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Distribution of Necromass under Different Forest Stands in a Savannah Ecosystem

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Authors' contributions

This work was carried out in group effort by all authors. Authors CQ, EDD and AA designed the study and wrote the protocol. Authors EDD, GDD, AA and HOT conducted the study, generated and analyzed the data and prepared the manuscript. Author HOT managed the literature searches and reviewed the pre-submission draft. All authors read and approved the final manuscript.

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ABSTRACT

The amount of environmental issues related to the loss of forest cover resulting from anthropogenic perturbations leading to low levels of production, and in consequence, intensification and increased deforestation are serious concerns in Ghana, especially in the Savanna Agro-ecological zones. The actual study was, however, carried out in Kenikeni, Sinsablegbinni and Klupene forest reserves. Using a randomly laid numbered 1 km x 1 km grid, which was sub-divided into sixteen sub-plots of 25 m x 25 m, the Nested Plot Design was employed in demarcating zones in each forest reserve for the study. In general, five plots were selected to constitute the Nested Plot in each reserve. Overall, the results showed that necromass C stock was in the order of Klupene forest (0.291 Mg C/ha) > Sinsablegbinni (0.136 Mg C/ha) > Kenikeni (0.090 Mg C/ha). The differences in necromass C stock among the various forests showed that the accumulation of necromass was higher in Klupene forest.

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1. INTRODUCTION

The Dictionary of Plant Sciences [1] defines Necromass as the mass of dead timber in a forest or the mass of dead plant material lying as litter on the ground surface. It is also the weight of dead organisms, usually expressed per unit of land or volume of water. The term is sometimes used to include the dead parts of living organisms, e.g. the bark and heartwood of trees. Soils with abundant necromass promotes biological activity and helps protect such soils from wind, rain and extremes of temperature. In forest ecosystems soil temperature influences organic decomposition, evolution or emission of CO_2 from soil respiration and the microbial transformation of nitrogen [2,3] and sulphur [4]. The area of surface covered by litter and canopies of plants has strong influence on soil temperature [2,3]. Changes in land use and cover, management and plant productivity may influence the biomass, structure, and functional processes of soil microorganisms through modification of the quantity and types of organic matter inputs [5,6]. Currently studies on carbon stocks (mainly on vegetation or above ground carbon, necromass etc.) are concentrated in the High Forest Zone of Ghana. However, quality data on the soil, vegetation and dead material carbon stocks in the Savanna (which forms two-thirds of Ghana's landmass) are lacking, with the Guinea Savanna zone, in particular, being an area that is starved of quality data on climate change. It is, thus, important to understand the dynamics of soil carbon as well as its role in terrestrial ecosystem carbon balance and the global carbon cycle. The objective of this study was, therefore, to determine the necromass carbon stock in three selected forest reserves in the Guinea Savanna agro-ecological zone of Ghana.

2. MATERIALS AND METHODS

2.1 Description of Study Areas

The study was carried out at the Kenikeni, Sinsablegbinni, and Klupene forest reserves in the Guinea Savanna Agro-ecological Zone of Ghana. The Guinea savanna is restricted to the northern portion of Ghana. Thus, all the three forest reserves are in the Northern Region of Ghana. The Kenikeni site is located in the Bole forest District (Bole Political District in the Northern Region). It lies between Longitude 1° 53' and 2° 30' West and Latitude 9° 06' and 9° 20' North with an area of 515.98 km^2 and 122.92 km as its perimeter. The vegetation is mainly woodland savanna composed of isolated medium height trees and relatively tall grass undergrowth. Trees crowns rarely overlap and deciduousness is characteristic of tree species in this Guinean savanna zone [7]. The soils are quite fertile and capable of supporting a large variety of crops. Tree density varies throughout the forest reserve, with dense clusters in lowland and riparian portions. The Sinsablegbinni forest reserve is in the Tamale Forest District (in the Tamale Metropolis). It stretches from Latitude 9°26' to 9°33' North and from Longitude 0°32' to 0°45' West. It has generally a flat topography characterized by sub-surface hardpans. The vegetation is mainly woodland savanna composed of isolated medium height trees with short grass undergrowth. The Klupene forest reserve is in the Yendi forest District (Yendi Municipality) (Fig. 1). It lies between Latitude 9° 27' to 9° 29' North and on Longitude 0° 00' to 0° 15' West in the Yendi forest district (Yendi Municipality). It comprises partly of a natural forest and a plantation stand. The vegetation is mainly woodland savanna composed of isolated medium height trees and relatively tall grass undergrowth.

