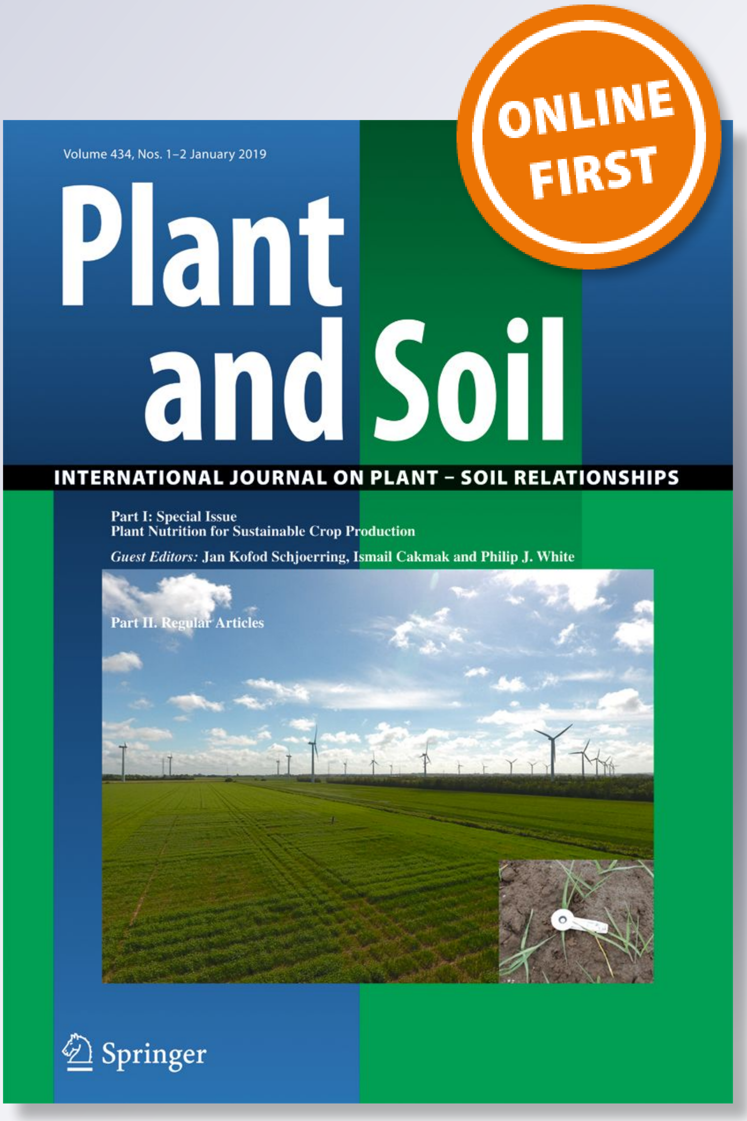
Shifting cultivation maintains but its conversion to mono-cropping decreases soil carbon and nitrogen stocks compared to natural forest in Western Ethiopia

Berhanu Terefe & Dong-Gill Kim

Plant and Soil
An International Journal on Plant-Soil Relationships

ISSN 0032-079X

Plant Soil
DOI 10.1007/s11104-019-03942-0



Springer

Plant Soil
https://doi.org/10.1007/s11104-019-03942-0

REGULAR ARTICLE

Shifting cultivation maintains but its conversion to mono-cropping decreases soil carbon and nitrogen stocks compared to natural forest in Western Ethiopia

Berhanu Terefe · Dong-Gill Kim

Received: 25 June 2018 / Accepted: 10 January 2019

Abstract
Aims This study was conducted to assess the effects of shifting cultivation and its conversion to mono-cropping on soil organic carbon (SOC) and total nitrogen (STN).
Methods We compared soil pH, texture, bulk density and SOC and STN contents and stocks (0–100 cm) in natural forest (NF), adjacent shifting cultivation (SC) areas (> 100 years old) having three (SC-3Y), five (SC-5Y) and seven (SC-7Y)-year-old fallowing, and 10 year-old mono-cropping field (MCF) converted from shifting cultivation in Western Ethiopia.
Results There was no significant difference in soil pH in NF and all shifting cultivation areas. However, MCF had lower soil pH compared to SC-3Y and SC-5Y. There was no or very little difference in soil texture and bulk density across the study sites. Shifting cultivation did not affect SOC and STN stocks. However, conversion of shifting cultivation to mono-cropping decreased SOC (45–50% over 10 years; loss of 11.6 ± 0.2 Mg C ha^{-1} yr.$^{-1}$) and STN stocks (18–45% over 10 years; loss of 0.6 ± 0.1 Mg N ha^{-1} yr.$^{-1}$).
Conclusions While shifting cultivation maintained SOC and STN, its conversion to mono-cropping decreased them, potentially contributing to global warming and decreasing soil fertility.

Responsible Editor: Remi Cardinael.

B. Terefe · D.-G. Kim (✉)
Wondo Genet College of Forestry and Natural Resources, Hawassa University, PO Box 128, Shashemene, Ethiopia
e-mail: donggillkim@gmail.com

Keywords Natural forest · Shifting cultivation · Mono-cropping · Soil bulk density · Soil organic carbon · Soil nitrogen

Introduction

Shifting cultivation, also termed as swidden or slash-and-burn agriculture, is an extensive farming system (e.g., Heinimann et al. 2017; Peng et al. 2014; Schuck et al. 2002). It has been one of the main agricultural systems practiced in the tropical and subtropical areas of Africa, America, Asia, Pacific and Caribbean, covering roughly 280 million hectares worldwide (Heinimann et al. 2017) and is a source of livelihoods for a half-billion people around the globe (van Vliet et al. 2012; Craswell et al. 1997). In general, the shifting cultivation cycle involves three phases: clearing specific forest area by the slashing and burning of vegetation, followed by cultivation of crops for one or two years, and followed by a variable fallow period to allow for the growth of secondary forests (e.g., Mertz et al. 2009; Fox et al. 2000; Eden and Andrade 1987).

Shifting cultivation has been considered as a driver of deforestation and forest degradation (e.g., Rahman et al. 2012; Ziegler et al. 2011; Mertz et al. 2009; Gibbs et al. 2007). It has been reported that shifting cultivation was responsible for 60% of deforestation and greenhouse gas (GHG) emissions around the tropics (e.g., Davidson et al. 2008; Geist and Lambin 2002). Others consider that shifting cultivation can impose serious negative environmental impacts including land

Published online: 26 January 2019

degradation (e.g., Peng et al. 2014; Rahman et al. 2012). However, recently studies argued that shifting cultivation can sustain ecosystems, livelihoods, culture and food security for millions around the tropics (e.g., Bruun et al. 2018; Dressler et al. 2017; van Vliet et al. 2012; Parrotta et al. 2012; Dalle et al. 2011). Therefore, further studies are urgently needed to better understand the impacts of shifting cultivation on various aspects of ecosystem services and livelihoods.

The impact of land-use change on soil C and N has been intensively studied since it may result in changing soil fertility, soil carbon and GHG emissions (e.g., Wainkwa Chia et al. 2017; Kim and Kirschbaum 2015; Wei et al. 2014). It is known that converting natural forest to agricultural lands can result in loss of soil C and N due to a reduction in the amount of biomass reverted to the soil; tillage-induced disturbances, decrease in soil aggregation, reduction in physical protection of the soil organic matter, and increase in soil erosion (e.g., Don et al. 2011; McLauchlan 2006; Murty et al. 2002). However, different results were reported from previous studies on how converting natural forest to shifting cultivation affects soil C and N. Studies found that shifting cultivation practices aggravated soil loss (Hattorie et al. 2005; Grange and Kansuntisukmonkol 2003) and decreased soil carbon and nitrogen (Mukul and Herbohn 2016; Ribeiro Filho et al. 2015). In contrast, other studies argued that shifting cultivations can decrease soil loss (Thomaz 2013) and conserve soil carbon (Chan et al. 2016; Sarkar et al. 2015). These varying results and uncertainties suggest that further studies are required to better understand the effect of shifting cultivation on soil C and N.

Shifting cultivation has been practiced in Eastern Wollega, Ethiopia for centuries. Recently, the local communities were forced to convert to conventional mono-cropping practices through the influence of governmental extension workers. Similar situations including the decrease of shifting cultivation and the conversion of shifting cultivation to mono-cropping or plantations has occurred in other regions in Ethiopia and other tropical countries (e.g., Kilawe et al. 2018; Bruun et al. 2017; Dressler et al. 2017; van Vliet et al. 2012; Bruun et al. 2009; Fox et al. 2009; Mertz 2009). van Vliet et al. (2012) discussed that the major driving factors for these conversions are market development, population growth, and public policies (particularly conservation policies). However, only a few studies investigated the impact of conversion of shifting cultivation to conventional cropping practices on soil C and N and the consequences of the impact (e.g., van Vliet et al. 2012; Bruun et al. 2009). Since it is expected that conversion of shifting cultivation to conventional cropping practices will increase (e.g., Heinimann et al. 2017; van Vliet et al. 2012) it is crucial to access how the conversion affects soil C and N, two important actors in greenhouse gas (GHG) emissions and soil fertility.

