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LAND USE CHANGE IMPACT ON SOIL ORGANIC CARBON AND WOODY SPECIES DENSITY IN SAVANNA WOOD LAND IN BURKINA FASO, WEST AFRICA

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ABSTRACT

Carbon emissions from land use change are insufficiently addressed in developing countries. While estimation of carbon stocks within different land management and cropping systems are an important element in design of productive land use systems that protect or sequester carbon. The aim of this study was firstly to assess SOC and N stocks and secondly to assess tree density, both related to different land use in savanna woodland. Results show that Savanna woodland soil organic carbon stocks (19.61±0.9 tC ha^{-1}) was greater than cropland (15.07±0.84tC ha^{-1}) and fallows (11.13±1.1 tC ha-1). However, fallow had lowest soil organic carbon stocks. Regarding Nitrogen, Fallow and Cropland had similar stocks with savanna woodland. For ratio C/N Cropland and Fallow had similar ratios and lower than Savana woodland. Lowest tree and shrubs density was obtained in farms. Shrubs density in fallow that was 763.9±114.6 shrubs ha^{-1} was similar to trees density in savanna woodland (712.3±83.7 shrubs ha^{-1}). These results suggest that landscape succeeds in restoring carbon from aboveground biomass in short term after conversion of savanna woodland to cropland but takes ùore longer to restore soil organic carbon.

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INTRODUCTION

Global climate change caused by rising levels of carbon dioxide (CO_2) and other greenhouse gases is recognized as a serious environmental issue of the twenty-first century. The role of land use change in impacting CO_2 levels and carbon (C) sink potential has attracted considerable scientific attention in the recent past, especially after the Kyoto Protocol. The post-Kyoto Protocol discussions on climate change are also heavily oriented towards an agenda on mitigating the rising atmospheric CO_2 levels through C sequestration in terrestrial vegetation systems (Kumar and Nair, 2011).

Causes of the decline in C and Ndue to land use are assigned usually to soils erosion and diminution of the vegetation. Soil organic carbon is lost through erosion, runoff and leaching and these are highly accelerated in cultivated land as compared to undisturbed forest or savanna woodlands. The amount of eroded carbon depending more on the erosion quantity than on the carbon content of the eroded sediments (Roose and Barthe, 2002). Many models (Boysen *et al*., 2014; Dass *et al*., 2013; Pitman *et al*., 2012; Port *et al*., 2012) had been establish to predict the trend but most of them are currently inadequate when applied to Africa (Bombelli *et al*., 2009) model simulations can provide just an approximate profile of Africa since these models are usually developed and validated for different latitudes (Bombelli *et al*., 2009). This is specially due to the scarcity of literature on carbon cycles and storage in the savanna-woodland and related land use options (Gattinger *et al*., 2012). Another argument in favor of the necessity to conduct such studies is that estimates of carbon stocks within different land management and cropping systems are an important element in the design of productive land use systems that protect or sequester carbon (Bationo *et al*., 2007). This is especially important in Burkina Faso as elsewhere in West African where population growth and natural forest transformation to agriculture area become an issue. Also, soil fertility depletion has been described as the single most important constraint to food security in West Africa (Bationo *et al*., 2007). The aim of this study is firstly to assess SOC and N stocks and secondly to assess tree density, both related to different land use in savanna woodland.

METHODOLOGY

Site: The study was carried out in Tiogo village (12°13'N, 2°42'W) located within the West Africa Sentinel Landscape defined by the Consortium Research Program on Forest Tree and Agro forestry CRP 6in the context of project entitled **"**Livelihood diversifying potential of livestock based carbon sequestration options in pastoral and agro-pastoral systems in Africa". The area is located 300 m a.s.l. and at about 120 km west of Ouagadougou, Burkina Faso (Figure 1). Phyto-geographically it is situated in the Sudanian regional centre of endemism in the transition from the north to south Sudanian Zone (Fontes *et al*. 1995).

