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SPATIO-TEMPORAL SCORCHED LAND AND RESULTANT SEQUESTERED SOIL ORGANIC CARBON IN SELECTED MIOMBO WOODLANDS OF WESTERN TANZANIA

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ABSTRACT

Ecological impacts of soil degradation in forests have been variably reported. The present study aimed at exploring the consequence of fire extent on the sequestration of soil organic carbon. Data for scorched land was captured by Landsat in Kitwe and Ilunde forests with different levels of fire extent in western Tanzania. Both forests were severely disturbed previously. Soil samples were collected from thirty plots located 150 m and 100 m apart in Ilunde and Kitwe forests respectively, for determination of soil bulky density and percentage organic carbon. In each plot soil samples were collected from four points, thereafter treated differently depending on the purpose of sampling. Percentage organic carbon was obtained using Walkley-Black method, and then the sequestered soil organic carbon was estimated in tonnes per hectare as a product of percentage organic carbon, soil depth and bulky density. The difference in sequestered soil organic carbon between the two forests was analyzed using t-test. Spatio-temporal scorched and vegetated land lands of the forests were produced from satellite images after computing Normalized Difference Vegetation Index (NDVI) for the years 1990, 2000 and 2011. In 30 cm soil depth, more soil organic carbon of 17.9 ± 0.9 t ha^{-} (two folds) was recorded from Kitwe than Ilunde forests ($P < 0.01$, $t = 9.935$, D.F. = 29). In Ilunde forest, the extent of fire increased with time, while scorched and vegetated lands increased and decreased with time respectively. In Kitwe forest, the trend was opposite whereby the scorched land decreased and vegetated land increased with time. Prevalence of wildfires over large areas in forests lowers soil organic carbon sequestration. The contribution of ash in enrichment of soil organic carbon sequestration in forests could be only overstated.

Key words: Fire extent; NDVI; scorched land; soil organic carbon; vegetated land

INTRODUCTION

Of the five principal global carbon pools, oceanic pool is the largest, followed by the geologic, then pedologic (soil), biotic and the atmospheric pool. Thus, soil organic matter represents the third largest carbon pool, with a global estimated total of 1526 peta gram C (Lal, 2004). Despite the large potential of soils to mitigate greenhouse gas emissions, soil carbon sequestration is not part of the carbon crediting scheme, mainly due to problems encountered in measuring soil carbon pools and changes accurately (Rossi *et al.*, 2009).

Sequestration of soil organic carbon depends on topographic variations, plant species composition, decomposition, soil texture, nutrient availability, biological activity, soil moisture and/or soil erosion and deposition within a landscape (Garten and Ashwood, 2002; Novara *et al.*, 2011). In miombo woodlands, accumulation of soil organic carbon and depletion are a result of dynamic interactions between fires and fire impacts (Bird *et al.*, 2000), land use

and cover change (Williams *et al.*, 2008), litter inputs (Nhantumbo *et al.*, 2009) and termites (Trapnell *et al.*, 1976), all of which vary spatially.

Fire extent (degree of spread) is one of the fire regime attributes of particular importance to land managers who closely monitor changes and trends in natural processes such as carbon sequestration (Sugihara *et al.*, 2006; Lutz *et al.*, 2011). Frequent uncontrolled fires affect organic matter levels by oxidizing litter before it can be broken down by decomposers, thereby releasing carbon dioxide to the atmosphere and other nutrients (Trapnell *et al.*, 1976; Medina, 1987; Schlesinger, 1999). Thus, soil organic matter can act as both source and sink of carbon depending on the prevailing conditions.

In Malawi soil organic carbon ranging from 1.2 to 3.7%, 0.35 to 1.2% and 0.65 to 2.3% has been reported in protected miombo woodlands, agricultural land and fallow land respectively (Walker and Desanker, 2004). Williams *et al.* (2008) reported a narrower range of organic carbon of 21–74 t C ha^{-1} in disturbed woodland of Mozambique compared to undisturbed miombo woodlands which ranged from 18–140 t C ha^{-1}. On the contrary, long term fires of ca. 50 years, increased total soil organic carbon (Ojima *et al.*, 1994; Bloesch, 1999). However, Richards (2009) reported no change in carbon storage in burned and unburnt soils for duration of one and three years in Australian tropical savanna.