The major objective of this study was to assess how shifting cultivation and its conversion to mono-cropping affected SOC and STN stocks by comparing SOC and STN stocks in natural forest, adjacent shifting cultivation and converted mono-cropping fields in Western Ethiopia. We hypothesized that both shifting cultivation and its conversion to mono-cropping decreased SOC and STN stocks compared to SOC and STN stocks in adjacent natural forest.

Materials and methods

Study site

The study was conducted in the Gudeya Billa District, western Ethiopia, which is located 275 km west of the capital city, Addis Ababa (Fig. 1). The study area receives a mean annual rainfall of 1682 mm with a unimodal pattern (Enkossa 2008). The area gets its highest rainfall between May and October, gradually decreasing in November and December, and with little or no rainfall during January and February (Enkossa 2008). The annual mean temperature averages 17 °C with maximum and minimum temperatures of about 22 and 11 °C, respectively (GARDO 2006). The topography of study area is characterised by rough topography with mountains, deep gorges, escarpments and plateaus (Enkossa 2008) and soil typology is vertisols (Jones et al. 2013; EPA 2003).

The study was conducted in adjacently located natural forest (hereafter referred to as NF), shifting cultivation areas having three (SC-3Y), five (SC-5Y) and seven (SC-7Y)-year-old fallowing and converted mono-cropping fields (MCF) from shifting cultivation 10 years ago (9° 20′ − 9° 25’ N and 36° 35′ − 37° 05′ E; 2100 m a.s.l.).

The NF covers approximately 6000 ha and is dominated by *Albizia gummifera*, *Trichilia emetic* and *Croton macroschatus*. This forest is found on plain land and

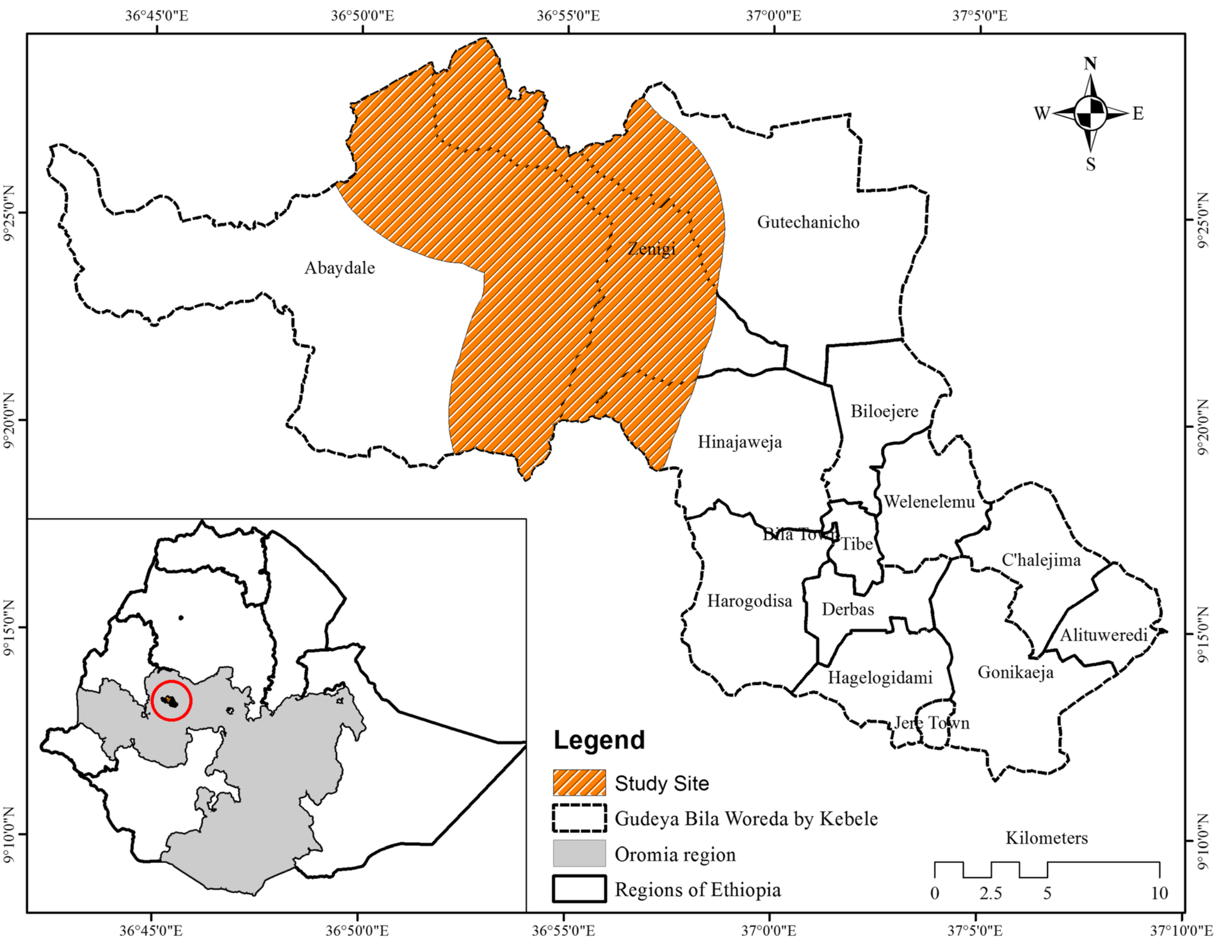


Fig. 1 Map of the study site (GudeyaBilla in Western Ethiopia)

conserved by the local communities for more than 300 years. The forest area is accessed for traditional honey production.

Shifting cultivation is a common land-use type and a major source of livelihood in the study area. The local communities have been practicing shifting cultivations for centuries and inherited the practice from their ancestors (personal communication). This agricultural technique involves three phases: First, local communities cut naturally-grown, 8 to 10-year-old secondary forests and burn them at the site between the end of April and beginning of May. Second, in the burned areas, local communities sow maize (*Zea mays* L.) or sorghum (*sorghum biocolor*) without tillage at the end of May. Using a locally prepared wooden stick (called a "*Hordaa*") they open a small hole in soil, insert seeds, and then put soil back into the hole. No irrigation and fertilizer is applied and crops are manually harvested in December. After harvesting, crop residues remain in the field. Third, local communities fallow the areas for 8 to10 years allowing natural regeneration of vegetation. For the study, areas under three (SC-3Y; 40 ha), five (SC-5Y; 40 ha) and seven (SC-7Y; 40 ha)-year-old fallowing were selected and they were adjacent to the NF.

The MCF (10 ha) was converted from shifting cultivation 10 years ago (in 2005). Local communities cultivate teff (*Eragrostis tef*), maize or sorghum in the MCF. Tillage practices by oxen ploughing (5–10 cm soil depth), is carried out three to four times before sowing. This is done using a traditional tillage implement called a *Maresha*. After the last ploughing, 2–3 people compact the soil using their feet to bury weeds and other vegetation and then cattle are brought in for further compaction. A mixture of inorganic fertilizers, urea and diammonium phosphate (DAP) (5:5) are applied (50 kg ha^{-1}) to the field during sowing time. Sowing time for teff is from June to July and it is manually harvested after 5 to 6 months. Maize or sorghum sowing season is from April to May depending on rain seasons and harvest occurs after 5 to 6 months. Crop residues remain in the field.

Soil sample collection and analyses

To determine SOC and STN stocks in NF, SC-3Y, SC-5Y, SC-7Y and converted MCF sites, soil samples were collected from six randomly selected spots at each site. For each spot, a 1 × 1 m soil profile was opened, and one intact horizontal soil sample core was collected using a soil core sampler (5 cm diameter) from the centers of the five consecutive soil depths, 0–10, 10–20, 20–40, 40–70 and 70–100 cm. Additional sub-samples were collected from the centers of the five consecutive soil depths.

The collected soil cores were used to determine bulk density by dividing the oven dry mass of soil at 105 °C by the volume of the core soil sampler (Grossman and Reinsch 2002). Soil samples collected from the 0–10 cm depth were used to determine soil texture with the Hydrometer method (Gee and Bauder 1979; Gee and Or 2002) by finding the sand, silt and clay percentages. Soil textural classification follows USDA system (Soil Survey Staff 1999). Furthermore, they were used to determine soil pH by using a 1: 2 of the soil: H_2O diluted soil solution and a pH meter (Accument 910, Fisher Scientific Ltd., Pitsburgh, PA, USA). The collected soil sub-samples were sieved through 2 mm mesh and used to determine SOC and STN contents with the Walkley and Black titration method (Walkley and Black 1934) and the Kjeldahle procedure (Bremner and Mulvaney 1982), respectively.

