC in fallow land was strongly related to the soil organic carbon ($r^2 = 0.84$, p<0.001). PBS in the fallow-land soils showed a significant linear relationship with some selected soil properties.

Discussion

Our findings indicate that cropland fallowing significantly improved and restored soil organic carbon by 28.6%, suggesting that organic matter buildup during the fallow period partly replaced organic matter lost during the cropping period. This could be explained by

Table 2. *Summary of Two-Way ANOVA results for soil organic carbon content (%), N_{tot} (%) and carbon-nitrogen (C:N) ratios of the top 0.2 m soil depth, in relation to altitudinal range and landuse type*

Source of Variation	SOC			T – N		C-N ratios	
	d.f.	MS	P-val.	MS	P-val.	MS	P-val.
Landuse (LU)	2	9.383	<0.001	0.084	0.001	13.722	0.042
Altitudinal range (AR)	2	33.193	<0.001	0.126	<0.001	20.789	0.010
LU × AR	4	0.364	0.729	0.010	0.346	3.434	0.479
Error	27	0.714		0.009		3.827	

Table 3. *Soil organic carbon (%), N_{tot} (%), Carbon-nitrogen (C:N) ratios, Exchangeable cations (cmol$_c$ kg^{-1}), CEC (cmol$_c$ kg^{-1}) and percentage base saturation (PBS) of the top 0.2 m soil depth, in relation to altitudinal range and landuse type (mean ±SE). Means followed by the same letter(s) for each variable in relation to altitudinal range and land use type are not significantly different (p = 0.05)*

Variables	**Altitudinal range**			**Landuse type**		
	Lower	Middle	Upper	Cropland	Fallow	Native forest
SOC	4.85 (±0.35)^{a}	5.36 (±0.32)^{a}	7.95 (±0.27)^{b}	5.04 (±0.52)^{a}	6.48 (± 0.46)^{b}	6.65 (±0.42)^{b}
TN	0.54 (±0.03)^{a}	0.60 (±0.03)^{a}	0.74 (±0.04)^{b}	0.55 (±0.04)^{a}	0.60 (±0.03)^{a}	0.72 (±0.04)^{b}
C/N	9.00 (±0.40)^{a}	8.94 (±0.37)^{a}	11.25 (±0.90)^{b}	8.92 (±0.48)^{a}	10.94 (±0.92)^{b}	9.33 (±0.36)^{ab}
Na	0.11 (±0.03)^{a}	0.33 (±0.06)^{b}	0.15 (±0.05)^{a}	0.06 (±0.02)^{a}	0.26 (± 0.02)^{b}	0.27 (±0.08)^{b}
K	1.33 (±0.35)^{a}	1.58 (±0.32)^{a}	1.04 (±0.28)^{a}	0.84 (±0.23)^{a}	1.69 (± 0.35)^{b}	1.42 (±0.33)^{ab}
Ca	8.54 (±1.39)^{a}	12.91 (±1.58)^{b}	11.16 (±1.42)^{ab}	10.35 (±1.26)^{a}	11.99 (±1.19)^{a}	10.27 (±2.04)^{a}
Mg	3.61 (±0.48)^{a}	4.18 (±0.48)^{a}	4.36 (±0.56)^{a}	3.24 (±0.31)^{a}	4.30 (± 0.49)^{a}	4.60 (±0.61)^{a}
CEC	35.83 (±2.56)^{a}	39.86 (±2.68)^{a}	47.36 (±2.69)^{b}	30.78 (±1.69)^{a}	43.73 (±1.89)^{b}	48.53 (±2.33)^{b}
PBS	37.99 (±4.66)^{a}	49.11 (±5.61)^{b}	34.86 (±3.16)^{a}	47.83 (±5.30)^{b}	41.62 (±3.74)^{ab}	32.50 (±4.53)^{a}

the progressive accumulation and decay of the aboveground herbaceous vegetation and root biomass (Samaké *et al.* 2005), and probably by the effects of crop residues left after harvest. Unfortunately, the absence of SOC measures before and after cropping, together with unknown actual above- and belowground litter inputs, does not allow us to explain the SOC increase between the fallow and cropland. The decrease in SOC under cultivation usually is the result of a combination of increased mineralization, because of increased soil temperature and a low input of fresh organic materials returned to the soil. Studies carried out under various tropical climates reported that short-term fallow (<4 years) was not able to increase soil organic carbon content significantly (Masse *et al.*, 2004).