Apart from factors influencing soil carbon sequestration, vegetation cover also plays a great role (Jobbágy and Jackson, 2000). It follows that soil carbon sequestration can be accelerated by increased plant growth, net primary production and decreased decomposition of organic carbon (Tieszen, 2000). Therefore, NDVI which is a dimensionless satellite metric used to indicate the relative abundance and activity of green vegetation may be linked to sequestered carbon in ecosystems (Huete *et al.*, 2002).

Earth observation satellites are currently applied to detect burnt areas on maps by means of images of NDVI based on a specific combination of red and near infrared bands, which specifically reflect the amount of green vegetation (Saatchi *et al.*, 2007). Scorched area caused by fire shows considerable reduction of reflectance because of carbonization, as it appears black in false color composites. In general, though the reflectance of forest is low in the visible part of the spectrum (except for the green region) and high in the near-infrared part, the spectral curve of the forest after burning becomes flat, resulting in burnt areas having high contrast compared to the surroundings (Salajanu and Jacobs, 2005).

The western region of Tanzania is dominated by miombo woodlands and yet has been identified as one of the most fragmented forests by uncontrolled fires in the country (National Aeronautics and Space Administration, 2010). However, estimations of soil organic carbon emanating from the ever spreading wildfires in miombo woodlands are limited. The present study aims at addressing the NDVI-determined scorched and vegetated land, and sequestered soil organic carbon in the study area.

MATERIAL AND METHODS

The present study was confined to forested ecosystems that are managed by different parties namely the Central Government (Ilunde) and Non-Governmental organizations and the Central Government (Kitwe). Kitwe forest is located between latitudes 4° 54' and 4° 55' S, and longitudes 29° 36' and 29° 37' E, while, Ilunde is located between latitudes 5° 00 and 6° 00 S, and longitudes 30° and 31° E (Figure 1).