There was no rock fragment content > 2 mm.

Determination of soil organic carbon and nitrogen stocks

SOC stocks (Mg ha^{-1}) for each sampled depth were calculated using the following equation (Solomon et al. 2002) (Eq. 1):

$$C = (z \times \rho_b \times c) \times 10 \quad (1)$$

where,

C SOC stock (Mg ha^{-1}) of sample depth;
z thickness of the sample depth (cm);
ρ_b bulk density (g cm^{-3}) of a sample depth; and
c SOC content (g kg^{-1}) of a sample depth.

In the same way, STN stocks (Mg ha^{-1}), for each sample depth was calculated using the following equation (Solomon et al. 2002) (Eq. 2):

$$N = (z \times \rho_b \times n) \times 10 \quad (2)$$

where,

N STN stocks (Mg ha^{-1}) of the sample depth;
z thickness of the sample depth (cm);
ρ_b bulk density (g cm^{-3}) of a sample depth; and
n STN content (g kg^{-1}) of a sample depth.

For soil samples collected from the NF and SC-3Y, SC-5Y and SC-7Y, SOC and STN stocks were summed up across sample depths. However, soil samples collected from MCF, SOC and STN stocks were determined differently, since soil compaction in MCF may influence the amounts of soils sampled from fixed soil depths (Solomon et al. 2002). The differences in soil bulk densities were treated by adjusting the thickness of each sampled layer in MCF with respect to equivalent mass of soils collected in NF using the following equation (Solomon et al. 2002) (Eq. 3).

$$Z_{corr} = \rho_{bNF} / \rho_{bMCF} \times z \quad (3)$$

where,

Z_{corr} adjusted thickness of a soil sample layer in MCF;
ρ_{bNF} bulk density of the sampled soil layer in NF;
ρ_{bMCF} bulk density of the sampled soil layer in MCF; and
z thickness of soil layer in MCF. The adjusted thickness of soil layers was used to determine SOC and STN stocks.

Statistical analyses

The normality of all data distribution was analyzed first using the Shapiro–Wilk Normality Test (Shapiro and Wilk 1965). One-way analysis of variance (ANOVA) was used to evaluate the difference in mean values of soil pH, bulk density, sand, silt, and clay contents and stocks of SOC and STN and C: N ratio in NF, SC-3Y, SC-5Y, SC-7Y and MCF. For ANOVA test, violation of assumptions of normal distribution (Shapiro–Wilk test), 'homoscedasticity' (Durbin–Watson statistic), and constant variance (Spearman rank correlation) was checked (Motulsky and Christopoulos 2004). When the assumption was violated, the Kruskal Wallis non-parametric analysis (Kruskal and Wallis 1952) was applied. All results were assessed at 5% significance level. The statistical analyses were conducted using SigmaPlot Ver. 11.0 (Systat Software Inc., San Jose, CA, USA).

Results

Soil pH, texture and bulk density

There was no significant difference in soil pH (0–10 cm soil layer) in NF (4.7 ± 0.5), SC-3Y (5.5 ± 0.4), SC-5Y (6.3 ± 0.4) and SC-7Y (4.4 ± 0.1) (Table 1). However, soil pH in MCF (3.9 ± 0.1) was significantly lower than SC-3Y and SC-5Y ($P < 0.05$) (Table 1).

There was no significant difference in proportion of sand, clay and silt across the study sites (0–10 cm soil layer) (Table 1).

In 0–10 cm soil layer, soil bulk density in SC-5Y (0.95 ± 0.03) was significantly but only slightly lower than NF, SC-3Y, SC-7Y and MCF (1.01 to 1.06) ($P < 0.05$) (Table 2). In 10–20 cm soil layer, there was no significant difference in bulk density in NF, SC-3Y, SC-5Y and SC-7Y (1.03 to 1.11) but bulk density in MCF (0.99 ± 0.02) was significantly but only slightly lower than other sites ($P < 0.05$) (Table 2). In 20–40 cm soil layer, there were no significant difference in bulk density in NF, SC-3Y, SC-5Y and SC-7Y (1.07 to 1.11) but bulk density of MCF (0.91 ± 0.02) was significantly but only slightly lower than other sites (P < 0.05) (Table 2). In 40–70 cm soil layer, there was no significance difference in bulk density among NF, SC-3Y and SC-7Y (1.06 to 1.13) and their bulk density were significantly higher than SC-5Y and MCF (0.88 to 0.96) (P < 0.05) (Table 2). In 70–100 cm soil layer, there was no significance difference in bulk density among NF, SC-3Y and SC-7Y (1.06 to 1.17) and their bulk densities were significantly higher than SC-3Y and MCF (0.90 to 0.99) ($P < 0.05$) (Table 2).

Soil organic carbon

In 0–10 cm soil layer, SOC content in MCF (19.9 ± 0.2 g kg^{-1}) was significantly ($P < 0.05$) lower than NF (36.6 ± 0.3 g kg^{-1}), SC-3Y (37.5 ± 0.3 g kg^{-1}), SC-5Y (38.9 ± 0.4 g kg^{-1}) and SC-7Y (36.9 ± g kg^{-1}) (Table 3). However, there were no significant differences in SOC contents among NF, SC-3Y, SC -5Y, and SC-7 Y (Table 3). In 10–20 cm soil layer, SOC content in MCF (15.2 ± 0.2 g kg^{-1}) was significantly lower than SC-3Y (33.9 ± 0.7 g kg^{-1}), SC-5Y (3.0 ± 0.2%) and SC-7Y (29.6 ± 0.2 g kg^{-1}) but there were no significant differences between NF (21.1 ± 0.1 g kg^{-1}), SC-3Y(33.9 ± 0.7 g kg^{-1}), SC-5Y(29.6 ± 0.2 g kg^{-1})and SC-7Y(27.5 ± 0.2 g kg^{-1}). In 20–40 cm soil layer, there were no significant differences in SOC contents in NF (16.9 ± 0.1 g kg^{-1}), SC-3Y (24.9 ± 0.2 g kg^{-1}), SC-5Y (30.6 ± 0.6 g kg^{-1}) and SC-7Y (21.3 ± 0.1 g kg^{-1}) but SOC contents in SC-3Y and SC-5Y were significantly higher than MCF (15.4 ± 0.1 g kg^{-1}) (P < 0.05). In 40–100 cm soil layer, there were no significant differences in SOC contents in NF, SC-3Y, SC-5Y, SC-7Y and MCF (Table 3).

Table 1 Soil pH and texture (0–10 cm layer) in natural forest (NF), shifting cultivation areas having three (SC-3Y), five (SC-5Y) and seven (SC-7Y)-year-old fallowing and 10 year-old mono-cropping field (MCF) converted from shifting cultivation

Land use type	Soil pH	Soil texture			
		Sand (%)	Clay (%)	Silt (%)	Soil class
NF	4.7 ± 0.5^{AB}	64 ± 1.40^{A}	21.8 ± 1.49^{A}	14.2 ± 1.97^{A}	Sandy loam
SC-3Y	5.5 ± 0.4^{A}	54 ± 3.89^{A}	31.8 ± 2.09^{A}	14.2 ± 2.56^{A}	Sandy loam
SC-5Y	6.3 ± 0.4^{A}	44 ± 5.78^{A}	35.8 ± 3.68^{A}	20.2 ± 2.80^{A}	Loam
SC-7Y	4.4 ± 0.1^{AB}	56 ± 2.29^{A}	23.8 ± 1.43^{A}	20.2 ± 1.75^{A}	Sandy clay loam
MCF	3.9 ± 0.1^{B}	53.9 ± 3.14^{A}	33.9 ± 2.27^{A}	12.2 ± 2.15^{A}	Sandy loam

Means followed by the same upper case letter(s) within a column are not significantly different

Values are shown as mean ± standard error

Table 2 Soil bulk density (g cm^{-3}) in natural forest (NF), shifting cultivation areas having three (SC-3Y), five (SC-5Y) and seven (SC-7Y)-year-old fallowing and 10 year-old mono-cropping field (MCF) converted from shifting cultivation

Soil layer (cm)	Land use type				
	NF	SC - 3Y	SC-5Y	SC-7Y	MCF
0–10	1.06 ± 0.06^{Aa}	1.04 ± 0.04^{Aa}	0.95 ± 0.03^{Ba}	1.01 ± 0.03^{Aa}	1.01 ± 0.03^{Aa}
10–20	1.14 ± 0.05^{Aa}	1.05 ± 0.02^{Aa}	1.03 ± 0.03^{Aa}	1.11 ± 0.03^{Aa}	0.99 ± 0.02^{Ba}
20–40	1.08 ± 0.06^{Aa}	1.07 ± 0.03^{Aa}	1.01 ± 0.04^{Aa}	1.11 ± 0.04^{Aa}	0.91 ± 0.02^{Ba}
40–70	1.06 ± 0.05^{Aa}	1.12 ± 0.02^{Aa}	0.96 ± 0.04^{Ba}	1.13 ± 0.03^{Aa}	0.88 ± 0.02^{Ba}
70–100	1.06 ± 0.07^{Aa}	1.17 ± 0.04^{Aa}	0.99 ± 0.02^{Ba}	1.11 ± 0.04^{Aa}	0.90 ± 0.02^{Ba}

