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Carbon Sequestration in Selected Grass Species in a Tropical Lowland Rainforest at Obafemi Awolowo University, Ile-Ife, Nigeria

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Abstract

Dry matter production and carbon stock in the pools of *Panicum maximum, Axonopus compressus* and *Cynodon dactylon* grass species were evaluated within the Obafemi Awolowo University, Ile-Ife, Nigeria. This was with a view to provide information on grass species serving as carbon sink and to assess their contribution to carbon stock in the terrestrial ecosystem. Four 15 m x 15 m sampling plots were established in each of the grass species sites; the plant samples were harvested by randomly placing ten 1m x 1m quadrats. The harvested plants were divided into above and below ground biomass. Floor litters (residue) samples were also collected. Ten soil samples were randomly collected from ten points in each plot at a depth of 0-20 cm, air-dried and analyzed for carbon content. Bulk density was also determined in each plot. The harvested plants were oven dried at 70°C to a constant weight, weighed, ground and analyzed for organic carbon content. There were significant differences ($p < 0.05$) in the dry matter production, carbon concentration and carbon stock across the three grass species. *Panicum maximum* had the highest dry matter production and carbon stock in the above and below ground biomass. It also had the highest carbon concentration in below ground biomass. The results concluded that grasslands can serve as a terrestrial carbon sink and their contribution varied across the studied grass species.

Keywords: Biomass, carbon stock, floor litters, *Panicum maximum*, sequestration, soil carbon.

Introduction

Carbon sequestration is the process of capturing and long-term storage of atmospheric carbon dioxide (Roger & Brent, 2012). Carbon sequestration describes long-term storage of carbon dioxide or other forms of carbon to either mitigate or defer global warming and avoid dangerous climate change (Holden, 2008). It has been proposed as a way to slow the atmospheric and

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marine accumulation of greenhouse gases, which are released by burning fossil fuels (Holden, 2008). Carbon dioxide is naturally captured from the atmosphere through biological, chemical or physical processes. Some anthropogenic sequestration techniques exploit these natural processes, while some use entirely artificial processes (Roger & Brent, 2012).

Terrestrial ecosystems constitute a major carbon sink owing to photosynthesis and storage of carbon dioxide in live and dead organic matter. Due to its numerous ancillary benefits (e.g. improved soil and water quality, restoration of degraded ecosystems, increased crop yield), terrestrial carbon sequestration is often termed as a win–win or no-regrets strategy (Lal et al., 2003). There are three principal components of terrestrial carbon sequestration: forests, soils and wetlands. Forest carbon is sequestered not only in harvestable timber, but also in woody debris, wood products and other woody plants encroaching upon grasslands (Wofsy, 2001).

Many debates have taken place on differences in the effectiveness of trees and native grasses in serving as carbon sinks (Piperno, 2006). It has been reported that trees and forest soils store more carbon than grasslands and grass vegetation (Pouyat et al., 2006). However, it is important to note some characteristics in grasses make it worthy of consideration as a terrestrial carbon sink and perhaps a more effective one than trees. Grasses are very effective at shifting carbon into the soil. Grasses for the most part have an annual root system with most of the smaller roots becoming established from the base of the plant. Thus, each year, many grasses will shed almost their entire root system into the soil which deposits large amounts of fibre (mostly carbon) into the soil and then plants go about consuming more carbon as they build a replacement root system (Anderson et al., 2010; Fissore et al., 2009).

Many native grasses form phytoliths (plant stones) that are solid aggregates of carbon within leaves. These are not just ordinary bundles of carbon but are highly durable globules of bound carbon that are not able to break down for thousands of years after production. It should be noted that not all grass species produce phytoliths, but native grasses seem particularly adept. However, trees are poor at forming phytoliths (Piperno, 2006). When trees break down either rapidly in a fire or slowly through death and decay, the carbon that was in their foliage is returned to the atmosphere. Thus, a tree is only a relative temporary solution to carbon sequestration. When grasses die, the leaves decompose and release carbon back into the atmosphere. Therefore the selection of longlife grass is important if the aim is to provide a long-term carbon sink. Clearly, native grasses are highly persistent in their natural environment and these are a natural choice (Schlesinger, 1990).