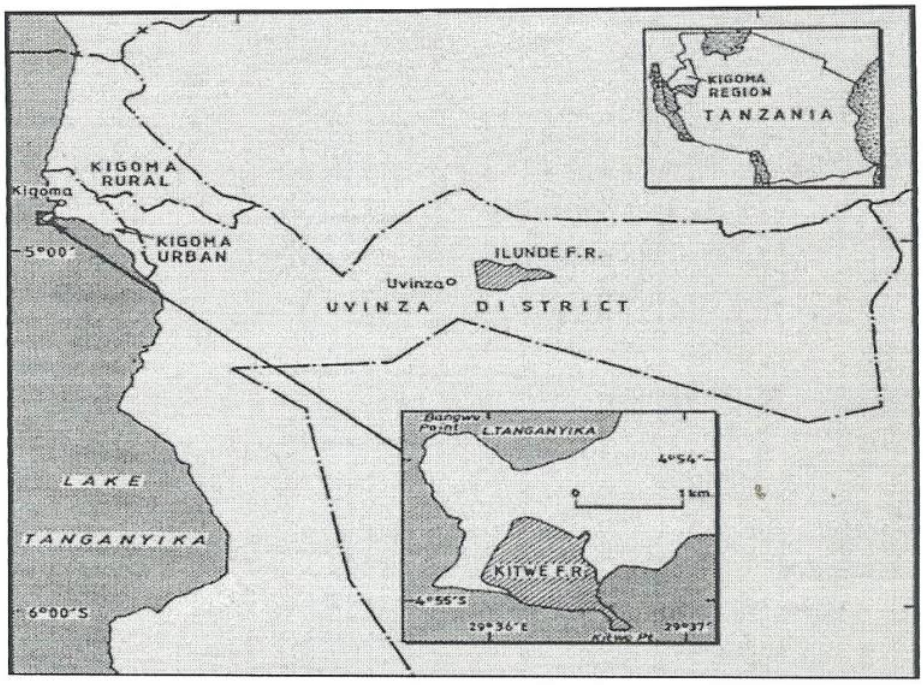


Figure 1. Location of the study area

Soil sampling and Landsat TM image analysis

In each forest, thirty sampling points were systematically established. In each plot, soil samples were collected using a soil auger from four points in accordance with Vesa *et al.* (2010). The samples were collected from three depths; 0-10, 10-20 and 20-30 cm. Such depths were selected so as to assess the trend of organic carbon accumulation from the soil surface. The soil samples were thoroughly mixed to form composite samples for each depth.

A sub-sample of the composite sample weighing 50 g was placed in a polythene bag and labelled. The samples were transported to the laboratory at the University of Dar es Salaam for analysis.

Samples for bulky density determination were collected using a steel core cylinder measuring 6.4 cm × 9.8 cm in the same plots where samples for organic carbon determination were collected. The core cylinder was carefully driven into the top soil from 0-10 cm to obtain undisturbed sample of organic soil. Another set of soil sample was taken from 10-20 cm depth and the last from 20-30 cm. The collected soil samples were immediately put in thick-gauze polythene bags, labelled and transported to the University of Dar es Salaam for bulky density determination.

On the other hand, burned areas which are normally characterized by deposits of charcoal, ash and removal of vegetation, were obtained from the Landsat TM images. The vegetated and scorched land of the two forests for the years 1990, 2000 and 2011 were computed using NDVI of Landsat image (Figures 2 and 3). Change detection was employed to facilitate the determination of changes in the burnt and unburnt lands from the year 1990 to 2011 in the study area.

Sample Treatment/Manipulation

A set of soil samples that were previously collected by using a steel core cylinder at three depths from each of the plots was used for bulk density determination. The bulk density of the soil was determined by the use of a known core volume method (Klute, 1986). The soil cores were oven dried to constant weight, and, bulk density was computed as follows:

$$\text{Bulky density} = \frac{\text{soil oven dry weight (g)}}{\text{Soil core volume or soil total volume (cm}^3\text{)}}$$

Organic carbon was determined by the Walkley-Black procedure (Walkley and Black, 1934). One gram of air-dried soil for 48 hours, ground and sieved through a 0.42 mm plastic sieve was put into a dry tared 250 mL conical flask. Ten ml of 1N Potassium dichromate ($K_2Cr_2O_7$) was added to the soil and the flask swirled gently. Twenty mL of

concentrated sulfuric acid (H_2SO_4) was added to the resulting suspension, and then the mixture was immediately swirled. The mixture was allowed to cool for about thirty minutes.

Two blanks (without soil) were prepared in the same way to standardize ferrous sulfate ($FeSO_4$). After cooling, 100 mL of distilled water were added to each of the flask for dilution. The mixtures in the flasks were then titrated with $FeSO_4$ solution using 3 to 4 drops of ferroin indicator. The colour changes were from greenish to dark green, to blue-green and finally to reddish-grey.

Soil organic carbon (t ha^{-}) = depth (cm) x bulk density (g/cm^3) x organic carbon content (%) (Broos and Baldock, 2008).

Computation of the burned and unburned areas was done using interpreter tool on Erdas Imagine 8.3.1 (GIS software) (www.intergraph.com) and Arc View GIS 3.2. The NDVI difference was computed by using model maker utility using Erdas imagine. Model make utility is a tool which enables to run a rapid definition of integrated raster and vector analyses and spatial modeling based on spatial modeler language. This software allows the user to perform numerous operations on an image and generate an answer to specific geographical questions. By manipulating imagery data values and positions, it is possible to see features that would not normally be visible and to locate geo-positions of features that would otherwise be graphical. The level of brightness or reflectance of light from the surfaces in the image can be helpful with vegetation analysis. By computing NDVI differences it was possible to use NDVI difference images and NDVI time series charts to assess the forest fires in those years.

