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Land Use and Soil Carbon Sequestration in the Kou Watershed, Burkina Faso

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Background: Soil organic carbon is an indicator that must be considered when assessing the sustainability of agroecosystems.

Aim: The aim of the study is to assess the impact of different land use patterns on soil organic carbon stock and the contribution of this component to climate change mitigation.

Methodology: soil samples were taken from depths of 0-15 cm and 15-30 cm along diagonal transects of study plots, with seventy-two composite samples collected in total.

Results: Soils in the riparian zone (23.77%) and irrigated crops (25.73%) were found to be the richest in clay. Only clay content was positively correlated with soil depth (r=0.104). The Kruskal-Wallis test shows that the amount of carbon varies significantly (p-values between 2.510^{-4} and 7.910^{-4}) across land use/land cover classes (LULC). Wetland (28.91 ± 2.83 t/ha) and woody savannah (28.53 ± 4.24 t/ha) had the highest carbon stock, and shrub savannah had the lowest (12.77 ± 0.82 t/ha). The carbon stock at a depth of 0-15 cm exceeds that found at 15-30 cm. Over the 1,330.80 ha of the Kou River riparian buffer zone, the total atmospheric carbon sequestered in the soil was 119,833.27 metric tons of CO_2.

Conclusion: The carbon sequestration capacity of the Kou River's riparian zone is significant in the context of climate change mitigation.

Keywords: Soil granulometry; atmospheric carbon; climate change; Kou River.

1. INTRODUCTION

Soil Organic Carbon (SOC) storage is a topic of prime importance in international negotiations aimed at combating climate change through greenhouse gas (GHG) emission reductions [1]. The medium and long-term evolution of soil organic stocks is an important indicator when evaluating the sustainability of agroecosystems and environmental protection [2]. Soils are of crucial importance for climate regulation. They can behave as a carbon sink or a carbon source, depending on their properties, climate, land use and land cover, etc. [3,4].

SOC content varies from one land-use type to another and can also change due to land-use change [5]. Total soil organic carbon concentration, total organic carbon stock and aggregates associated with organic carbon decrease rapidly during the first 4 years after conversion from forest to cropland [6].

In Burkina Faso, falling crop yields are evidence of declining soil fertility [7]. Research has shown that soil organic carbon stock varies significantly with depth [2-4]. One of the major levers that can be used to halt rising atmospheric CO2 levels would be to increase the carbon stock in the top 30 centimeters of soil by 0.4% each year on a global scale [8]. Currently, land in the Kou River sub-watershed in Houet Province of Burkina Faso is subjected to over farming and overexploitation. Analysis of vegetation dynamics shows a considerable reduction in forest cover in favor of crops and anthropogenic use such as houses [9]. Poor agricultural practices in this watershed have resulted in a reduction in soil quality [10].

The present study adds to the evidence in the body of literature cited above; the objective of this study is to assess the impact of different land use patterns on soil organic carbon stock and the contribution of this component to climate change mitigation efforts in the Kou River sub-watershed. The study is based on the following research hypothesis: soil organic carbon stock is higher in forested areas than in areas under crop cultivation.

2. METHODOLOGY

2.1 Study Area

This study was carried out in the Kou River watershed. More specifically, the data were collected in the riparian conservation zone of the Kou River along a distance of approximately 73 km. This area is located in Southwest Burkina Faso between longitudes 4° 08' W and 4° 36' W and latitudes 10° 55' N and 11° 32' N. According to Thiombiano [11], the area has a South Sudanian climate zone.

2.2 Sampling

Soil cores were taken with an auger at depths of 0-15 cm and 15-30 cm. In each of the nine land-use categories [9], four rectangular plots were marked out and samples were taken along the diagonals. A composite sample was taken from each plot, based on a mixture of 5 samples. To determine bulk density, a tray topped by a 100 cm^3 metal cylinder was used to sample soil volumes. These cores were subsequently oven-dried at 105°C for 24 hours to obtain the dry weight [2].

2.3 Sample Analysis Methods

Organic carbon was determined using the [12] method at the Soil Fertility and Production Systems Study and Research Laboratory (LERF-SP) at Nazi Boni University. In this study, soil carbon content estimation was measured using the approach developed by the IPCC and successfully used by other authors [13,14]. It involved measuring total organic carbon content at different soil depths and transforming these data, considering the soil bulk density and stoniness.

Bulk density was calculated after drying soil samples using the following equation:

$$\mathbf{DA = Ms / Vc}$$

Where **Ms** = the mass of dried soil at 105°C, **Vc** = the volume of the cylinder.