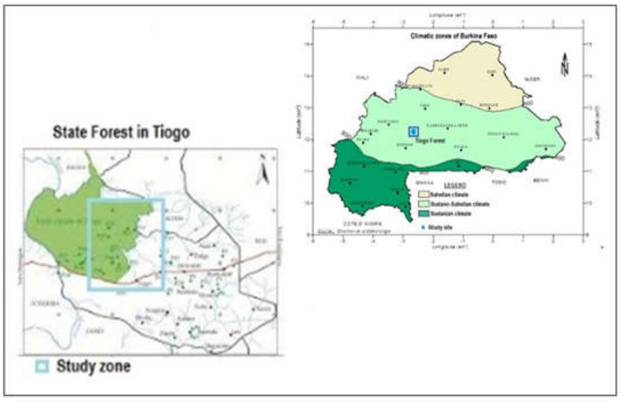

Figure 1. Study site location

The unimodal rainy season lasts about 6 months, from May to October. The mean annual rainfall for the years 1992-2019 was 837 ± 158 mm with large inter-annual variability. The number of rainy days per annum during this period was 62 ± 12. Mean daily minimum and maximum temperatures were 16°C and 32°C in January (the coldest month) and 26°C and 40°C in April (the hottest month), yielding an aridity index 0,29. Most frequently encountered are Lixisols (LX) according to the FAO soil classification system (Driessen *et al*., 2001). The soils are mainly deep (>75 cm) silty-clay and are representative of large tracts of the Sudanian Zone in Burkina Faso (Pallo, 1998).Vegetation is savanna woodland with a grass layer dominated by the annual grasses *Andropogon pseudapricus* and *Loudetia togoensis* as well as the perennial grasses *Andropogon gayanus* and *Andropogon ascinodis* (Sawadogo *et al.*, 2005). The main forb species are *Cochlospermum planchoni*, *Borreriaspp* and *Wissadula amplissima*. Mimosaceae and Combretaceae dominate the woody vegetation component. Agroforestry parklands are the main production systems. Sorghum, occupying 90% of cropped lands in association with cowpea, peanut and beans. Farming system consists of alternating cycles of cultivation and fallows which length is decreasing. Characteristic for this farming system is the preservation of some important tree species (e.g., *Vitellaria paradoxa, Adansonia digitata, Parkiabig lobosa, Lannea microcarpa, Tamarindus indica*) in croplands. Farming system is strongly affected by human activities, e.g., livestock grazing, fires and various harvestings of natural products (including fuel wood, thatching materials, poles for construction and edible and medicinal plants). Fires are also used to clear fallows for cultivation and to prepare fields for sowing at the end of the dry season (Sawadogo, 2009).

Data collection and analysis

Experimental design: This study was carried in the sentinel site based in Tiogo build on the Land Degradation Surveillance Frame- work developed within the Africa Soil Information System (AfSIS, www.africasoils.net). The sentinel site approach and it the sampling design are widely described by (Vågen *et al*., 2010). Briefly the site consists of 10 km × 10 km block, divided into 16 sub-blocks (clusters, 2.5 km × 2.5 km) with 10 plots (50x50cm) randomly distributed within each cluster. This site in Tiogo covers part of the state forest and part of the cultivated area which borders it (Figure 2). In this study, we have differentiated plots located in the field, fallow, flooding zone and natural forests uplands. The system is such that in cultivated area, fields and fallows are arranged randomized. Randomly may eliminated biases due to convenience sampling and allowed representative sample to capture land use effect on SOC, vegetation density and soil properties.