Means followed by the same upper case letter(s) across rows and / or lower case letters within a column are not significantly different

Values are shown as mean ± standard error

There was no significant difference in SOC stocks (0–100 cm soil layer) among NF (188.7 ± 4.7 Mg C ha^{-1}), SC-3Y (243.5 ± 14.2 Mg C ha^{-1}), SC-5Y (229.9 ± 36.1 Mg C ha^{-1}), and SC-7Y (254.8 ± 15.6 Mg C ha^{-1}) (Table 4). The SOC stocks in MCF (126.6 ± 9.0 Mg C ha^{-1}) were 48.0% lower than SC-3Y and 50.3% lower than SC-7Y ($P < 0.05$) (Table 4). The SOC stocks in MCF were 44.9% lower than SC-5Y but the difference was not statistically significant. Since difference of SOC stocks between average of SC-3Y, SC-5Y and SC-7Y and MCF was 116 ± 2 Mg C ha^{-1} and MCF has been cultivated over 10 years after conversion

Table 3 Soil organic carbon (SOC) and total nitrogen (STN) contents (g kg^{-1}) and C: N ratio in natural forest (NF), shifting cultivation areas having three (SC-3Y), five (SC-5Y) and seven (SC-7Y)-year-old fallowing and 10 year-old mono-cropping field (MCF) converted from shifting cultivation

Soil layer (cm)	Land use type				
	NF	SC-3Y	SC-5Y	SC-7Y	MCF
SOC (g kg^{-1})					
0–10	36.6 ± 0.3^{Aa}	37.5 ± 0.3^{Aa}	38.9 ± 0.4^{Aa}	36.9 ± 0.3^{Aa}	19.9 ± 0.2^{Ba}
10–20	21.1 ± 0.1^{ABa}	33.9 ± 0.7^{Aa}	29.6 ± 0.2^{Aa}	27.5 ± 0.2^{Aa}	15.2 ± 0.2^{Ba}
20–40	16.9 ± 0.1^{ABa}	24.9 ± 0.2^{Aa}	30.6 ± 0.6^{Aa}	21.3 ± 0.1^{ABa}	15.4 ± 0.1^{Ba}
40–70	13.4 ± 0.1^{Aa}	18.7 ± 0.2^{Aa}	20.4 ± 0.4^{Aa}	19.5 ± 0.3^{Aa}	12.9 ± 0.07^{Aa}
70–100	15.5 ± 0.1^{Aa}	14.6 ± 0.1^{Aa}	14.8 ± 0.5^{Aa}	21.0 ± 0.3^{Aa}	12.7 ± 0.2^{Aa}
STN (g kg^{-1})					
0–10	2.8 ± 0.03^{ABa}	2.2 ± 0.04^{Ba}	2.9 ± 0.03^{Aa}	2.8 ± 0.03^{ABa}	1.5 ± 0.03^{Ba}
10–20	2.1 ± 0.03^{Aa}	2.1 ± 0.01^{Aa}	2.3 ± 0.01^{Aa}	2.3 ± 0.03^{Aa}	1.6 ± 0.01^{Aa}
20–40	1.9 ± 0.03^{Aa}	1.7 ± 0.02^{Aa}	1.7 ± 0.01^{Aa}	1.9 ± 0.02^{Aa}	1.3 ± 0.01^{Aa}
40–70	1.0 ± 0.02^{Aa}	1.4 ± 0.02^{Aa}	1.1 ± 0.01^{Aa}	1.9 ± 0.02^{Aa}	1.2 ± 0.01^{Aa}
70–100	1. 3 ± 0.02^{Aa}	1.2 ± 0.02^{Aa}	1.0 ± 0.01^{Aa}	1.7 ± 0.01^{Aa}	1.3 ± 0.02^{Aa}
C:N ratio					
0–10	13.5 ± 1.6^{Aa}	21.1 ± 5.1^{Aa}	14.1 ± 2.1^{Aa}	14.7 ± 3.1^{Aa}	17.9 ± 5.9^{Aa}
10–20	11.2 ± 2.0^{Aa}	15.9 ± 2.9^{Aa}	13.0 ± 1.2^{Aa}	13.8 ± 2.8^{Aa}	9.6 ± 0.7^{Aa}
20–40	9.7 ± 1.0^{Aa}	17.0 ± 4.2^{Aa}	19.5 ± 5.2^{Aa}	12.1 ± 1.5^{Aa}	12.2 ± 0.7^{Aa}
40–70	13.8 ± 1.1^{Aa}	14.7 ± 2.3^{Aa}	19.1 ± 3.8^{Aa}	9.9 ± 1.2^{Aa}	10.7 ± 2.0^{Aa}
70–100	13.0 ± 1.4^{Aa}	12.3 ± 1.1^{Aa}	16.7 ± 7.3^{Aa}	13.5 ± 2.7^{Aa}	11.2 ± 1.9^{Aa}

Means followed by the same upper case letter(s) across rows and / or lower case letters within a column are not significantly different

Values are shown as mean ± standard error

Table 4 Soil organic carbon stocks (0–10, 0–20, 0–40, 0–70 and 0 − 100 cm; Mg C ha^{-1}) and total nitrogen stocks (0–10, 0–20, 0–40, 0–70 and 0 − 100 cm; Mg N h^{-1}) in natural forest (NF), shifting cultivation areas having three (SC-3Y), five (SC-5Y) and seven (SC-7Y)-year-old fallowing and 10 year-old mono-cropping field (MCF) converted from shifting cultivation

Soil Variable	Soil layer (cm)	Land use types				
		NF	SC-3Y	SC-5Y	SC-7Y	MCF
SOC stocks (Mg C ha^{-1})	0–10	38.2 ± 1.4^{Ac}	39.3 ± 3.9^{Ac}	36.9 ± 3.9^{Ac}	42.2 ± 3.5^{Ac}	20.2 ± 1.7^{Be}
	0–20	62.0 ± 1.3^{Abc}	75.6 ± 6.0^{Abc}	67.5 ± 5.1^{Abc}	72.5 ± 4.2^{Abc}	35.3 ± 2.7^{Bde}
	0–40	98.1 ± 1.8^{ABabc}	129.1 ± 10.7^{Aabc}	130.1 ± 17.0^{Aab}	119.8 ± 6.9^{Aabc}	60.2 ± 3.9^{Bc}
	0–70	140.1 ± 2.5^{ABab}	192.2 ± 12.3^{Aab}	186.1 ± 24.5^{Aab}	185.6 ± 12.9^{Aab}	92.1 ± 6.2^{Bb}
	0–100	188.7 ± 4.7^{ABa}	243.5 ± 14.2^{Aa}	229.9 ± 36.1^{ABa}	254.8 ± 15.6^{Aa}	126.6 ± 8.9^{Ba}
STN stocks (Mg C ha^{-1})	0–10	2.9 ± 0.2^{Ae}	2.3 ± 0.4^{ABe}	2.8 ± 0.3^{Ae}	3.1 ± 0.3^{Ac}	1.5 ± 0.3^{Bc}
	0–20	5.4 ± 0.5^{Ad}	4.5 ± 0.3^{ABd}	5.2 ± 0.4^{Ad}	5.6 ± 0.5^{Abc}	3.1 ± 0.3^{Bbc}
	0–40	9.3 ± 0.4^{Ac}	8.0 ± 0.6^{ABc}	8.6 ± 0.4^{ABc}	9.7 ± 0.8^{Aabc}	5.4 ± 0.4^{Babc}
	0–70	12.5 ± 0.8^{Bb}	12.6 ± 0.6^{Bb}	11.7 ± 0.7^{BCb}	16.3 ± 1.2^{Aab}	8.7 ± 0.8^{Cab}
	0–100	16.5 ± 0.8^{Ba}	16.9 ± 0.4^{Ba}	14.7 ± 0.9^{BCa}	21.9 ± 0.9^{Aa}	12.1 ± 1.2^{Ca}

Means followed by the same upper case letter(s) across rows and / or lower case letters within a column are not significantly different

Values are shown as mean ± standard error

from shifting cultivation, a loss of 11.6 ± 0.2 Mg C ha^{-1} yr.$^{-1}$ in MCF was estimated.