Recently, there has been renewed interest in using grasslands as pathways for terrestrial carbon sequestration to mitigate the effect of CO_2 on global warming, as well as to utilize grassland biomass to produce biofuel and reduce our dependency on fossil fuels. This interest appears to be in conflict with each other. However, it is reasonable to believe that grasslands can be used in both roles while still maintaining their ability to provide environmental services without degradation of the grasslands (Larry & Dismas, 2008). A large proportion of the carbon that enters the soil has been reported to be returned to the atmosphere through respiration carried out by roots and soil organisms (Trumbore, 2000). The distinction between autotrophic and heterotrophic respiration in soils is difficult to make (Trumbore, 2000) and estimates are extremely uncertain, but the fraction of CO_2 evolution attributable to root respiration can vary between 16 and 95 %. Other significant losses of carbon in grasslands have been reported to be through soil erosion and soil water drainage containing dissolved organic carbon (Kalbitz et al., 2000).

More has been written about the use of vegetation as a means of removing carbon from the atmosphere and storing in a plant's tissue. Relatively little work has been carried out on the use of grasses as a carbon storage sink and this is probably because they are annual plants and their carbon sequestration potential is on a short-term basis. However, there is a need to continue to evaluate the roles grasses can play in the issue of carbon storage. This study focused on carbon sequestration in three grass species monocultures, *Panicum maximum, Axonopus compressus* and *Cynodon dactylon*. This is aimed at proffering insights into the contribution of these grass species in serving as a carbon sink via terrestrial carbon sequestration and also to provide information on the amount of organic carbon stored in the grasses' biomass and the soil on which they grow. The specific objectives of this study are: (i) to estimate the carbon stock in the above ground biomass (leaf and stems) and below ground biomass (roots) of each grass species; and (ii) to estimate the carbon stock in the soils on which the grass species grow and hence determine the total carbon sequestered by the grass species.

Materials and Methods

Study area

The study area is Obafemi Awolowo University, Ile-Ife, Osun state, Nigeria. Ile-Ife lies on Latitude 7˚32'N and Longitude N 4˚31'E with the elevation of Ife ranging from 215 m to 457 m above sea level (Hall, 1977). The climate of the area is a tropical type with two prominent seasons, the rainy and the dry seasons. The annual rainfall average is 1400 mm yr^{-1} (Oke & Isichei, 1997) and it showed two peaks, one in July and the other in September. The mean annual temperature ranges from 27˚C to 34˚C (Oke & Isichei, 1997). The soil of the area is derived from material of an old basement complex which is made up of granitic metamorphosed sedimentary rock (Hall, 1977). The soils are moderate to strongly leached and have low to medium humus content, weak acid to neutral surface layers and moderate to strongly acidic sub-soils. The soils which are usually acidic contain less than 10% clay which is mainly kaolinite and hence are characterised by low cation exchange capacity and low water holding capacity (Ayodele, 1986). The soil has been classified as lixisols (FAO/UNESCO, 1974) and utisols (USDA, 1975). The original vegetation of Ile-Ife is lowland rainforest as climax vegetation (Keay, 1989). The forest sub-type is dry deciduous forest (Onochie, 1979). Keay (1989) described the vegetation as the Guinea-Congolian drier forest type. Most of the original lowland rainforests have however been massively destroyed leaving remnants of fallow land and a secondary forest scattered around. Tree plantations like *Theobroma cacao, Cola nitida, Tectona grandis and Elaeis guineensis* are also common around the area.

Sampling procedure

Four 15 m x 15 m sampling plots were established in each of the grass species sites, each plot contained individual grass species of the tree grass species. Grasses were randomly collected at ten points per plot using the 1 m x 1 m sized quadrat. The detached parts of the grass species referred to as residue, within the quadrat were also collected. Both the grass species and their residues were bagged separately, labeled and transported to the laboratory where they were oven dried at 70˚C to a constant weight, weighed and ground. The collection was done in October 2013; the peak of the rainy season in Nigeria since the plants thrive better during the season and go into dormancy in the dry season. The ground grasses and residue were analyzed to determine organic carbon content according to the (Allen et al., 1986) method at the Department of Botany. The percentage of organic carbon concentration and carbon stock were calculated using the equation:

$$\text{Ash \%} = \frac{Wc - Wa}{Wb - Wa} \times 100 \quad (1)$$

$$\text{C concentration \%} = (100\text{-Ash \%}) \times 0.58 \quad (2)$$

Where: W_a = weight of crucible; W_b = weight of oven dried ground sample and crucible; W_c = weight of ash and crucible and
C = organic carbon.
Carbon stock = Carbon concentration x Dry matter weight (3).

