Geoderma 261 (2016) 70–79

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Impact of changes in land use, species and elevation on soil organic carbon and total nitrogen in Ethiopian Central Highlands

Mehari A. Tesfaye [a,c,1], Felipe Bravo [a,c], R. Ruiz-Peinado [b,c], Valentín Pando [a,c], Andrés Bravo-Oviedo [b,c,*]

[a] *Escuela Técnica Superior de Ingenierías Agrarias, Universidad de Valladolid (Campus de Palencia), Avda. Madrid, 44, 34071 Palencia, Spain*
[b] *INIA-Forest Research Center, Ctra A. Coruña, km. 7.5, Madrid, Spain*
[c] *Sustainable Forest Management Research Institute, UVa–INIA, Spain*

ARTICLE INFO

Article history:
Received 11 December 2014
Received in revised form 3 June 2015
Accepted 30 June 2015
Available online 23 July 2015

Keywords:
Forest floor
Mineral soil
Soil depth
Mixed model
Species identity
Impact assessment

ABSTRACT

African tropical forests are thought to play an important role in global carbon sequestration. However, the increasing rate of deforestation and the impact of changes in land use require a critical and updated look at what is happening. This work emphasizes the role of bulk density as a main driver in carbon (C) and nitrogen (N) stock in four land-use categories: natural forest, tree plantations, crop land and degraded soil. The study was conducted in the Central Highlands of Ethiopia, where deforestation and human pressure on native forests are exacerbated and erosion has caused extensive soil loss. The methodological approach consisted of evaluating the confounding effect of bulk density and then estimating C and N stocks based on a fixed-mass method rather than the usual fixed-depth method, in order to compare differences across land use categories. We hypothesized that elevation gradient would play a determining role in C and N concentrations and stocks in native forest, whereas tree species would be the main factor in plantations. C and N concentrations and bulk densities in mineral soil were analyzed as repeated measures in an irregular vertical space ranging from 0–10 cm, 10–30 cm, 30–50 cm and 50–100 cm, using a linear mixed model approach. Single observations from the forest floor were analyzed by a general linear model. Results indicated that soil depth is a more important factor than elevation gradient in native forests, though C and N concentrations and stocks diminished near human settlements. Native forest stored on average 84.4%, 26.4% and 33.7% more carbon and 82.4%, 51.8% and 27.1% more nitrogen than bare soil, crop land and plantations, respectively. Conversion of crop and degraded land to plantations ameliorated soil degradation conditions, but species selection did not affect carbon and nitrogen stocks.

1. Introduction

Forests in general and forest soils in particular play a vital role in carbon balance. The global soil carbon pool has been estimated to contain more than 3.3 times the atmospheric carbon pool and 4.5 times the biotic pool (Lal, 2004). Forest soils also account for 54% of stored carbon in old-growth forests (Luyssaert et al., 2008). Pan et al. (2011) quantified global forest carbon sinks and estimated the total stock to be 861 Pg, of which 383 Pg (45%) is in soil (to a depth of 1 m), 363 Pg (42%) in above and belowground biomass, 73 Pg (8%) in deadwood and 43 Pg (5%) in litter. One-third of the world's soil carbon is stored in the tropics (Lemma et al., 2006).

In forest ecosystems, biomass and soil carbon are stored in dynamic equilibrium with the environment. soil organic carbon (SOC) is affected by environmental factors such as topography, parent material or soil depth (Fu et al., 2004; Johnson et al., 2000). The key relationships between environmental factors and soil depth are often indirect and potentially complex. Topography influences precipitation, temperature, solar radiation and relative humidity (Tsui et al., 2004); aspect determines length of exposure to sunlight and can influence soil weathering and vegetation (Rech et al., 2001; Sidari et al., 2008; Yimer et al., 2006).

Land use and plant species also significantly influence SOC estimations. In the tropics, deforestation and changes in land use are significantly impacting the global carbon cycle by increasing the rate of carbon emissions (Silver et al., 2000). Conversion of forest into agricultural ecosystems negatively affects SOC concentration and stock by 20–50% (Solomon et al., 2002; Lal, 2005; Lemenih and Itanna, 2004). In tropical forests, which serve as powerful carbon sinks, deforestation accounts for 20% of total anthropogenic CO_2 emissions into the atmosphere (Baccini et al., 2008).