Soil total nitrogen

There was no significant difference in STN contents (1.0–2. 9 g kg^{-1}) throughout soil layers, 0–10, 10–20, 20–40, 40–70 and 70–100 cm across all the study sites except that in 0–10 cm soil layer, STN content of SC-5Y (2.9 ± 0.03 g kg^{-1}) was significantly higher than MCF (1.5 ± 0.03 g kg^{-1}) (Table 3).

The STN stocks (0–100 cm soil layer) in SC-7Y (21.9 ± 0.9 Mg N ha^{-1}) were significantly ($P < 0.05$) higher than NF (16.5 ± 0.8 Mg N ha^{-1}), SC-3Y (16.9 ± 0.4 Mg N ha^{-1}) and SC-5Y (14.7 ± 0.9 Mg N ha^{-1}) but there were no significant differences in STN stocks among NF, SC-3Y and SC-5Y (Table 4). The STN stocks in MCF (12.1 ± 1.2 Mg N ha^{-1}) were 26.7% lower than NF, 28.4% lower than SC-3Y and 44.7% lower than SC-7Y ($P < 0.05$) (Table 4). The STN stocks in MCF were 17.7% lower than SC-5Y but the difference was not statistically significant (Table 4). The difference of STN stocks between MCF and average of SC-3Y, SC-5Y and SC-7Y was 6.0 ± 1.0 Mg N ha^{-1}. Since MCF has been cultivated over 10 years after conversion from shifting cultivation, it is estimated that loss of 0.6 ± 0.1 Mg N ha^{-1} yr.$^{-1}$ in MCF.

Soil C:N ratio

C: N ratios ranged roughly from 10 to 20 across all the sites and throughout soil layers and there were no significant differences in C: N ratios (Table 3).

Discussion

Soil pH

There was no significant difference in soil pH across natural forest and shifting cultivation areas. The results indicate that conversion of natural forest to shifting cultivation and following long-term practices of shifting cultivation did not affect soil pH. The lack of observed change of soil pH is different from previous studies. A meta-analysis of Ribeiro Filho et al. (2015) found that soil pH increased under shifting cultivations. The increase of soil pH may be attributed to demobilization of base cations (K^+, Ca^{2+} and Mg^{2+}) in burnt vegetation and their incorporation into the soil with ash (e.g., Nye and Greenland 1960) and the heating of the superficial layer of the soil caused by the use of fire (e.g., De Rouw 1994). It is hypothesized that that the amount of demobilized basic cations from burnt biomass was not large enough to affect soil pH in the shifting cultivation areas.

Soil pH in the converted mono-cropped field was significantly lower than some of shifting cultivation areas. It indicates that converting shifting cultivation to mono-cropping decreased soil pH. The observed decrease of soil pH may be attributed to applied inorganic fertilizer (urea and DAP) in the mono cropping fields since NH_4^+ ion and NO_3^- anion from N-fertilizers are likely to play roles in affecting acidification (e.g., Tian and Niu 2015; Geisseler and Scow 2014; Lucas et al. 2011).

Soil texture

Soil texture was not significantly different across natural forest, shifting cultivation areas and converted mono-cropping fields. The results indicate that neither conversion of natural forest to shifting cultivation, nor the following conversion of shifting cultivation to mono-cropping affected soil texture. However, those results are different from major findings of previous studies. A meta-analysis of Ribeiro Filho et al. (2013) found that shifting cultivation resulted in the alteration of the fine fraction due to repeated fire. It is hypothesized that fire intensity might not be strong enough to affect soil texture in the shifting cultivation areas.

Soil bulk density

The study found that soil bulk densities were not significantly different or only slightly different across the natural forest, shifting cultivation areas, and mono-cropping fields. The results indicate that conversion of natural forest to shifting cultivation and following long-term practices of shifting cultivation did not affect soil bulk density. Similarly, Osman et al. (2013) did not show any considerable effect of shifting cultivation on soil physical properties including water holding capacity, bulk density, moisture content and particle density in Bangladesh. The lack of change of soil bulk density observed in the conversion from natural forest to shifting cultivation is different from common findings in shifting cultivation. Global meta-analyses of Ribeiro Filho et al. (2013) and Mukul and Herbohn (2016) found that soil bulk density was decreased by shifting cultivation. The decrease in bulk density following shifting cultivation can be can explained by the collapse of the organo-mineral aggregates by fire (Giovannini et al. 1988) and sealing due to the clogging of soil pores by ash or the freed clay minerals (Durgin and Vogelsang 1984). Lack of change of soil bulk density observed in the conversion of natural forest to shifting cultivation can be explained by different hypotheses. First, no severe fire-caused soil disturbance occurred in the shifting cultivation. Repeated burning every 8 to 10 years may not allow excessive fuel loads to accumulate and accordingly fire intensity may not be severe enough to affect soil physical properties. Second, cultivation following fire did not affect soil bulk density. Local communities cultivated the burned areas with minimum soil disturbance (ex. open a small hole with a wooden stick) and this practice might not disrupt soil structure and soil macroaggregates affecting soil bulk density.

This study found that there was no or very little change of soil bulk density in the conversion from shifting cultivation to mono-cropping. The result is different from common observation of altered soil bulk density due to land-use changes. Global meta-analyses (e.g., Shi et al. 2013; Don et al. 2011; Murty et al. 2002) and studies conducted in Ethiopia (e.g., Wainkwa Chia et al. 2017; Yimer et al. 2007; Lemma et al. 2006) commonly found an increase of soil bulk density after a land use change from natural forest to agricultural land (ex., 17% increase; Shi et al. 2013). It is known that the increase of bulk density can be attributed to soil disturbance and compaction due to agricultural activities such as use of heavy machinery and soil tilling (e.g., Shi et al. 2013; Don et al. 2011; Murty et al. 2002). No, or very little change of soil bulk density observed in this study suggests that applied tillage practices in the mono cropping fields (traditional oxen ploughing with "*maresha*" and compaction for weed control during sowing of teff) may not affect soil bulk density.

Soil carbon and nitrogen

Soil organic carbon stocks (188 Mg C ha^{-1} in 0–100 cm layer) in natural forest in our study area were in the range of SOC stocks in natural forests reported (127–271 Mg C ha^{-1} in 0–100 cm layer) in previous Ethiopian studies (Wainkwa Chia et al. 2017; Kim et al. 2016). However, the stocks were higher than globe average (113 Mg C ha^{-1}; Sombroek et al. 1993) and average of cool temperate wet forest (139 Mg C ha^{-1}; Post et al. 1982).

Previous studies found that shifting cultivation significantly affected soil carbon and nitrogen. Global meta-analyses of Ribeiro Filho et al. (2015) and

Mukul and Herbohn (2016) found that soil carbon and nitrogen were significantly reduced under shifting cultivation. This was mainly due to the volatilization of SOM caused by fire, increased mineralization of SOM, leaching, runoff and erosion during cultivation and fallowing periods (Mukul and Herbohn 2016; Ribeiro Filho et al. 2015). However, in this study there was no significant difference in SOC and STN stocks between natural forest and shifting cultivations. It is notable that the observed higher STN stocks in one of shifting cultivation sites compared to natural forest and other shifting cultivation sites was caused by higher STN contents in deep soil layers (40–100 cm) (Table 4). Therefore, the observed higher STN stocks in one of the shifting cultivation sites might be attributed to the nature of the site rather than the effect of shifting cultivation. The results indicate that converting natural forest to shifting cultivation and the following long-term shifting cultivation practices did not affect SOC and STN stocks in the study areas. Similarly, in Malaysia, SOC stocks (0–90 cm soil layers) were not significantly different between native forest and shifting cultivation sites cultivating rice and pepper with 11–13 years of fallow (Neergaard et al. 2008). We hypothesized the potential reasons for the observed no change of SOC and STN stocks: First, repeated fire in shifting cultivation might not be severe enough to affect SOC and STN. Global meta-analyses by Nave et al. (2011), Boerner et al. (2009), Wan et al. (2001) and Johnson and Curtis (2001) found that prescribed fire did not have significant overall effects on either SOC or STN, because prescribed fires tend to be implemented under fairly low fuel loads and favorable weather conditions (Nave et al. 2011). Similarly, a study conducted in a montane forest in southern Ethiopia found that traditional fire management, burning forest regularly, did not affect SOC and STN stocks (Kim et al. 2016). Combustion of SOC begins at 200 to 250 °C and is completed at around 460 °C (Giovannini et al. 1988). It is hypothesized that the burned soils in the shifting cultivation might never experience temperatures high enough for oxidation, thus SOC and STN were not changed. It is suggested that further study will consider investigating fire temperature in the shifting cultivation. Second, applied cultivation methods in the shifting cultivation might not affect SOC and STN. Unlike modern conventional cultivation methods, applied traditional cultivation methods in the shifting cultivation, including no tillage, manual harvesting, and retaining crop residues, may not increase decomposition of soil organic matter and prevent soil erosion and run-off, resulting in no change of SOC and STN. Third, 8 to 10 years of fallow might be long enough to restore disturbed soil, and nutrients depleted from organic matter from burning, and following one year of cultivation, resulting in no change of SOC and STN stocks in the study site.