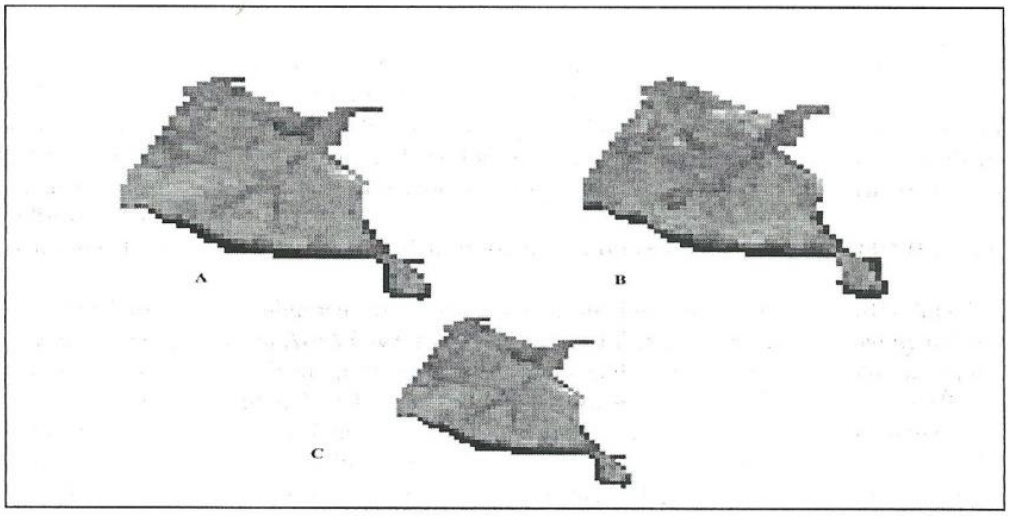


Figure 2. Computed NDVI for burnt and vegetated areas in Kitwe forest

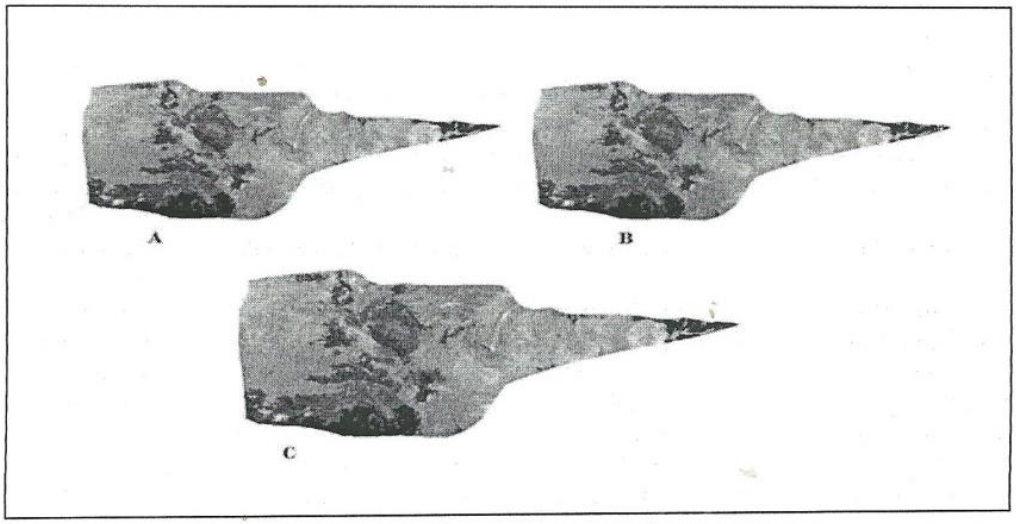


Figure 3. Computed NDVI for burnt and vegetated areas in Ilunde forest

RESULTS

Sequestered Soil Organic Carbon

The results in Table 1 show that higher mean soil organic carbon that accumulated in 0-30 cm of 17.9 ± 0.9 t ha^{-} was recorded in Kitwe forest, while the value of 9.2 ± 0.3 t ha^{-} was recorded in Ilunde forest ($P < 0.01$, $t = 9.935$, D.F. = 29). Also, in both forests, the highest amount of soil organic carbon was recorded in the upper layer of the soil of 0-10 cm and the lowest carbon being recorded in the middle layer of soil of 10-20 cm. That is, the trend in the soil organic carbon in descending order was; upper layer > lower layer > middle layer. Furthermore, dead wood carbon stock was high in Ilunde forest where there are high extent fires than in Kitwe forest. On the contrary, higher carbon stock of the litter was recorded in Kitwe forest than in Ilunde forest.

The Extent of Fire

Figure 4 summarizes the extent of fire in terms of percentage of the burnt area of the forest and percentage of vegetated area in the studied forests. In Ilunde forest, the extent of fire was high in that the scorched land increased with time, while the vegetated land decreased with time. In Kitwe forest, the opposite trend was observed whereby the scorched land and vegetated areas decreased and increased with time respectively.

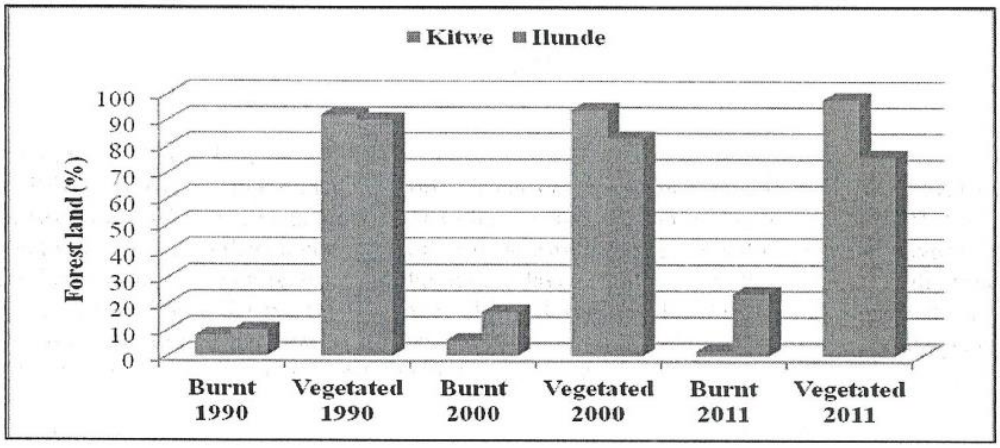