Soil collection

Ten soil samples were randomly collected from each of the plots at a depth of 0- 20 cm using a soil auger and bagged and labeled. Each soil sample was air-dried in the laboratory, passed through a 2-mm sieve and analyzed for organic carbon at the Soil Science Laboratory, Faculty of Agriculture, OAU Ile- Ife using the Chromic Acid Digestion method (Walkley-Black method, 1934). Soil bulk density measurements are needed to convert soil carbon concentration i.e. mass carbon per unit mass soil into inventories or storage i.e. mass per unit area. The soil bulk density was determined according to the method of (Blake & Hartge, 1986).

Statistical Analysis

One way analysis of variance (ANOVA) was used to test for significance in the carbon concentration, dry matter production and carbon stock of the above and below ground biomass and soil of each of the grass species. The significant means were separated using LSD post hoc analysis ($p = 0.05$). The statistical procedures were performed using SPSS 17 model; the values were first tested for normality and homogeneity in order to satisfy assumption of analysis of variance.

Results

Dry matter production

The dry matter production of the above ground biomass across the three grass species studied were significantly ($p = 0.003$) different. The highest value was recorded in *Panicum maximum* and there was no difference between the values of *Axonopus compressus* and *Cynodon dactylon* (**Table 1**). The dry matter production of the below ground biomass across the three grass species followed the same trend. The below ground biomass was significantly ($p = 0.004$) different with *P. maximum* having the highest value (**Table 1**). The values of the residue dry matter production were also found to be significantly (p = 0.002) different. *Panicum maximum* had the highest amount while *Axonopus compressus* and *Cynodon dactylon* had equal values (**Table 1**).

Table 1. Dry matter production of the above, below ground biomass and floor litter recorded at the three grass species studied. Results are presented as mean and standard error, where n = 10

Grass species	AGB (Kg m^{-2})	BGB (Kg m^{-2})	Residue (Kg m^{-2})
Panicum maximum	0.11 ±0.03[a]	0.07±0.02[a]	0.06±0.02[a]
Axonopus compressus	0.04±0.00[b]	0.01±0.00[b]	0.01±0.00[b]
Cynodon dactylon	0.03±0.00[b]	0.01±0.00[b]	0.01±0.01[b]

*Values with different letters are significantly different across the column at α level of 0.05.
AGB and BGB means above ground biomass and below ground biomass respectively.

Organic Carbon concentration (%)

Results from this study showed that there was no significant (p > 0.05) difference in the concentration of carbon of the above ground biomass across the three grass species studied (Figure 1). The highest value was observed in *Axonopus compressus* and the lowest was observed in *Cynodon dactylon* (Figure 1). There was a significant (p = 0.000) difference in the carbon concentration of the below ground biomass across the three grass species studied. The value was highest in *Panicum maximum* while *Cynodon dactylon* had the lowest value (**Figure 1**). The result obtained in the carbon concentration of the residue was similar to that of above ground biomass, where the concentration was not found to be significantly (p > 0.05) different for all the grasses (**Figure 1**).

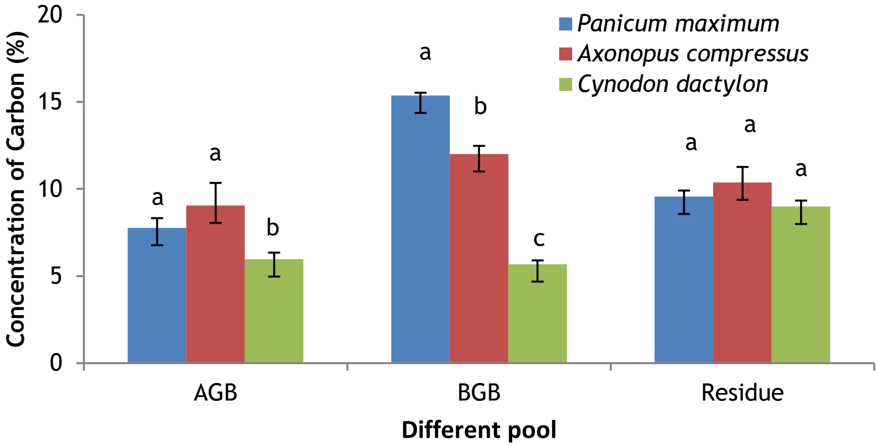

Figure 1. Carbon content of the above, below ground biomass and floor litter (residue) recorded at the three grass species sites. Vertical bar represents the standard error of the mean, (n = 10). Bars with similar letters are not significantly different across the species at $p < 0.05$.