The current study found that there was no significant difference in SOC and STN stocks in different fallow periods. Similarly, a few studies found no clear relation between fallow length and soil carbon and nitrogen in Myanmar (Chan et al. 2016), Malaysia (Bruun et al. 2006), Indonesia (Mertz et al. 2008) and Thailand (Grange and Kansuntisukmongkol 2003). However, some studies found soil carbon and nitrogen increased with fallow length, in India (Sarkar et al. 2015), Indonesia (Kleinman et al. 1996) and Laos (Roder et al. 1995). It is hypothesized that the discrepancy might be attributed to the different status of soil carbon and nitrogen storage capacity in soil under fallow (Sarkar et al. 2015). If soil under fallow is already saturated with organic matter and remains in a steady state of soil organic matter, soil carbon and nitrogen may not change with fallow length. This may be the case of the current study as well as others (Chan et al. 2016; Mertz et al. 2009; Bruun et al. 2006) showing no change of soil carbon and nitrogen with fallow length. However, if soil under fallow is unsaturated with organic matter, soil carbon and nitrogen increase with fallow length due to newly added organic matter inputs from litter and roots of growing vegetation, especially at higher elevations and lower temperatures. This may be the case of studies (Sarkar et al. 2015; Kleinman et al. 1996; Roder et al. 1995) showing an increase of soil carbon and nitrogen with fallow length.

The study found that SOC and STN stocks in converted mono-cropping fields were 45–50% and 18–45% lower than shifting cultivation sites, respectively. The results indicate that conversion of shifting cultivation to conventional mono-cropping resulted in loss of SOC (45–50% over 10 years; 11.6 ± 0.2 Mg C ha^{-1} yr.$^{-1}$) and STN stocks (18–45% over 10 years; 0.6 ± 0.1 Mg N ha^{-1} yr.$^{-1}$). Similarly, global meta-analyses and reviews (e.g., Dressler et al. 2017; van Vliet et al. 2012; Bruun et al. 2009) commonly reported that the transition of shifting cultivations to conventional agriculture resulted in loss of soil carbon (13–40%; Bruun et al. 2009) and soil fertility. There might be several potential reasons on the loss of SOC and STN stocks in conversion of shifting cultivation to conventional mono-cropping (e.g., van Vliet et al. 2012; Bruun et al. 2009). First, loss of SOC and STN could happen since physical disturbance of soil by tillage practices may increase decomposition of organic matter including soil C and N (e.g., McLauchlan 2006; Six et al. 2004; Murty et al. 2002). Second, removed perennial vegetation can result in decreased soil inputs of organic matter from vegetation litter and roots (e.g., McLauchlan 2006; Six et al. 2004; Murty et al. 2002). Third, less vegetation cover and use of conventional tillage in the converted mono-cropping fields may increase wind and water erosion, which can cause loss of soil C and N (e.g., Delgado et al. 2013; Wairiu and Lal 2003).

Observed loss of SOC stocks (45–50%) following conversion of shifting cultivation to conventional mono-cropping in this study was greater than other studies (13–40%; Bruun et al. 2009). It may be attributed to higher SOC stocks in shifting cultivation in this study since it has been known that a natural forest having higher SOC results in greater carbon loss in its conversion to agricultural lands (e.g., Kim and Kirschbaum 2015; Don et al. 2011; Guo and Gifford 2002). Further studies are required to identify major mechanisms and quantify their contribution to the loss of SOC and STN stocks in conversion of shifting cultivation to mono-cropping.

Implications

In contrast to previous research, this study found that long-term shifting cultivation did not affect soil pH, soil texture, soil bulk density, and SOC and STN stocks. The results suggest that the current perception of the negative impacts of shifting cultivation on soil properties, including soil carbon and nutrients, should be re-visited. More studies are required to assess impacts in different regions and environmental conditions.

Losses of SOC and STN and decreased soil pH following shifting cultivations to mono- cropping fields have an implication for global climate change and local livelihoods. Decreasing SOC and STN can increase emissions of soil greenhouse gases (GHG) such as carbon dioxide (CO_2) and nitrous oxide (N_2O) (e.g., Kim and Kirschbaum 2015; Snyder et al. 2009) and contribute to global climate change. Decreased STN and soil pH can result in another issue of degrading soil fertility, potentially causing decreased crop yield in the mono-cropped fields (e.g., Dressler et al. 2017; van Vliet et al. 2012). More studies are urgently needed to assess how increasing conversion of shifting cultivation to mono-cropping in tropical areas affects soil carbon, GHG emissions and nutrient and crop yields.

Conclusions

This study found that conversion of forest to shifting cultivation did not affect SOC and STN stocks, but conversion of shifting cultivations to mono-cropping fields decreased both SOC and STN stocks. The results suggest that in the study area, shifting cultivation maintains soil carbon and nitrogen, which are critical for sustaining soil fertility and preventing global warming. However, conversion of shifting cultivation to mono-cropping can lead to depleting soil fertility and contributing to global warming. Further studies are recommended to assess how shifting cultivation and its conversion to mono-cropping affect soil carbon and nitrogen in different regions.

Acknowledgements The authors wish to thank the farmers and staff of Gudeya Bila Wereda administrations and sectors, especially Development Agents members of Zengi station who allowed and supported us to conduct the study. We are also grateful to Weyinshet Aferik and Alima Gibiril for assisting in field and laboratory work, Habitamu Taddese for creating a map of the study areas and Zebene Asfaw, Fantaw Yimer, Mulugeta Limenih, Robert Sturtevant, Tracy Beedy, and Demel Teketay for constructive and valuable comments in the earlier manuscript. Financial support was provided by African Forest Forum, MRV project of Wondo Genet College of Forestry and Natural Resources, International Atomic Energy Agency (IAEA) Coordinated Research Project (CRP D1 50.16) Minimizing Farming Impacts on Climate Change by Enhancing Carbon and Nitrogen Capture and Storage in Agro-Ecosystems and Korea International Cooperation Agency (KOICA) project (NO. 2018-004) Strengthening the Capacity to Address Climate Change on Forestry Sector in Ethiopia.

References

Boerner RE, Huang J, Hart SC (2009) Impacts of fire and fire surrogate treatments on forest soil properties: a meta-analytical approach. Ecol Appl 19:338–358. https://doi.org/10.1890/07-1767.1

Bremner JM, Mulvaney CS (1982) Nitrogen-total. In: Page AL, Miller RH, Keeney DR (eds) Methods of soil analysis 2. Soil Sci Soc Am, Madison, pp 595–624

Bruun TB, Mertez O, Eliberling B (2006) Linking yields of upland rice in shifting cultivation to fallow length and soil properties. Agric Ecosyst Environ 113:139–149. https://doi.org/10.1016/j.agee.2005.09.012

Bruun TB, de Neergard A, Lawrence D, Ziegler AD (2009) Environmental consequences of the demise in swidden cultivations in Southeast Asia: carbon storage and soil quality. Hum Ecol 37:375–388. https://doi.org/10.1007/s10745-009-9257-y

Bruun TB, Neergaard A, Burup ML, Hepp CM, Larsen MN, Abel C, Aumtong S, Magid J, Mertz O (2017) Intensification of upland agriculture in Thailand: development or degradation? Land Degrad Dev 28:83–94. https://doi.org/10.1002/ldr.2596

Bruun TB, Berry N, de Neergaard A, Xaphokahme P, McNicol I, Ryan CM (2018) Long rotation swidden systems maintain higher carbon stocks than rubber plantations. Agric Ecosyst Environ 256: 239–249. https://doi.org/10.1016/j.agee.2017.09.010

Chan N, Takeda S, Suzuki R, Yamamoto S (2016) Assessments of biomass recovery and soil carbon storage of fallow forests after swidden cultivation in the Bago Mountains Myanmar. New For 47:565–585. https://doi.org/10.1007/s11056-016-9531-y

Craswell ET, Sajjapongse A, Howlett DJB, Dowling AJ (1997) Agroforestry in the management of sloping lands in Asia and the Pacific. Agrofor Syst 38:121–137. https://doi.org/10.1023/A:1005960612386

Dalle SP, Pulido MT, de Blois S (2011) Balancing shifting cultivation and forest conservation: lessons from a "sustainable landscape" in southeastern Mexico. Ecol Appl 21:1557–1572. https://doi.org/10.1890/10-0700.1