Figure 4. The extent of fire at approximately ten years interval in the study area

Table 1. Organic carbon in the 0-30 cm soil depth, dead wood and litter at the study area

Soil depth (cm)	Kitwe (t ha^{-})	Ilunde (t ha^{-})
0 – 10	7.6 ± 0.59	4.28 ± 0.27
10 – 20	4.8 ± 0.5	2.47 ± 0.19
20 – 30	5.45 ± 0.43	2.54 ± 0.21
Total	**17.9 ± 0.9**	**9.2 ± 0.3**
Dead wood	0.46 ± 0.18	0.67 ± 0.1
Litter	12.6 ± 1.03	2.57 ± 0.35

A = 1990 B = 2000 C = 2011

Discussion. In the studied miombo woodlands, the higher value of soil organic carbon of 17.9 ± 0.9 t ha^{-} was recorded in Kitwe forest, with the lowest recorded in Ilunde forest (9.2 ± 0.3 t ha^{-}). Low fire extent in Kitwe forest in the studied years contributed to increased plant growth and productivity in that there was very high accumulation of leaf litter which plays a positive role in sequestering carbon to the soil. Most studies had reported that the quantity of soil organic carbon following disturbance starts to increase after five years later on (Aweto, 1981; Szott *et al.*, 1999). On the contrary, soil recovery following previous disturbance is possibly interrupted by repeated fires spreading over large forestland which decompose organic matter that exceed the microbial decomposition of organic

matter. It is likely that Ilunde forest was converted into source of carbon dioxide rather than sink for carbon. The large part of Ilunde forest is changing to a bare land and ultimately limiting organic matter accumulation. This observation was also reported by Trapnell *et al.* (1976) and Schlesinger (1999).