It covers almost two-thirds of the country with an approximate area of 147,900 km^2. It is the largest ecological zone and is characterized by a monomodal or unimodal rainfall pattern spanning 5-6 months with a period of 6-7 months of pronounced drought in a year. Average annual rainfall, temperature, relative humidity, wind speed, sunshine hours and solar radiation are 1,033 mm, 28.1°C, 61%, 138 km/day, 7.3 hours and 19.6 MJ/m^2/day respectively. Potential evaporation is 1720 mm per annum and the annual aridity index is 0.60 [8].

2.2 Plot Lay-out and Sampling Design

The Nested Plot Design [9] was adopted as the plot design for the three forest reserves. To achieve this, in each stratum (forest district), a numbered 1 km x 1 km grid was constructed after which a transparent map of each forest reserve was superimposed. The intersection of the 1 km x 1 km was numbered sequentially and randomly selected. This selected grid (longitude and latitude) constituted the starting point or point of commencement of each of the one

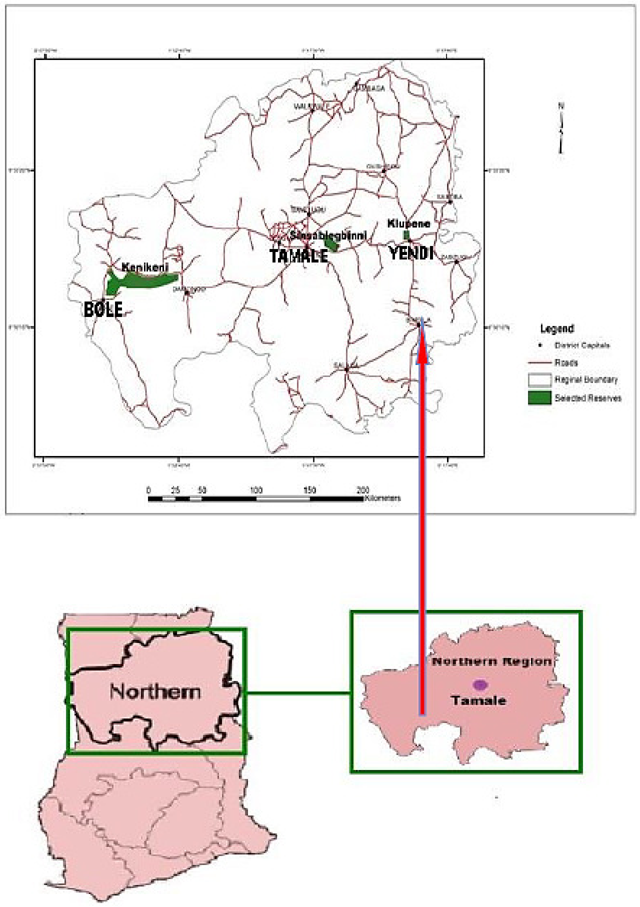

Fig. 1. Map of the Northern Region showing the locations of the five forest reserves

hectare plot. The randomly laid one-hectare plot (100 m x 100 m) in each forest reserve was sub-divided into sixteen sub-plots (25 m x 25 m). Five sub-plots were selected to constitute the Nested Plot Design (Fig. 2) [9].

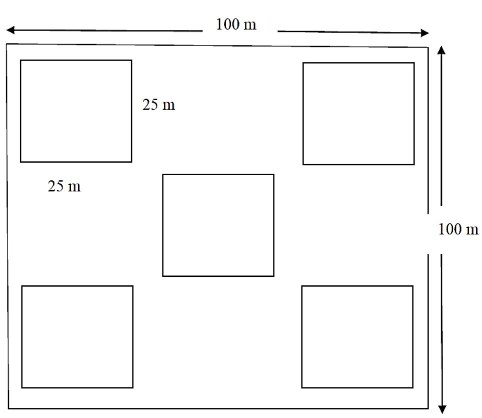

Fig. 2. Simple representation of experimental plot Lay-out

2.3 Non-tree Vegetation and Necromass Carbon Stock

The non-tree vegetation (shoots and roots of the grass vegetation) and surface litter (necromass) in the five 1 m x 1 m quadrats were collected and their fresh mass weighed in the field, using digital weighing scale. Samples were taken for oven drying at 75°C to constant mass [10]. The dry mass of the samples were calculated as:

$$W_{nt} = \frac{W_{sd}}{W_{sf}} \times W_{tf} \times \frac{10000}{A} \quad (1)$$

Where W_{nt} (Mg ha^{-1}) is either litter or non-tree biomass, W_{sd} (g) is sample dry mass, W_{sf} (g) is sample fresh mass, W_{tf} (Mg) is total fresh mass of either the litter or non-tree in the quadrat and A (m^2) is the size of the quadrat. The carbon content values given by [11] as 0.4748, 0.3746 and 0.2998 for wood, herbs and litter, respectively, were used to convert the tree, non-tree (grass) and litter biomass to the corresponding carbon biomass.