Carbon stock

The carbon stock for each species of grasses were studied across the four different pools i.e. the above ground biomass, the below ground biomass, residue and soil. Result from this study showed that there was a significant ($p = 0.017$) difference in the above ground biomass carbon stock across the three species of grasses studied (**Table 2**). The highest carbon stock in the above ground biomass was recorded in *Panicum maximum* while the lowest value was recorded in *Cynodon dactylon* (**Table 2**). In the below ground biomass, carbon stock was found to be significantly ($p = 0.002$) higher in *Panicum maximum* compared to the other two grass species, while there was no significant difference in the other two grasses (**Table 2**). Similarly, there was a significant ($p = 0.010$) difference in the carbon stored in residues across the three grass species. *Panicum maximum* residue stored the highest carbon while *Cynodon dactylon* stored the lowest (**Table 2**).

Table 2. Mean carbon stock and standard error of the different pools across the three grass species. Results are presented as mean and standard error, where n = 10.

Grass species	AGB (Kg m^{-2})	BGB (Kg m^{-2})	Residue (Kg m^{-2})
Panicum maximum	0.93 ± 0.28^a	1.01 ± 0.28^a	0.54 ± 0.14^a
Axonopus compressus	0.32 ± 0.07^b	0.10 ± 0.04^b	0.04 ± 0.01^b
Cynodon dactylon	0.19 ± 0.02^b	0.06 ± 0.01^b	0.03 ± 0.01^b

*Values with different letters are significantly different across the column at α level of 0.05.

AGB and BGB means above ground biomass and below ground biomass respectively.

Soil

The mean values of soil bulk densities determined for *P. maximum, A. compressus* and *C. dactylon* were not significantly ($p = 0.853$) different (**Table 3**). However, the carbon concentration was significantly ($p = 0.004$) different across the three grass species (**Table 3**). The highest carbon concentration was recorded in *Cynodon dactylon* while *Panicum maximum* had the lowest. There was a significant ($p = 0.033$) difference in the soil carbon stock across the three grass species. The highest carbon was stored in soils of *Cynodon dactylon* while *Axonopus compressus* stored the least amount of carbon (**Table 3**).

Table 3. Bulk density, carbon concentration and carbon stock across the soils of the three grass species. Results are presented as mean and standard error, where n = 10

Grass species	Bulk density ($g\ cm^{-3}$)	Carbon concentration ($g\ kg^{-1}$)	Carbon stock ($Kg\ m^{-2}$)
Panicum maximum	1.03 ± 0.04^{a}	0.86 ± 0.20^{b}	0.18 ± 0.02^{b}
Axonopus compressus	1.05 ± 0.09^{a}	1.01 ± 0.18^{b}	0.21 ± 0.04^{b}
Cynodon dactylon	1.00 ± 0.00^{a}	2.22 ± 0.35^{a}	0.45 ± 0.08^{a}

*Values with different letters are significantly different across the column at α level of 0.05

Generally, the summary of the total of dry matter production, carbon concentration and carbon stock determined across the grass species studied is shown in Table 4. Results showed that the highest total carbon in all the pools was stored by *Panicum maximum* while *Cynodon dactylon* had the least carbon concentration. *Panicum maximum* produced the highest dry matter while both *Cynodon dactylon* and *Axonopus compressus* produced equal amount of dry matter (**Table 4**).

Table 4. Total dry matter production, Carbon concentration and Carbon stock across the three grass species

Grass species	Dry matter ($Kg\ m^{-2}$)	Concentration of Carbon (%)	Carbon stock ($Kg\ m^{-2}$)
Panicum maximum	0.24	33.57	2.66
Axonopus compressus	0.05	32.45	0.67
Cynodon dactylon	0.05	22.87	0.73

Discussion

Carbon concentration

Among the three grass species, the highest total carbon concentration was recorded in *Panicum maximum* while the lowest concentration was found in *Cynodon dactylon*. The highest total carbon concentration recorded in *Panicum maximum* compared to other grasses might be the result of its high below ground biomass carbon concentration. The higher below ground biomass carbon concentration of *Panicum maximum* was attributed to its deep penetrating roots unlike the other grass species, *Panicum maximum* which has a deep penetrating and bulky root structure. This observation is in agreement with the findings of (Anderson et al., 2010; Fissore et al., 2009) who reported that the deeper the root of native grasses, the greater the amount of carbon that could be stored in their roots.