According to Certini (2005), the most sensitive change in soil during burning is loss of organic matter, and hence organic carbon due to litter reduction. The effect of fire on soil organic carbon is highly variable from total destruction of soil organic matter to partially scorching depending on fire severity, dryness of the surface organic matter and fire type (Gonza´lez-Pe´rez *et al.*, 2004). This implies that areas with different levels of fire extent experience different regeneration potential subsequently different productivity and different soil organic carbon stock. This could be the reason for varied levels in soil organic carbon in the studied forests.

During fires specifically ground level-fires, the leaf litter and grasses that contribute much to the soil organic carbon become utilized as fuels. The soils will finally be depleted of organic carbon.

In Kitwe forest the higher value of soil organic carbon could be associated with enormous accumulation of leaf litter and consequently increased soil organic carbon stock. On the contrary, in Ilunde the lower soil organic carbon stock could be associated to high fire extent, which may contribute to the increase in soil erosion and therefore to soil organic carbon mobilization. This could be accompanied with increased easiness to soil erosion due to temporal removal of the herbaceous layer, resulting into loss of topsoil layers hence lower soil organic carbon. According to Novara *et al.* (2010), soil organic matter redistribution by water erosion is accelerated after forest fires, and contributes to degradation of soils.

The amount of litter biomass mainly depends on the vegetation cover type which will in turn reflect the severity of fire. In the present study, it was observed that Ilunde forest which had high fire extent had small amount of litter and ultimately low soil organic carbon compared to Kitwe forest where leaf litter and debris accumulation on the forest floor was very high (Figure 5).



Figure 5. Litter accumulation in Kitwe forest floor

In both forests the relatively higher levels of soil organic carbon were detected in the 0 – 10 cm layer, followed by the 20 – 30 cm one and the lowest was between 10 and 20 cm depth. This trend could be caused by the surface accumulation of organic matter exceeding the decomposition of organic matter, also, leaching of humus into the lower layers and shedding of roots into the lower depths in the three woodlands. In the forest with high fire extent it is likely that after fires, there is resprouting of species which adds litter above the ground during the dry season that will eventually add some quantities of soil organic carbon to the soil pool. The accumulated surface organic carbon in this forest is likely to be leached after wildfire episodes hence increasing the stock of organic carbon in the deeper layer of soils. According to Ketterings and Bigham (2000), after fire episode, a trend to coarser soil textures is observed due to some heat induced formation of stable aggregates of clay and silt fractions with easy seepage.

Accumulation of organic carbon on the surface of the forest with high fire extent suggests that the surface layers of soils apart from having some leaf litter were dominated by charcoal formed by incomplete combustion of plant materials which could be responsible for elevating the surface organic carbon stock. According to Vargas *et al.* (2008), soils that are frequently burned contain high concentrations of black carbon. Presence of more soil organic

carbon on the surface layers of soils was also reported by Jobbagy and Jackson (2000). Also, a similar trend in accumulation of organic carbon was reported by Mabuza (2011).
These results on effect of fire extent on sequestration of soil organic carbon are in agreement to that of Walker and Desanker (2004) who reported that shifting agriculture reduced soil organic carbon by an average of 14%. Similarly, Schlesinger (1986) estimated 30% loss of carbon over 20 to 50 years period after forest clearance.

CONCLUSION

Within 30 cm soil depth a significantly higher soil organic carbon stock of 17.9 ± 0.9 t ha^{-} was recorded in a forest with a small scorched land between 1990 and 2011. On the contrary, lower soil organic carbon of 9.2 ± 0.3 t ha^{-} was observed in a forest with a large scorched land. An increase in fire extent with years implies that almost all the forestland becomes touched by fire, ultimately lowering the sequestration of soil organic carbon. On the other hand, low fire extent results into patchy and negligible reduction in soil organic carbon sequestration.
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