Changes in N_{tot} were less variable than changes observed in SOC in cropland and fallow-land soils. Accumulation of SOC content was higher at higher elevations, which may be attributed to slow litter decomposition, confounded by low temperature conditions. With a decrease in temperature with altitude, a lower decomposition rate is to be expected at the higher altitudes (Samaké *et al.*, 2005, Yimer *et al.*, 2006).

The results presented above also showed that cropland-fallowing brought about significant enrichment of the soils with respect to exchangeable Na^+, K^+, and CEC. The changes in CEC due to fallowing are remarkable. CEC concentrations across all landuse types varied significantly, due to differences in the amounts of soil organic carbon. When the fairly low clay content is taken into consideration, it is clear that the contribution made to CEC by organic substances is critical. The cation exchange capacity, which is used to describe soil fertility (Roder *et al.*, 1995), was higher by 29.6% in soils under fallow as compared to cropland, which most likely is attributable to the increase in the amount of organic carbon during fallowing. This finding has important implications, because it suggests that soil CEC is not likely to be significantly increased, except by improving the organic matter (carbon) content of the soil. The percentage base saturation of the studied soils was significantly higher in the croplands

Table 4. *Summary of Two-Way ANOVA results for soil pH (H_2O), exchangeable cations ($cmol_c\ kg^{-1}$)), CEC ($cmol_c\ kg$-^{1}) and percentage base saturation in the top 0.2 m soil depth, in relation to altitudinal range and landuse type*

Source of variation		**pH**		**Na**		**K**		**Ca**		**Mg**		**CEC**		**PBS**	
	d.f.	MS	P-val	MS	P-val	MS	P-val	MS	P-val	MS	P-val	MS	P-val	MS	P-val
Landuse (LU)	2	0.610	0.019	0.159	<0.001	2.288	0.036	11.295	0.542	6.134	0.076	1011.719	<0.001	713.801	0.004
Altitudinal range (AR)	2	0.324	0.105	0.154	<0.001	0.893	0.249	57.925	0.056	1.849	0.435	410.858	<0.001	672.677	0.006
LU × AR	4	1.204	<0.001	0.074	0.001	4.794	<0.001	85.869	0.005	7.774	0.018	30.014	0.297	1011.318	<0.001
Error	27	0.132		0.012		0.610		18.000		2.155		23.166		106.037	

than in fallow and native forests. Base cations stored in wood and shrubs are released at burning, and replace hydrogen at the exchange sites of the soil, increasing the base saturation. Moreover, the fewer exchange sites with smaller amounts of organic matter and more base cations, also leads to higher base saturation (Yimer *et al.* 2008a).

Conclusions

The positive effect of cropland fallowing on soil organic carbon content, exchangeable K^+ and CEC obtained in the present study confirmed that cropland fallowing still needs to be considered as an important and essential management practice for soil-nutrient restoration in the Bale Mountains. However, successful restoration of soil nutrients normally requires a long fallow period, because the loss of nutrients during the cultivation phase can no longer be restored by short fallow periods. Thus, it is suggested that an appropriate alternative technology (*e.g.* planted fallow with suitable tree species) should be considered, which would have wider acceptance by the farmers, and have a potential to generate additional products and bring immediate benefits while replenishing soil-nutrient stocks.

As fallow becomes more relevant, because of the need to maintain and restore soil productivity, it is also necessary to understand the dynamics of soil properties and associated crop productivity under such traditional fallowing practices. Therefore, an understanding of the rationale behind this cultivation practice and dynamics is a necessary step towards assisting farmers to develop their system in productive and environmentally sound directions.

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Acknowledgements

This study was financed through SIDA support to Wondo Genet College of Forestry, Ethiopia. Special thanks are expressed to Dr. Mulualem Tigabu, Faculty of Forest Sciences, SLU, Umeå, for constructive comments. We also thank staff members of the Bale Mountains National Park headquarters; Mr. Estefanos Mathewos, staff member of Wondo Genet College of Forestry & Natural Resources; the Rira Village Peasants' Association Office and the communities for their assistance during fieldwork.