The following equation was used to calculate soil carbon stock:

$$\mathbf{SOC_{Depth} = ([SOC] \times DA \times P \times (1-frag) \times 10)}$$

Where: **SOC** = organic carbon stock $\mathbf{SOC_{Depth}}$ = organic carbon content (metric tons C/ha); **[SOC]** = organic carbon concentration, obtained by laboratory analysis (g C kg/soil); **DA** = apparent density (metric tons of soil/m^3); **P** = soil horizon depth (m); **frag** = percentage volume of coarse fragments / 100. The carbon equivalent (atmospheric CO_2) was estimated in the riparian conservation zone at 3.67, employing the method used by Tsoumou [15].

L'analyse granulométrique a été faite en trois (03) fractions suivant la méthode densimétrique.

2.4 Statistical Analysis

Data were processed and analyzed using the R 4.3.1 statistical software package. The normality of the data was verified using the Shapiro-Wilk test. The Kruskal-Wallis test was used to compare the variation in carbon stock between different land use types (5%). Granulometric variables were subjected to analysis of variance (ANOVA), and means separation was performed with Fisher's LSD test at the 5% threshold.

3. RESULTS AND DISCUSSION

3.1 Grain Size According to Land Use and Depth

Analysis of variance of soil physical parameters over the two depths shows a significant difference for all three parameters ($p < 0,05$) between the different types of land use (Table 1). At a depth of 0-15 cm, the highest sand content was found in the shrub savannah (81.62%) and in the mango orchards (78.92%). The lowest rate is found in the humid zone (32.84%). Soil in irrigated crops (25.73%) and in the humid zone (23.77%) is richest in clay (0-15 cm). Silt content is also high in the humid zone (43.38%) and in irrigated crops (34.56%). The high sand content in the grassy savannah and the mango orchard land use categories could be explained by their state of degradation following water erosion. The high clay and silt content in the wetland zone may be an indication of its high fertility. This area is virtually unexploited. As far as irrigated crops are concerned, ploughing techniques are thought to be responsible for the texture observed. The clay and silt content of cultivated plots is lower than that of uncultivated plots [16]. The overall granulometry of the Kou riverbanks is richest in sand, followed by silt and clay. The high sand content is thought to be due to over-farming in the area. Land use and topographic gradient significantly affect soil physicochemical properties [17].

3.2 Variation in SOC Stock According to Depth and Land Use Category

The results of the interactive effect of land use and depth on SOC stock are presented in Table 2. The Kruskal-Wallis test shows that at a depth of 0-15 cm (p-value= 2.510^{-4}), except between wooded savannah and wetland, organic carbon varies significantly across land use categories. At a depth of 15-30 cm (p-value= 7.910-4), there was a significant difference in carbon stock between certain land use categories. There was no significant difference between open forest, gallery forest, forest plantation, and wooded savannah at this depth. This variation in SOC from one land use category to another is in line with the results obtained by Yaméogo [5]. Furthermore, Köchy [18]. concluded that globally the largest SOC reserves are located in strategic points such as wetlands and peatlands. The high amount of SOC stock in the wetland and tree savannah categories would be due, on the one hand, to the transport and deposition of chemical elements by runoff water, and on the other hand to the high representativeness of woody vegetation in this land use category. Being downstream, the wetland receives all of the water flowing through the other land use categories during periods of flooding. In this vein, the work of Wang [19] has shown that trees have the potential to influence soil properties both quantitatively and qualitatively through leaf and root litter. Conversely, in a study by Seboko [20], soil moisture had no effect on SOC stock. This result could be explained by the minor level of soil disturbance in this land use category.

For all land use categories, the 0-15 cm depth had the highest SOC stock. At depths of 0-15 cm, the wetland (28.91±2.83 t/ha) and tree savannah (28.53±4.24 t/ha) had the highest SOC stock. This is followed by open forest (23.08±1.61 t/ha) and forest plantation (22.32±1.86 t/ha). Mango orchard (15.22±1.66 t/ha) and shrub savannah (12.77±0.82 t/ha) recorded the lowest stocks. At depths of 15-30 cm, only the humid zone stands out from the others, with a stock of 25.58±2.10 t/ha. At this depth, open forest (17.38±2.59 t/ha), gallery forest (16.78±1.54 t/ha) and tree savannah (18.14±2.72 t/ha) showed no statistically significant differences. The decrease in SOC stock from surface to greater depths in the riparian conservation zone is aligned with results published by Wang [21]. The same finding was obtained by Koala [4] and Dorvil [22] independently in Burkina Faso and Haiti. Awoonor [23] reached the same result in the humid savannah region of Ghana. This drop in SOC with increasing depth in the soil profile is explained by the organic matter content accumulated at the soil surface by litter and root biomass. The increase in C stocks in the upper layer of the soil was likely observed because this is the zone of intensive humus formation and fine root development [24].