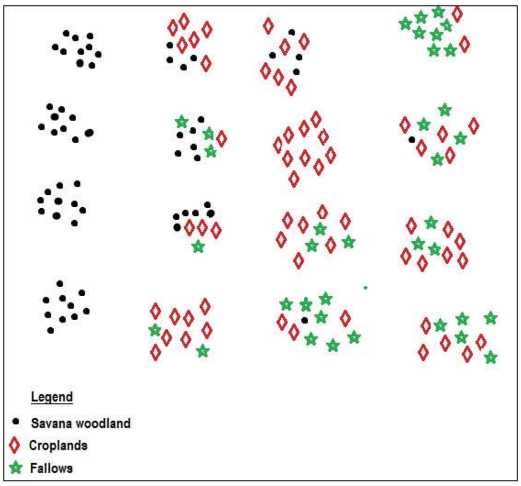

Figure 2: Distribution of plots in the study site

Soil carbon assessment: In each plot (50mX50m), sub-samples of soil were collected at four points (sub-plots) at 0-20 cm deep. One soil core sample was also taken from central sub-plot of each plot for soil mass determination. Four sub-samples for each plot were mixed thoroughly to derive one composite soil sample per plot. The soil samples were air dried, crashed and sieved through a 2 mm sieve before analysis. Total carbon was determined using combustion method at soil laboratory in World Agroforestry Centre, Kenya. All soil samples were scanned for mid infrared soil spectroscopy. Soils samples were analyzed for soil organic carbon concentration (g kg^{-1}) with thermal oxidation method (Skjemstad and Baldock, 2008) using a carbon analyzer according to Standard ISO 10694: Soil quality - Determination of organic and total carbon after dry combustion (elementary analysis).

Most commonly used method in estimating SOC is to determine total organic carbon at different soil depths, taking bulk density and course fragments into account (Batjes, 2001). Result can be expressed in Kg m^{-2}, t ha^{-2} or Gt (Pg) over a specified area and depth (Batjes and Dijkshoorn, 1999). However, many studies indicated that estimation of soil carbon stocks to a fixed depth using single depth bulk density are mostly biased (Lee *et al.*, 2009; MURTY *et al.*, 2002; VandenBygaart and Angers, 2006). So In this study we used the soil mass instead of bulk density, to calculate soil carbon stocks (Eq. 1). During soil sampling the mass of soil was determined for each depth.

$$SOC = \frac{\frac{C}{100} x soil\,mass}{A} \times 100 \qquad (1)$$

Where: SOC is soil organic carbon stock (t C ha^{-1}); C is soil organic carbon concentration of soil fines (fraction < 2 mm) determined in the laboratory (g kg^{-1}); Soil mass is the fine mass of soils collected from a given sampling depth; A is area of the hole that the sample is collected calculated using the auger radius (r=3.8 cm); 100 is used to convert the unit to t C ha^{-1}.

Tree density measurement: Density of woody species was measured on four sample point in each plot. Four sub-plots of about 100 m2 were installed for that. Woody species were sorted in shrub (height <150 cm) and trees (height > 150 cm) and were measured separately. Method of T-Square (Diggel, 1977) was used. T-square sampling method is one of distance sampling methods for estimating plant density and canopy cover. In this methods distance of nearest shrub from sample point measured. In the second stage, imaginary linedraws perpendicular on the line that connected to sample points and nearest shrub, and distance of shrub to nearest shrub measured. For plant density measurements, the following formula of Diggle (1977) was used

$$N = \frac{n^2}{2 * \sum(xi) * [\sqrt{2}\sum(zi)]}$$

Where N = density (N/ha); n= Sample size; xi= Distance from the random point I to the nearest organism and zi = Distance from the nearest organism to the second one

Data analysis: Carbons, Nitrogen, Trees density were not normal distributed according to Shapiro-Wilk test performed, so they were log-transformed to achieve normality need. Then, multivariate variance was performed to assess spatial variability of soil carbon and trees density. Plots were considered as random effects. Tukey-test was used to compare SOC, N, C/N and trees density means between land uses types. All statistical tests were performed using transformed soil carbon stocks, but non-transformed values were used to report average values. All statistical analyses were done with SPSS 22 software package (Copyright SPSS for Windows, Release 2013: IBM corporation).