The highest soil carbon concentration that was observed in *Cynodon dactylon* compared to other pools across the three grass species may show that *Cynodon dactylon* has a limit to the amount of carbon it can store in its vegetative parts even when there is an abundance of carbon in its soil pool. Schnitzer (1991) had earlier pointed out that there was a high rate of root decomposition in *Cynodon dactylon* and this may have contributed to the enhanced addition of carbon from the plant's root to the soil during the decomposition process.

The higher dry matter production recorded in *Panicum maximum* and across the various pools may be a result of its high vegetative yield. The vegetable matter produced by *Panicum maximum* was the highest. Various adaptive characteristics of this plant conferred upon it this advantage, part of which is its preference for shade which was well provided for by the trees growing around. With the availability of this condition and many others, the plant will multiply quickly and form a luxuriant growth unlike the creeping *Axonopus compressus* and the less large *Cynodon dactylon* (Botha & Botha, 1996). *Cynodon dactylon* does not grow well under the shade (Walker et al., 2001) while *Axonopus compressus* is generally a low-growing grass (Wong et al., 1998). The lack of significant difference in the bulk density of soils across the study sites where the three grass species were collected from could be due to similarities in the climate and management history of the plots from which the grass monocultures were collected.

Carbon stock

The soil across the three grass species except for *Panicum maximum* and *Axonopus compressus* stored more than 30 % of the total carbon and this is in agreement with reports cited in (Daigneault, 2006) where it was reported that soil stores about 39 % of the total carbon sequestered in grasses. *Panicum maximum* soil stored about 6.67 % carbon and this may be due to the hoard of carbon by the luxuriant, vibrant, hale and bulky above and below ground biomass (Schnitzer, 1991). This observation however contradicts the findings of Lal et al. (1995) who reported that soil stores up to three times organic carbon compared to other components of plants. High soil carbon stock in *Cynodon dactylon* is dependent on its soil carbon concentration and storage and this could be the result of high decomposition rate of its above and below ground biomass. The carbon stock of a plant is determined by how long the plant lives and how big it grows at maturity. It has been reported that grasses for the most part have an annual root system with most of the smaller roots becoming established from the base of the plant. Thus, each year, many grasses shed almost their entire root system into the soil which deposits large amounts of fibre (mostly carbon) into the soil and then the plants go about consuming more carbon as they build a replacement root system (Anderson et. al, 2008, Fissore et al., 2009.

The high carbon storage in the soil of *Cynodon dactylon* may also be dependent on its dislike for shade (Walker et al., 2001), which inhibits the vibrant and agile growth of its vegetative and root part and hastens its death and decomposition. Deep penetrating roots store and hoard carbon away from the soil (Fissore et al., 2009) and this could explain the high soil carbon stock in *Panicum maximum* compared with the reported soil storage (Daigneault, 2006) of about 39 % of the total plant's carbon.

Conclusion

From this study, it was clear *Panicum maximum* had the highest carbon stock among the three grass species across the above and below ground biomass. It also had the highest dry matter production and carbon concentration. The *Cynodon dactylon* soil stored more carbon than the *Axonopus dactylon* soil. However, *Axonopus dactylon* stored more carbon across its other pools i.e. above ground biomass, below ground biomass and residue in comparison with *Cynodon dactylon*. The carbon stored in above ground biomass was more than the below ground biomass among the grass species. From the study, it is entirely reasonable to believe that grasslands can be used as terrestrial carbon sinks while still maintaining their ability to provide environmental services without degradation of grasslands.

Based on this study, it is recommended that disturbance through burning and harvesting of biomass from these grass species should be discouraged as much as possible since disturbance is most likely to alter the level of carbon stored in the biomass. Also the integrity of soils of the grass cover should be maintained by reducing disturbance that is associated with soil erosion, burning or harvesting.

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