2.4 Statistical Analyses

Data obtained (from soil, vegetation and necromass) were analysed using Genstat statistical package (12th edition). Treatment means compared using ANOVA and LSD at 5% level of probability.

3. RESULTS AND DISCUSSION

Measured necromass carbon stock (NCS) across the three study sites are presented in Figs. 3 and 4. In this study, necromass included both standing and fallen dead plants. During the 12-month sampling period, the minimum and maximum values of NCS in all three stands differed by factors of 0.09 Mg C ha^{-1} at Kenikeni and 0.29 Mg C ha^{-1} at Klupene.

The high proportion of NCS in the Klupene forest relative to those of Kenikeni and Sinsablegbinni may well have arisen as a result of three interacting factors, viz., the high density of dead plant materials produced in the system due to the intensified removal of trees, short life-span of plants, especially, grasses, and the relatively slow decomposition rate of dead plant materials than in the other forests. The slow decomposition rate could possibly have been the result of a myriad of factors including climatic conditions, species composition, successional stage and soil fertility [12]. Thus, the difference in the regeneration rate over the degradation rate, coupled with the high density of dead plants could be responsible for the significant rate of accumulation of necromass at Klupene. However, these measurements of necromass are inconsistent with literature values for moist tropical forests, since the proportion of carbon in necromass to total carbon in tropical forests range from 2% to 40% [13,14]. For instance, the proportion of aboveground necromass to aboveground biomass in different moist tropical forests were in the order of 2–18% in Venezuela [15], 33% at the wet forest at La Selva in Costa Rica [16], and 18% [17] to 33% [18] at the Tapajos National Forest in Brazil. Consequently, measurements of fallen coarse necromass in undisturbed forests in terra firma in Brazil recorded 48.0 Mg C ha^{-1} [18] and 42.8 Mg C/ha [19] for the upper limit, 27.6 Mg C ha^{-1} [17], 15 Mg C ha^{-1} [20], and 16.5 Mg C ha^{-1} [21] in the middle, and 9.5 Mg C ha^{-1} [22] and 5.8 Mg C ha^{-1} [23] on the lower limit. In the floodplains of the Amazon, necromass was 1.8–5.7 Mg C/ha [24]. Similar to this study, other studies [17,21,25,26] have examined necromass in secondary forests and logged forests.