Table 1. Physical parameters of the soil according to land use type

Parameters	**Sand (%)**		**Clay (%)**		**Silt (%)**	
	0-15 cm	**15-30 cm**	**0-15 cm**	**15-30 cm**	**0-15 cm**	**15-30 cm**
Irrigated crops	39,70±3,71a	40,71±4,62a	25,73±1,23a	25,73±1,23a	34,56±2,58a	33,56±4,63a
Rainfed crops	60,05±3,03b	61,55±4,37bc	15,93±1,23b	16,43±1,68b	24,02±2,33b	22,02±3,66bcd
Sparse forest	67,40±0,94c	67,90±2,35cd	8,33±1,26cd	8,33±1,26c	24,26±1,47cd	23,76±3,17cd
Gallery forest	60,17±0,47b	56,86±3,75c	9,31±0,98d	13,72±1,13bd	30,51±0,84d	29,41±2,77ac
Forest production	59,80±0,00b	60,64±1,18c	12,01±0,49e	12,62±0,24d	28,19±0,49e	26,74±1,03ad
Tree savanna	68,87±2,17c	75,98±0,98d	9,31±1,69d	10,29±0,98cd	21,81±0,94d	13,72±7,10be
Bush savanna	81,62±0,94d	77,45±1,60d	5,64±0,94f	11,27±0,98cd	12,74±1,39f	11,27±1,87e
Mango orchard	78,92±0,98d	72,43±10,89bd	5,88±0,80cf	8,32±2,99c	15,19±1,26cf	19,24±8,45de
Humid zone	32,84±0,98e	32,34±3,35a	23,77±0,49a	21,27±0,962e	43,38±0,94a	46,38±4,18f
F	298,7	104,89	258,43	74,037	196,77	97,721
P	$2e^{-16\,***}$	$2{,}721\ 10^{-9\,***}$	$1{,}655e^{-11\,***}$	$3{,}2310^{-8\,***}$	$8{,}279e^{-11\,***}$	$1{,}743\ 10^{-8\,***}$

Values with the same letter in the same column are not statistically significant according to Fisher's LSD test at the 5% threshold

Table 2. Combined effect of land use/land cover category and depth on SOC stock

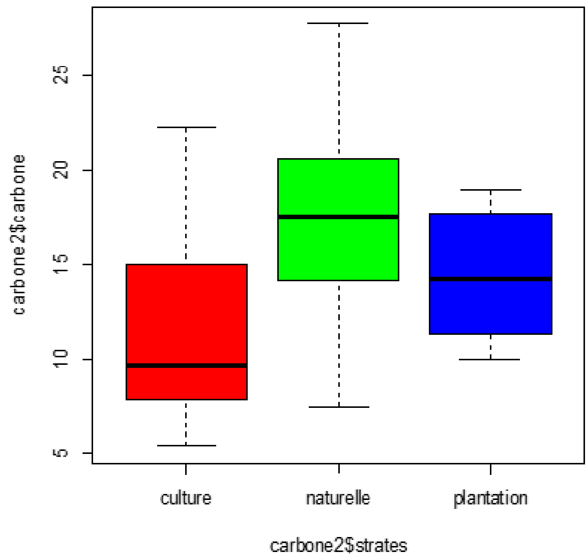
Land use/land cover	**Carbon stock (t/ha)**	
	0-15 cm	**15-30 cm**
Irrigated crops	17,6±4,03b**cde**	14,41±6,89**bc**
Rainfed crops	16,89±2,86**cde**	8,82±1,19**c**
Sparse forest	23,08±1,61**ab**	17,38±2,59**ab**
Gallery forest	18,11±1,79**bcd**	16,78±1,54**ab**
Forest production	22,32±1,86**abc**	17,70±0,98**ab**
Tree savanna	28,53± 4,24**a**	18,14±2,72**ab**
Shrub savanna	12,77±0,82**e**	8,92±0,96**c**
Mango orchard	15,22±1,66**de**	11,13±0,88b**c**
Humid zone	28,91±2,83**a**	25,58±2,10**a**
K-W (P-value)	0,0002474	0,0007913

P-values (P < 0.05) indicate a significant difference. Numbers with the same letters in the same column are not significantly different