Mitigation strategies to reduce the impact of climate change (FAO, 2006) by augmenting carbon sequestration and reducing CO_2 emissions from soils include proper forest management and afforestation or reforestation programs. Quantification and continuous assessment of changes in C and N pool sizes and fluxes are fundamental to understanding

* Corresponding author at: INIA-Forest Research Center, Ctra A. Coruña, km. 7.5, Madrid, Spain.
E-mail address: bravo@inia.es (A. Bravo-Oviedo).
[1] Present address: Ethiopian Environment and Forest Research Institute (EEFRI), P.O. Box 25436, code 1000, Addis Ababa, Ethiopia.

http://dx.doi.org/10.1016/j.geoderma.2015.06.022
0016-7061/

the effects of changes in land use/land cover on ecosystem functioning and limiting greenhouse gas emissions (Jaramillo et al., 2003; Lemma et al., 2006).

Deforestation is a continuous process in Ethiopia (Nyssen et al., 2004) although reliable data on forest cover change is scarce (Pankhurst, 1995). Tree plantations cover approximately 500,000 ha (WBISPP, 2005), of which 133,041 ha was established as public plantations between 1978 and 1989. The most common species are *Eucalyptus spp.* (58%), *Cupressus lusitanica* (29%), *Juniperus procera* (4%) and *Pinus spp* (2%) (Moges et al., 2010). The Highlands account for 45% of the country's total area, supporting about 85% of the human population and 75% of the livestock population. Forest cover can be broadly separated into dry or moist montane forest. Dry montane forests are dominated by schlerophyll evergreen, while moist montane forests are characterized by large broadleaf and soft-leaf species (Gatzweiler, 2007). However, much of the Highland forest is disappearing or being converted into agricultural land (Teketay, 2001). Annual deforestation in the Highlands is estimated at 150,000 to 200,000 ha, fertile topsoil loss is estimated at 1.9 billion Mg of soil yr^{-1}, and an average of 42 Mg ha^{-1} is eroded annually (UNEP, 2002; World Bank, 2001). Ethiopia also has one of the highest rates of soil nutrient depletion (Lemma et al., 2006).

The Chilimo forest is one of the few remnants of native dry afromontane forest, located in the central highland plateau of Ethiopia. Native coniferous species predominate in this mixed broad-leaf and coniferous forest, where the main species include *J. procera*, *Podocarpus falcatus*, *Prunus africana*, *Olea europaea ssp. cuspidiata*, *Scolopia theifolia*, *Rhus glutinosa*, *Olinia rochetiana*, *Allophylus abyssinicus* (Kelbessa and Soromossa, 2004). A center of biodiversity and endemism, the Chilimo forest is also home to over 180 bird species, 21 mammal species and several precinctive subspecies such as the Menelik's bushbuck, vervet monkey, Colobus monkey, Anubis baboon and leopard (Woldemariam, 1998). Soromessa and Kelbessa (2014) reported a total of 213 different plant species categorized into 83 families, including 17 plant species that are unique to the Chilimo forest. Due to continuous deforestation, the Chilimo forest cover has declined from 22,000 ha in 1982 to 6000 ha in 1991 (Shumi, 2009). Consequently, some plant species are becoming endangered (Soromessa and Kelbessa, 2014) as the need for fuel wood, arable land and timber drive forest degradation (Soromessa and Kelbessa, 2013). In order to minimize deforestation, the forest has been categorized as one of Ethiopia's 58 national priority forest protection areas and receives more attention due to its potential as a carbon sink. Alternative strategies to reduce the pressure on the native forest by alleviating the fuel wood shortage include fast-growing tree and shrub plantations around homesteads, establishment of clear farm boundaries and wood lots in nearby rural communities (Alebachew, 2012). At the same time, carbon assessment of the forest floor and mineral soil is generating vital information regarding the importance of the forest for carbon exchange and climate change mitigation at local, regional and international levels. The history, topography, stewardship and intense transformation in land use of the Chilimo forest make it an optimal case study.