RESULTS

Influence of land use and Soi Carbon stock: Soil total organic carbon differed significantly between land uses (Figure 3). *Flooding zone* had the highest soil organic carbon stocks (24.01±2.95 tC ha^{-1}). *Savanna woodland* (19.61±0.9 tC ha^{-1}) soil organic carbon stocks was greater than *crop land* (15.07±0.84tC ha^{-1}) and *fallows* (11.13±1.1 tC ha^{-1}). However, fallow had lowest soil organic carbon stocks. Regarding Nitrogen, Fallow and Cropland had similar stocks with savanna woodland. Ratio C/N differed significantly between land uses. Cropland and Fallow had similar ratios. Savana woodland and flooding zones had greater ratio

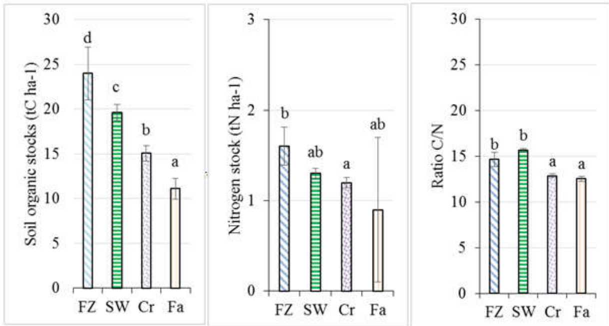

Figure 3. Soil organic carbon and Nitrogen Stock in Tiogo, Burkina Faso. FZ: Flooding Zone, SW: Savanna woodland, Cr : Cropland and Fa: Fallow

Soil Nitrogen is an important component as it greatly influences influences SOM decomposition and humification rates. Total nitrogen concentration varied from 0.9±0.8 tN ha-1 in Falows to 1,6±0,21 tN ha-1 (Table 1). In the studied layer (0-20 cm) total nitrogen was greater in Flooding zone. The soil under flooding zone showed best results, presenting 23%, 33% and 77% more total nitrogen than respectively Savanna woodland, Cropland and Fallows.

Impact of land use change on Trees density: Land use change has impacted significantly shrubs and trees density. Lowest tree and shrubs density was obtained in farms. Shrubs density in fallow that was 763,9±114.6 shrubs ha^{-1} was similar to trees density in savanna woodland 712.3±83.7 shrubs ha^{-1}(Table 2). However trees density in fallow (382.7±96.8 trees ha-1) was higher than density in farm (99.7±69.6 trees ha^{-1}) but less than savanna woodland trees density (610.2±70.7 trees ha^{-1}) (Figure 4).

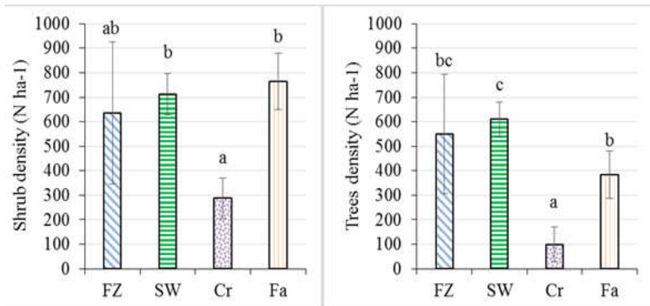

Figure 4. Trees and shrubs densities in studied land use in Tiogo, Burkina Faso. FZ: Flooding Zone, SW: Savanna woodland, Cr: Cropland and Fa: Fallow

DISCUSSION

Influence of land use and Soi Carbon stock: Soil organic carbon (SOC) and Nitrogen (N) apart from their role in climate mitigation are source and sink for nutrients and plays a vital role in soil fertility maintenance (Bationo *et al*., 2007). Carbon stocks (19.61±0.9 tC ha^{-1}) in Savanna woodland is comparable to the range of 8 to 20 t C ha^{-1} found in Senegal by Touré *et al.* (2013). Low amount of carbon in fallow land has also been highlighted by work undertaken in northern Ghana (Boakye-danquah *et al*., 2014). However, the carbon content found in fallows (13.05 t C ha^{-1}) and fields (25.56 t C ha^{-1}) by these same authors is on average higher than what we found in our study. (11.13±1.1 and 15.07±0.84 t C ha^{-1} respectively in fallow and cropland). These differences can be explained not only by climate-related factors (Han *et al.*, 2008; Reeder et Schuman, 2002), but also by differences in agricultural practices and age of fallows. Balance of organic matter in soils is disturbed by human activities such as agricultural practices. Soil organic carbon storage in soils is result of difference between soil organic carbon inputs and mineralization rates in each of organic carbon reservoirs. (Post et Kwon, 2000). Agricultural activities can therefore increase or decrease the soil organic matter content in the long term. (Bonino, 2006; Preez *et al.*, 2011). In study site, tillage is usually performed manually and farms are lightly fertilized. (Ndo, 2014). These present results could suggest that quantities of fertilizers applied are not sufficient to increase soil's carbon content.