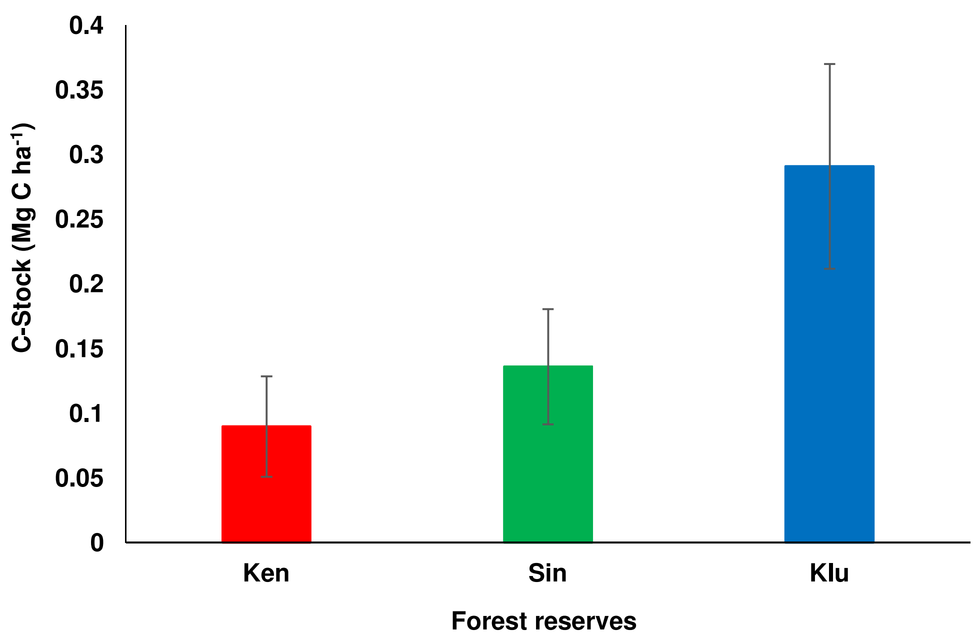

Fig. 3. Necromass carbon stock in the three forest reserves

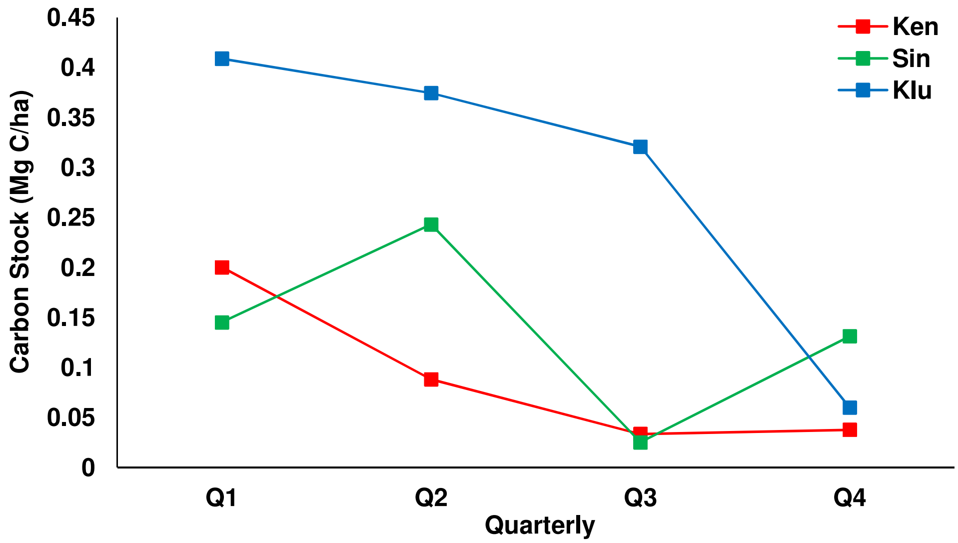

Fig. 4. Trend of necromass carbon stock in the three forest reserves

It is worthy to note that, the variations in NCS among the different sites are not simply due to changes in total biomass, even though there were significant differences in the biomass. The site distribution of NCS may then principally relate to the potential of plant biomass decomposition in the various forests. Hence, the slow rate of decomposition, compared to regeneration, may be responsible for the accumulation of necromass, as discussed above. Conversely, the rate of decomposition was measured in this study, and therefore, awaits confirmation from future studies. The measurements revealed marked temporal variations in NCS (Fig. 4) within and among the various study sites. Measurements in the first quarter (June – August), which we could observe through the major rainy season, revealed that NCS was high in Klupene and Kenikeni forests, but low in Sinsablegbinni. The distribution pattern of NCS in Klupene and Kenikeni forests with time followed a similar trend, wherein, NCS decreased towards the dormant (drier) seasons. Thus, soil moisture content had a pronounced influence on NCS, however, the effects of soil moisture content seemed to differ with location as shown in Fig. 4. For instance, NCS was low in the first quarter, but had the highest peak in the short dry period. This implies that there might have been more nutrient release during the dry season than during the wetter period, probably due to an increase in decomposing soil fauna in the drier periods [26]. On the other hand, the reduction in NCS towards the dry season in Klupene and Kenikeni might be explained by rapid decomposition processes in the hot weather during the dry season.

The distribution pattern in Sinsablegbinni followed an undefined (zig zag) pattern with significant peaks in the second and fourth quarters of the sampling period. Thus, seasonal maximum NCS for Klupene and Kenikeni forests were measured in the first quarter, whereas, that of Sinsablegbinni was in the second quarter. In spite of the differences in the distribution pattern of NCS in Kenikeni and Sinsablegbinni, the seasonal minimum in both forests were recorded in the third quarter (December – February), which represents the major dry season of the year. However, the seasonal minimum for Klupene was observed in the fourth quarter (March – May), which marked the transition from the dry season to the major rainy season. In general, seasonal peaks of NCS were observed in June – August for Klupene and Kenikeni, and September – November for Sinsablegbinni, and minima in March – May for Klupene, and December – February for Kenikeni and Sinsablegbinni. The trend of temporal variation of NCS was smooth in Klupene and Kenikeni forests, but noisy (random) in the Sinsablegbinni forest. This indicates that the seasonal minima and maxima in NCS of the three forests did not occur simultaneously. Relatively, seasonality in grass C stock was less pronounced than in NCS in all the three forests. Although maxima and minima did not occur synchronously in the three stands, NCS tended to be less at the end of the relatively dry period in August than after the wetter period in June.

4. CONCLUSIONS

High proportion of necromass C stock was found in the Klupene forest relative to those of Kenikeni and Sinsablegbinni forest reserves, which was probably due to the high density of dead plants in the Klupene forest and high amount of incident solar radiation. This partly indicates the potential of the carbon sink of the Klupene forest. The variation of necromass C stock among the various forests showed that the accumulation of necromass was higher in the degraded forest. The pattern of distribution could potentially be indirectly explained by soil respiration which is temperature dependent. Further work should consider decoupling the factors controlling C dynamics for a better understanding of the mechanisms driving age and management-related patterns of C stock, the changes in species composition and nutritional properties and for improving the ability to model in carbon cycles in these critical biome.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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