Davidson EA, De Abreusa Sá TD, Reis Carvalho CJ, De Oliveira Figueiredo R, Md K, Kato OR, Ishida FY (2008) An integrated greenhouse gas assessment of an alternative to slash and-burn agriculture in eastern Amazonia. Glob Chang Biol 14: 998–1007. https://doi.org/10.1111/j.1365-2486.2008.01542.x

De Rouw A (1994) Effect of fire on soil, rice, weeds and forest regrowth in a rainforest zone (CÔte d'lvoire). Catena 22: 133–152. https://doi.org/10.1016/0341-8162(94)90022-1

Delgado JA, Nearing MA, Rice CW, Donald LS (2013) Conservation practices for climate change adaptation. Adv Angron 121:47–115. https://doi.org/10.1016/B978-0-12-407685-3.00002-5

Don A, Schumacher J, Freibauer A (2011) Impact of tropical land-use change on soil organic carbon stocks – a meta-analysis. Glob Chang Biol 17:1658–1670. https://doi.org/10.1111/j.1365-2486.2010.02336.x

Dressler WH, Wilson D, Clendenning J, Cramb R, Keenan R, Mahanty S, Bruun TB, Mertz O, Lasco RD (2017) The impact of swidden decline on livelihoods and ecosystem services in Southeast Asia: a review of the evidence from 1990 to 2015. Ambio 46:291–310. https://doi.org/10.1007/s13280-016-0836-z

Durgin PB, Vogelsang PJ (1984) Dispersion of kaolinite by water extracts of Douglas-fir ash. Can J Soil Sci 64:439–443. https://doi.org/10.4141/cjss84-044

Eden MJ, Andrade A (1987) Ecological aspects of swidden cultivation among the Andoke and Witoto Indians of the Colombian Amazon. Hum Ecol 14:339–359. https://doi.org/10.1007/BF00888030

Enkossa W (2008) Floristic analysis of Alata-Bolale forests in Gudeya Bila wereda, East Welega Zone, Oromia Regional state. MSc. Thesis, Addis Ababa University, Addis Ababa, Ethiopia

EPA (2003) State of environmental report for Ethiopia. Environmental Protection Authority, Addis Ababa, Ethiopia. https://urldefense.proofpoint.com/v2/url?u=http-3Apublication.eiar.gov.et-3A8080xmluihandle1234567891196&d=DwIFaQ&c=vh6FgFnduejNhPPD0flyRaSfZy8CWbWnIf4XJhSqx8&r=EJ-tCmWkbJK5LFJWLWVAfMcPPk1q8riPr7SCkGQjQDFCcA9EwveP9uaYl-3N-h&m=4Pja1dvAVXrGSmqUvmMwbEBb4FguRXjBQFktCtK3L9U&s=iVm7CagnZSfYNqoZTWnwUv8KSH-4_EA43yKdVu3I&e. Accessed 24 Jan. 2019

Fox J, Truong DM, Rambo TA, Tuyen NP, Cuc LT, Leisz S (2000) Shifting cultivation: a new old paradigm for managing tropical forests. BioScience 50:521–528. https://doi.org/10.1641/0006-3568(2000)050[0521:SCANOP]2.0.CO;2

Fox J, Fujita Y, Ngidang D, Peluso N, Potter L, Sakuntaladewi N, Sturgeon JM, Thomas D (2009) Policies, political – economy, and swidden in Southeast Asia. Hum Ecol 37:305–322. https://doi.org/10.1007/s10745-009-9240-7

GARDO (2006) Gudaya Bila Woreda Rural development office, Annual Report. Gudaya Bila Woreda

Gee GW, Bauder J (1979) Particle size analysis by hydrometer: a simplified method for routine textural analysis and a sensitivity test of measurement parameters. Soil Sci Soc Am J 43:1004–1007. https://doi.org/10.2136/sssaj1979.03615995004300050038x

Gee GW, Or D (2002) Particle-size analysis. In: Dane JH, Topp CG (eds) Methods of soil analysis: part 4. Physical methods. Soil Science Society of America Inc. and American Society of Agronomy Inc., Madison, pp 255–293

Geisseler D, Scow KM (2014) Long-term effects of mineral fertilizers on soil microorganisms- a review. Soil Biol Biochem 75:54–63. https://doi.org/10.1016/j.soilbio.2014.03.023

Geist HJ, Lambin EF (2002) Proximate causes and underlying driving forces of tropical deforestation. BioScience 52:143–150. https://doi.org/10.1641/0006-3568(2002)052[0143:PCAUDF]2.0.CO;2

Gibbs HK, Brown S, Niles JO, Foley JA (2007) Monitoring and estimating tropical forest carbon stocks: making REDD a reality. Environ Res Lett 2:1–13. https://doi.org/10.1088/1748-9326/2/4/045023

Giovannini G, Lucchesi S, Giachetti M (1988) Effect of heating on some physical and chemical parameters related to soil aggregation and erodibility. Soil Sci 146:255–261

Grossman RB, Reinsch TG (2002) Bulk density and linear extensibility. In: Dane JH, Topp GC (eds) Methods of soil analysis. Part. 4 physical methods. Soil Science Society of America, Inc. and American Society of Agronomy, Inc., Madison, pp 201–254

Grange I, Kansuntisukmongkol K (2003) Effect of fallow length on soil structure, hydraulic properties, and soil organic C in a swidden cultivation system of western Thailand. Trop Agric 80: 246–251

Guo LB, Gifford RM (2002) Soil carbon stocks and land use change: a meta analysis. Glob Chang Biol 8:345–360. https://doi.org/10.1046/j.1354-1013.2002.00486.x

Hattorie D, Sabang J, Tanaka S, Kendawang JJ, Ninomiya I, Sakurai K (2005) Soil characteristics under three vegetation types associated with shifting cultivation in a mixed dipterocarp forest in Sarawak, Malaysia. Soil Sci Plant Nutr 51:231–241. https://doi.org/10.1111/j.1747-0765.2005.tb00027.x

Heinimann A, Mertz O, Frolking S, Egelund Chistensen A, Humi K, Sedano F, Parsons Chini L, Sahajpal R, Hansen M, Hurtt G (2017) A global view of shifting cultivation: recent, current, and future extent. PLoS One 12(9):e0184479. https://doi.org/10.1371/journal.pone.0184479

Johnson DW, Curtis PS (2001) Effects of fire forest management on soil C and N storage: a meta analysis. For Ecol Manag 140:227–238. https://doi.org/10.1016/S0378-1127(00)00282-6

Jones A, Breuning-Madsen H, Brossard M, Dampha A, Deckers J, Dewitte O, Gallali T, Hallett S, Jones R, Kilasara M, Le Roux P, Micheli E, Montanarella L, Spaargaren O, Hiombiano L, Van Ranst E, Yemefack M, Zougmoré R (2013) Soil atlas of Africa. European Commission, Publications Office of the European Union, Luxembourg, p 176

Kilawe CJ, Mertz O, Birch-Thomsen T, Maliondo SM (2018) Transformation of shifting cultivation: extent, driving forces and impacts on livelihoods in Tanzania. Appl Geogr 94:84–94. https://doi.org/10.1016/j.apgeog.2018.03.002

Kim D-G, Kirschbaum MUF (2015) The effect of land-use change on the net exchange rates of greenhouse gases: a compilation of estimates. Agric Ecosyst Environ 208:114–126. https://doi.org/10.1016/j.agee.2015.04.026

Kim D-G, Taddese H, Belay A, Kolka R (2016) The impact of traditional fire management on soil carbon and nitrogen pools in a montane forest, southern Ethiopia. Int J Wildland Fire 25:1110–1116. https://doi.org/10.1071/WF16022

Kleinman PJ, Bryant RB, Pimentel D (1996) Assessing ecological sustainability of slash-and-burn agriculture through soil fertility indicators. Agron J 88:122–127. https://doi.org/10.2134/agronj1996.00021962008800020002x

Kruskal WH, Wallis WA (1952) Use of ranks in one-criterion variance analysis. J Am Stat Assoc 47:583–621 https://www.jstor.org/stable/2280779

Lemma B, Kleja DB, Nilsson I, Olsson M (2006) Soil carbon sequestration under different exotic tree species in the southwestern highlands of Ethiopia. Geoderma 136:886–898. https://doi.org/10.1016/j.geoderma.2006.06.008

Lucas RW, Klaminder J, Futter MN, Bishop KH, Egnell G, Laudon H, Hogberg P (2011) A meta-analysis of the effects of nitrogen additions on base cations: implications for plants, soils, and streams. For Ecol Manag 262:95–104. https://doi.org/10.1016/j.foreco.2011.03.018

McLauchlan K (2006) The nature and longevity of agricultural impacts on soil carbon and nutrients: a review. Ecosystems 9:1364–1382. https://doi.org/10.1007/s10021-005-0135-1

Mertz O (2009) Trends in shifting cultivation and the REDD mechanism. Curr Opin Environ Sustain 1:156–160. https://doi.org/10.1016/j.cosust.2009.10.002