Flooding zones which are located in low glacis had high carbon and nitrogen stocks. These stocks could be formed by erosion which scraps carbon and nitrogen from areas located in high glacis, thus enriching the sediments in these wetlands. (Rooseet Barthe, 2002). These stocks thus formed tend to stabilize because hydromorphy does not favor the mineralization of organic matter

Impact of land use change on Trees density and implication in soil organic carbon: Trees density decrease with land use change in the study area that is characterized by degradation of vegetation. While change in vegetation leads to modification of physicochemical characteristics of soil, which can also contribute to a reduction in the soil's organic carbon reserves. (Bonino, 2006). Despite shrubs recovery, fallow had a lower carbon stock than the other types of land use considered in this study. Several authors have noted a considerable increase in soil organic carbon due to fallow (Abril et Bucher, 2001; Ardo et Olsson, 2003; Preez *et al.*, 2011). This is due to the fact that reconstitution of vegetation cover of agricultural land increases carbon stock of above-ground biomass. Vegetation contributes to regeneration of carbon stock in soil by transfer of carbonaceous substances and organic matter resulting from fine roots mortality in their process of renewal. Accumulation occurs until the soil reaches a new balance between inputs (litter, rhizo-deposition) and losses (respiration, leaching) of carbon (Jandl *et al.*, 2007). Fallows considered in our study have ages that varied from 3 years to 19 years. This time could be short enough for a replenishment of carbon and nitrogen given generally advanced degradation in which farms are fallows. Fairly long time it takes for soil carbon to replenish has already been noted bySierra *et al.*, (2012), who reported no significant trend in soil carbon recovery 35 years after disturbance (Detwiler, 1986). For Nitrogen previous work has shown that starting soil organic carbon levels could not be reached even after 52 years after forest restoration (Tavares *et al.*, 2011). Studies carried out in Burkina as part of « fallow project » confirm the ineffectiveness of fallow for restoration of soil organic carbon stock (Ouattara *et al*, 2000).However, fallow allows a rapid return to soil stability after 3 years. However, these studies show that the behavior depends on type of fallow, soil, nature of the vegetation in the site (Bernhard-Reversat*et al.*2000).

Conclusion

The aim of this study was firstly to assess SOC and N stocks and secondly to assess tree density, both related to different land use in savanna woodland. We succeeded to establish baseline data on soil organic carbon stocks in Tiogo forest and agricultural zone bordering it. Reference data on soil organic carbon were 24.01±2.95 tC ha^{-1}, 19.61±0.9 tC ha^{-1}, 15.07±0.84 tC ha^{-1} and 11.13±1.1 tC ha^{-1}Respectively for *Flooding zone*, *Savanna woodland*, *cropland* and *fallows*. For Nitrogen data were 1.6±0.2 tN ha^{-1}, 1.3±0.06 tN ha^{-1}, 1.2±0.06 tN ha^{-1} and 0.9±0.8 tN ha^{-1}Respectively for *Flooding zone*, *Savanna woodland*, *cropland* and *fallows*. These results suggest that landscape succeeds in restoring carbon from aboveground biomass in short term after conversion of savanna woodland to cropland but takes more longer to restore soil organic carbon. For this, particular attention must be given to this carbon pool in any arrangements tending to carbon sequestration.

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