On these premises, we hypothesized that soil organic carbon (SOC) and soil organic nitrogen (SON) stock in the forest floor and in mineral soil would vary along an elevation gradient in native forest. Likewise, land use and tree species would also determine SOC and SON stocks at different depths. The specific research questions to be addressed in this study are (1–5):

1. Do carbon and nitrogen concentration and stock in the forest floor vary along an elevation gradient?
2. Does soil bulk density significantly vary across land use categories and/or soil depths?
3. Do carbon and nitrogen concentrations and stocks in mineral soil change at different soil depths along an elevation gradient in native dry afromontane forests?
4. How does intensive land use change soil carbon and nitrogen concentrations and stocks at different soil depths?
5. Does species selection have any effect on carbon and nitrogen concentrations and stocks at different soil depths in plantations?

2. Materials and methods

2.1. Study site location and description

The experimental site is located in the Chilimo–Gaji dry afromontane forest of the Western Shewa zone of the Dendi district in the central Highlands of Ethiopia. The forest is surrounded by crop land (mainly teff, *Eragrostis tef*), degraded areas and three 28 year old plantations of *Eucalyptus saligna*, *C. lusitanica* and *Pinus patula*. Geographically it is located from 38° 07′ E to 38° 10′ E longitude and 9° 30′ to 9° 50′ N′ latitude, at an elevation of 2170 to 3054 m above sea level (Fig. 1, Table 1). The mean annual temperature of the area ranges between 15 and 20 °C and the mean annual precipitation is 1264 mm. A total of 33 different native species (22 tree and 11 shrub species) were recorded in the forest. The quadratic mean diameter, i.e. the square root of the ratio of square of diameter at breast height to number of stems, of the sampled plantation and natural forest ranged from 12.79 to 26.12 cm and the basal area for the sample plots studied ranged from 13.81 to 25.5 m^2 ha^{-1} (Table 1).

2.2. Forest floor sampling

The Chilimo forest site was stratified into 3 major natural forest patches: Chilimo, Gallessa, and Gaji. Thirty-five 20 × 20 m plots were laid out following a top-down gradient, from the top edge of the mountain to the bottom, and approximately 150 m away from the outer ridge in order to avoid edge effects. The distance between one plot edge to the next plot was 100 m and plot location was determined using measuring tape, GPS, altimeter and compass. Twenty-one forest floor samples were collected within a 0.25 × 0.25 m (0.0625 m^2) metallic frame in the center of the main plot.

2.3. Mineral soil sampling

Mineral soil samples were taken below the forest floor up to a nominative depth of 1 m. Firstly, sample pits (1 m long × 60 cm wide) were dug at the center of the main plot in every other plot. A total of 28 pits (13 in natural forest, 9 in plantations, 3 in cultivated land and 3 in degraded lands) were dug for soil collection. Samples were taken from four soil depth categories (0–10 cm, 10–30 cm, 30–50 cm and 50–100 cm). Soil bulk density was calculated with a 5-cm high cylinder that was introduced vertically in one sampling point for each depth interval. A total of 112 mineral soil samplings and other 112 cores were collected for analyzing organic C %, total N % and bulk density respectively.

2.4. Laboratory analysis

Forest floor sample layers were air-dried and homogenized prior to analysis. All samples were weighed and sub-samples were oven-dried for 24 h at 65 °C to constant weight. The chemical analysis for organic carbon in the forest floor was done by drying samples at 105 °C and subsequently burning using the loss-on-ignition method at 400 °C, (Ben-Dar and Banin, 1989). Then soil organic matter was converted into organic carbon according to Eq. (2)

$$\%SOM = \frac{w\,105 - w\,400}{w\,105} \times 100 \quad (1)$$

$$\%\,C = \%SOM \times 0.58 \quad (2)$$

where, C: the organic carbon concentration, SOM: soil organic matter; w105: weight of dry soil sample at 105 °C, w400: weight of ground