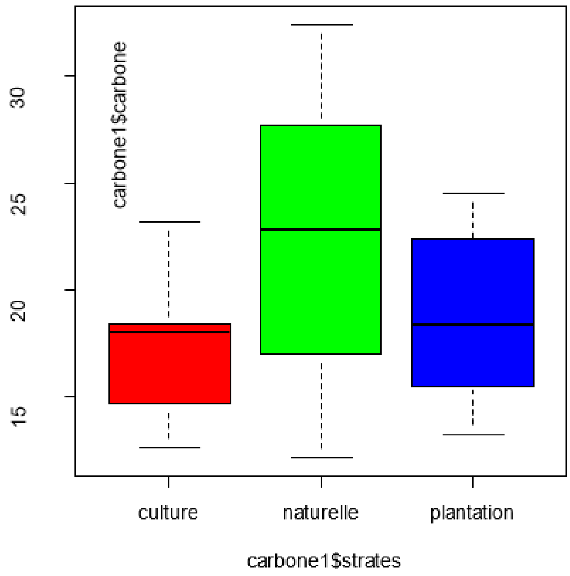
Table 3. Estimating the potential for atmospheric carbon sequestration in soil

Land use/land cover	Land area (ha)	Carbon equivalent (0-15 cm) _tCO_2/ha	Carbon equivalent (15-30 cm) _tCO_2/ha	Total carbon equivalent (tCO_2)
Irrigated crops	53,90	64,64±14,78**bcde**	52,89±25,29**bc**	6334,87
Rainfed crops	767,85	61,99±10,49**cde**	32,36±4,34**c**	72446,64
Sparse forest	0,06	84,71±5,91**ab**	63,79±9,52**ab**	8,91
Gallery forest	0,41	66,45±6,57**bcd**	61,57±5,65**ab**	52,49
Forest production	0,16	81,90±6,83**abc**	64,97±3,59**ab**	23,50
Tree savanna	0,94	104,72±15,56**a**	66,57±10**ab**	161,01
Shrub savanna	504,02	46,86±3,02**e**	32,74±3,52**c**	40119,99
Mango orchard	0,02	55,88±6,11**de**	40,86±3,24**bc**	1,93
Humid zone	3,42	106,10±10,38**a**	93,88±7,73**a**	683,93
K-W (P-value)		2,5710^{-4}	7,9110^{-4}	
Total	**1330,80**			**119 833,27**

P-values (P < 0.05) indicate a significant difference. Numbers with the same letters in the same column are not significantly different



a. 0-15 cm



b. 15-30 cm

Fig. 1. SOC stock dispersion in anthropogenic and natural land use/land cover categories

3.3 Impact of Human Activities on SOC

At depths of 0-15 cm, the SOC stock varied slightly between land use categories (p-value= 0.1). At depths of 15-30 cm, however, the stock was statistically different from one land use category to another (p-value=0.04). Fig. 1 shows that, whatever the depth, the SOC stock in natural environments is higher than that in tree plantations, which in turn is also higher than that in cultivated areas. This could be explained by increasingly intensive anthropogenic activities across land use categories, leading to greater ecosystem degradation in orchards and cropped areas. Wetlands were found to be rich in fine soil particles (clay and silt). According to Wei [6], the total SOC stock decreases rapidly during the first 4 years after conversion of forest to cropland. Also, Awoonor [23] indicate that conversion of native forests to arable land significantly reduced C stocks in the upper layers of the soil profile.

3.4 Variation in CO_2 Sequestration Potential as a Function of Land Use

Table 3 presents results for the atmospheric carbon sequestration potential of the soil. The total amount of atmospheric carbon (CO_2) sequestered in the soil (0-30 cm) in the riparian conservation zone is estimated at 119,833.27 metric tons. Rainfed cropland and agroforestry contributed 60.47% to the total potential observed, while shrub and grass savannah contributed 33.47% and irrigated cropland contributed only 5.28%. Other land use categories contributed less than 2%.

With regard to atmospheric carbon sequestration per hectare, the Kruskal-Wallis test shows a significant difference (p-value= 2.5710^{-4} for the 0-15 cm depth and p-value= 7.9110^{-4} for 15-30 cm depth) across different land use categories. Whatever the depth, the greatest potential for atmospheric carbon sequestration per hectare is found in the wetland and wooded savannah categories, with 106.10±10.38 t/ha and 104.72±15.56 t/ha in the 0 to 15 cm section, respectively, and 93.88±7.73 t/ha and 66.57±10 t/ha in the 15 to 30 cm section, respectively. According to Derrien [3], soils are crucial to climate regulation. Indeed, they contain three times more carbon in total than the atmosphere, in the form of organic carbon present in organic matter (OM).

4. CONCLUSION

From this study, we found that the wetland and irrigated crop land cover categories are the richest in clay and silt. The greatest quantities of SOC and CO_2 were found at a depth of 0-15 cm. Overall, natural land cover types had higher rates of SOC than areas under crop cultivation. In the Kou River riparian conservation zone, the potential atmospheric carbon (CO_2) sequestered in the soil was estimated at 119,833.27 metric tons. Further research should be conducted to estimate the total carbon emission rate from the various land use categories in the Kou River watershed.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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