Mertz O, Wadley RL, Nielsen U, Bruun TB, Colfer CJ, de Neergaard A, Jepsen MR, Martinussen T, Zhao Q, Noweg GT (2008) A fresh look at shifting cultivation: fallow length an uncertain indicator of productivity. Agric Sys 96: 75–84. https://doi.org/10.1016/j.agsy.2007.06.002

Mertz O, Padoch C, Fox J, Cramb RA, Leisz SJ, Lam NI, Vien TD (2009) Swidden change in Southeast Asia: understanding causes and consequences. Hum Ecol 37:259–264 https://www.jstor.org/stable/40343969

Motulsky HJ, Christopoulos A (2004) Fitting models to biological data using linear and nonlinear regression: a practical guide to curve fitting. Oxford University Press, New York

Mukul SA, Herbohn J (2016) The impacts of shifting cultivation on secondary forests dynamics in tropics: a synthesis of the key findings and spatio temporal distribution of research. Environ Sci Pol 55:167–177. https://doi.org/10.1016/j.envsci.2015.10.005

Murty D, Kirschbaum MUF, Mcmutrie RE, Mcgilvra H (2002) Does conversion of forest to agricultural land change soil carbon and nitrogen? A review of the literature. Glob Chang Biol 8:105–123. https://doi.org/10.1046/j.1354-1013.2001.00459.x

Nave LE, Vance ED, Swanston CW, Curtis PS (2011) Fire effects on temperate forest soil C and N storage. Ecol Appl 21:1189–1201. https://doi.org/10.1890/10-0660.1

Neergaard A, Magid J, Mertz O (2008) Soil erosion from shifting cultivation and other small holder land use in Sarawak, Malaysia. Agric Ecosyst Environ 125:182–190. https://doi.org/10.1016/j.agee.2007.12.013

Nye PH, Greenland DJ (1960) The soil under shifting cultivation, Technical Communications 51, Harpenden, UK

Osman KS, Jashimuddin M, Haque SMS, Miah S (2013) Effect of shifting cultivation on soil physical and chemical properties in Bandarban hill district, Bangladesh. J For Res 24:791–795. https://doi.org/10.1007/s11676-013-0368-3

Parrotta JA, Wildburger C, Mansourian S (2012) Understanding relationships between biodiversity, carbon, forest and people: The key to achieving REDD+ objectives, Aglobal assessment report. Global expert panel on Biodiversity, Forest Management, and REDD+ World Serous Volume 31. International Union of Forest Research Organizations (IUFRO), Vienna, Austria

Peng L, Zhiming F, Luguang J, Chenihual L, Jingua Z (2014) A review of swidden agriculture in Southeast Asia. Remote Sens 6:1654–1683. https://doi.org/10.3390/rs6021654

Post WM, Emanuel WR, Zinke PJ, Stangenberger AG (1982) Soil carbon pools and world life zones. Nature 298:156–159. https://doi.org/10.1038/298156a0

Rahman SA, Rahman MF, Sunderland T (2012) Cause and consequences of shifting cultivation and its alternative in the hill tracts of eastern Bangladesh. Agrofor Syst 84:141–155. https://doi.org/10.1007/s10457-011-9422-3

Ribeiro Filho AA, Adams C, Murrieta RSS (2013) The impact of shifting cultivation on tropical forest soil: a review. Bol Mus Para Emílio Goeldi Ciênc hum 8:693–727. https://doi.org/10.1590/S1981-81222013000300013

Ribeiro Filho AA, Adams C, Manfrendini S, Aguilar R, Neves W (2015) Dynamics of soil chemical properties in shifting cultivation systems in the tropics: a Meta analysis. Soil Use Manag 31:474–482. https://doi.org/10.1111/sum.12224

Roder W, Phengchanh S, Keoboulapha B (1995) Relationships between soil, fallow period, weeds and rice yield in slash-and-burn systems of Laos. Plant Soil 176:27–36. https://doi.org/10.1007/bf00017672

Sarkar D, Bungbungcha Meitei C, Baishya LK, Aas A, Ghosh S, Chongloi LK, Rajkhowa D (2015) Potential of fallow chronosequence to conserve soil organic carbon in Northeast India. Catena 135:321–327. https://doi.org/10.1016/j.catena.2015.08.012

Schuck EC, Nganje W, Yantio D (2002) The role of land tenure and extension education in the adoption of slashes and burn agriculture. Ecol Econ 43:61–70. https://doi.org/10.1016/S0921-8009(02)00180-5

Shapiro SS, Wilk MB (1965) An analysis of variance test for normality (complete samples). Biometrika 52:591–611 http://www.jstor.org/stable/2333709

Shi S, Zhang W, Zhang P, Yongqiang Y, Ding F (2013) A synthesis of change in deep SOC stores with afforestation of agricultural soils. For Ecol Mange 296:53–63. https://doi.org/10.1016/j.foreco.2013.01.026

Six J, Bossuyt H, Degryze S, Denef K (2004) A history of research on the link between (micro) aggregates, soil biota, and soil organic matter dynamics. Soil Tillage Res 79:7–31. https://doi.org/10.1016/j.still.2004.03.008

Snyder CS, Bruulsema TW, Jensen TL, Fixen PE (2009) Review of greenhouse gas emissions from crop production systems and fertilizer management effects. Agric Ecosyst Environ 133:247–266. https://doi.org/10.1016/j.agee.2009.04.021

Soil Survey Staff (1999) Soil Taxonomy. A basic system of soil classification for making and interpreting soil surveys, 2nd edition. Agricultural Handbook 436, Natural Resources Conservation Service, USDA, Washington DC, USA, pp 869

Solomon D, Fritzszhe F, Lehmann J, Tekalign M, Zech W (2002) Soil organic matter dynamics in the subhumid agro ecosystems of the Ethiopian naturals. Soil Sci Am J 66:969–978. https://doi.org/10.2136/sssaj2002.9690

Sombroek WG, Nachtergaele FO, Hebel A (1993) Amounts, dynamics and sequestering of carbon in tropical and subtropical soils. AMBIO 22:417–426 http://www.jstor.org/stable/4314120

Thomaz EL (2013) Slash-and-burn agriculture: establishing scenarios of runoff and soil loss for a five-year cycle. Agric Ecosyst Environ 168:1–6. https://doi.org/10.1016/j.agee.2013.01.008

Tian D, Niu S (2015) A global analysis of soil acidification caused by nitrogen addition. Environ Res Lett 10:024019. https://doi.org/10.1088/1748-9326/10/2/024019

van Vliet N, Mertz O, Heininmann A, Langanke T, Pascual U, Schmook B, Adams C, Schmidt-Vogt D, Messerli P, Leisz S, Castella J-C, Jørgensen L, Birch-Thomsen T, Hett C, Bech-Bruun T, Ickowitz A, Vu KC, Yasuyuki K, Fox J, Padoch C, Dressler W, Ziegler AD (2012) Trends, drivers and impacts of changes in swidden cultivation in tropical forest-agriculture frontiers: a global assessment. Glob Environ Chang 22:418–429. https://doi.org/10.1016/j.gloenvcha.2011.10.009

Wainkwa Chia R, Kim D-G, Yimer F (2017) Can afforestation with Cupressus lustanica restore soil C and N stocks depleted by crop cultivation to levels observed native systems? Agric Ecosyst Environ 241:67–75. https://doi.org/10.1016/j.agee.2017.03.023

Wairiu M, Lal R (2003) Soil organic carbon in relation to cultivation and top soil removal on sloping lands of Kolombangara, Solomon Islands. Soil Tillage Res 70:19–27. https://doi.org/10.1016/S0167-1987(02)00116-2

Walkley A, Black IA (1934) An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Sci 37:29–38

Wan S, Hui D, Luo Y (2001) Fire effects on nitrogen pools and dynamics in terrestrial ecosystems: a meta- analysis. Ecol Appl 11:1349–1365. https://doi.org/10.1890/1051-0761(2001)011[1349:FEONPA]2.0.CO;2

Wei X, Shao M, Gale W, Li L (2014) Global pattern of soil carbon losses due to the conversion forests to agricultural lands. Sci Rep 4:4062. https://doi.org/10.1038/srep04062

Yimer F, Ledin S, Abdelkadir A (2007) Changes in soil organic carbon and total nitrogen contents in three adjacent land use types in the Bale Mountains, south-eastern highlands of Ethiopia. For Ecol Manag 242:337–342. https://doi.org/10.1016/j.foreco.2007.01.087

Ziegler AD, Fox JM, Webb EL, Padoch C, Leisz S, Cramb RA, Mertz O, Bruun TT, Vien TD (2011) Reorganizing contemporary roles of swidden agriculture in transforming landscapes of Southeast Asia. Conserv Biol 25:846–848 http://www.jstor.org/stable/27976544