Research & Reviews: Research & Reviews: Journal of Ecology and Environmental Sciences

e-ISSN: 2347-7830
p-ISSN: 2347-7822

# Drivers of Biomass Stocks Variability in Land Uses in the Togodo Protected Area Complex and Fringe Zone in South-Eastern Togo West Africa

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**Research Article**

Received date: 03/02/2020

Accepted date: 19/02/2020

Published date: 24/02/2020

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Keywords: Land use, Land conversion, Management patterns, Environmental factors, Forest ecosystems, Togo, West Africa

## ABSTRACT

**Objective:** West Africa region is marked by a change in land use with the conversion of forest land and wooded areas into agricultural land or other uses to meet the needs for agricultural lands and forest products of the fast-growing human population. These frequent changes influenced the biomass and carbon sequestration in land cover properties and land use patterns. Although many studies have focused on carbon stocks in African forests, knowledge on the influence of land-use changes on biomass productivity is still insufficiently documented in most Sub Sahara countries and particularly in Togo. This study aims to evaluate the impacts of land-use changes on biomass productivity and to determine the drivers of the spatial distribution of biomass in different ecosystems in South-Eastern Togo.

**Methods:** Three types of data were collected namely dendrometric data through forest inventories, herbaceous biomass data through plot cutting and root biomass data through soil sampling.

**Results:** Based on existing allometric models and weighing of herbaceous and roots, the results obtained for the different land uses reflect a high variability in the average total biomass, i.e. 266.24 ± 14.37 t/ha, 183.04 ± 20.44 t/ha, 99.89 ± 11.15 t/ha, 79.88 ± 3.38 t/ha and 49.80 ± 4.25 t/ha respectively for teak plantation, semi-deciduous forest, wooded savannahs, fallows and farm-land. Biomass productivity across different land uses shows a very high variability ($p<0.001$). Biomass values obtained indicates also a significant difference between the above-ground and the underground compartments of the different ecosystems ($p<0.001$).

**Conclusion:** Our results emphasise that the main factors influencing the variability of biomass stocks include land use and management patterns, biotic factors and climatic factors. All these results help to put in place appropriate management systems for relatively well-conserved ecosystems in order to increase carbon sequestration of the ecosystems and their capacity to provide ecosystem services.

## INTRODUCTION

West Africa is characterized by the rapid growth of its population (2.7% per year over the past 40 years), leading to increased demand for agricultural land and forest products [1]. As a result, 90% of the original primary forest cover in this region has disappeared and the rest is highly fragmented and degraded [2,3]. These forest ecosystems are among the most threatened on the continent [4] and the remaining trees are under high human pressure [5]. The region has also been identified as a climate change hotspot where an increased probability of hazards, vulnerability, and exposure are frequently meeting [6]. Climate change and variability and its effects are inducing significant land use/land cover changes in the sub-region, resulting in unprecedented deforestation rates, and degradation of arable lands and deterioration of ecological systems [7].

Indeed, the West African region is marked by a change in land use with the conversion of forest land and wooded areas into agricultural land or other uses to meet the needs of a growing population [8]. These frequent land-use changes have an impact on carbon sequestration in vegetation cover, influencing climate on a continental scale. The Intergovernmental Panel on Climate Change (IPCC) reported that land-use change contributed approximately 20% of global anthropogenic carbon dioxide emissions in the 1990s (80% from fossil fuel combustion [9]), with tropical deforestation accounting for the largest share [10]. In the current context of climate change, tropical forest ecosystems are well known for their important role in the global carbon cycle and are an important carbon sink. According to Van der Werf GR et al. [11], the loss of forest cover resulting from deforestation and degradation of tropical forests contributes to about 10%-15% of annual global greenhouse gas emissions.

However, knowledge on the productivity of plant communities and their reference level through biomass and carbon stock assessment are still insufficiently documented in most Sub Sahara countries [12] and particularly in Togo. A better understanding of biomass production in forest ecosystems and their evolution after conversion to other land use, such as farming, is essential to assess the resilience of cropping systems and their capacity to provide ecosystem services. Biomass is influenced by management legacies, landscape configuration, changes in vegetation properties and land use patterns [13], but these factors have scarcely been studied. To do this, biomass estimates at local and regional scales provide essential data for extrapolating biomass stocks to all ecosystems or for modeling the ecosystem carbon cycle, as well as more reliable emission estimates under the land-use change scenario [14].

This information will serve for ecosystem management planning and are also crucial for research to quantify their potential to mitigate the adverse effects of climate change. Therefore, the provision of these types of data is now a prerequisite for valuation on the carbon market in order to benefit from the remuneration for reducing deforestation related to the mechanism for "reducing emissions from deforestation and forest degradation and the role of conservation activities, sustainable forest management and the improvement of forest carbon stocks in developing countries" (REDD +). This compensation mechanism has been presented as a means of reducing global emissions by generating income for developing countries [15] while contributing to the conservation of forest ecosystems [16].

Nowadays for Togo, accurate estimation of ecosystem biomass is crucial for many applications from commercial timber exploitation to the global carbon cycle [17,18]. This is all the more important as the country is committed to promoting the role of ecosystems in the global issue of mitigating global warming. The country has also integrated REDD + process into its national development plan to enable forests and trees outside forests to continue to play their important socio-economic and ecological roles. In this context, the present study is carried out in the ecosystems of Togo do protected area complex and its peripheral area in South-Eastern Togo to analyze the impacts of land use/land cover changes on biomass productivity and its variability in relation to land use patterns. Togo protected area complex is one of the priorities protected area in Togo because it brings fundamental protection to ecosystems, contributes significantly to the forest resources safeguard, water management, carbon storage and climate stabilization, and preserves many threatened animals, plants species and natural habitat. It is in this protected area one could find relic dry semi-deciduous forests in the high agricultural landscape of southern Togo. This reserve contains the last population of forest buffalo in Togo. The site is close to Lome the capital town and is, therefore, a great opportunity for ecotourism.

e-ISSN: 2347-7830
p-ISSN: 2347-7822

By selecting Togo do protected area complex, the purpose of this paper is to evaluate the vulnerability of the ecosystems and civil population to inter-annual variations and longer trends in climate, to analyse suited adaptation strategies, to develop new concept of monitoring and forecasting warning system, useful for food security, risk management, and civil protection. Otherwise, the data collected enable to establish a baseline situation in terms of ecosystem productivity in Togo do protected area complex with a view to setting up a mechanism for monitoring the carbon stock of this region. Specifically, this paper aims to:

- Analyse the variability of biomass through land use/occupation patterns
- Determine the drivers of the spatial distribution of biomass in different ecosystems. The basic assumption is that the conversion of forest land to other forms of use, particularly non-forest uses, modifies and significantly reduces primary productivity in terms of biomass in forest ecosystems

## MATERIALS AND METHODS

### Study Area

The study is carried out in the lower valley of the Mono River, which includes the Togodo protected area complex and its peripheral zone (Figure 1). The area covers 39,500 ha, including 25,500 ha for the Togodo protected area complex and 14,000 ha for the peripheral zone. In this area, the mainland uses identified are (18)

- semi-deciduous forests with an area of 4,050 ha
- wooded savannah with an area of 15,700 ha
- forest plantations including teak and palm: 4,900 ha
- fallows at different stages: 7,300 ha
- farmlands: 7,550 ha

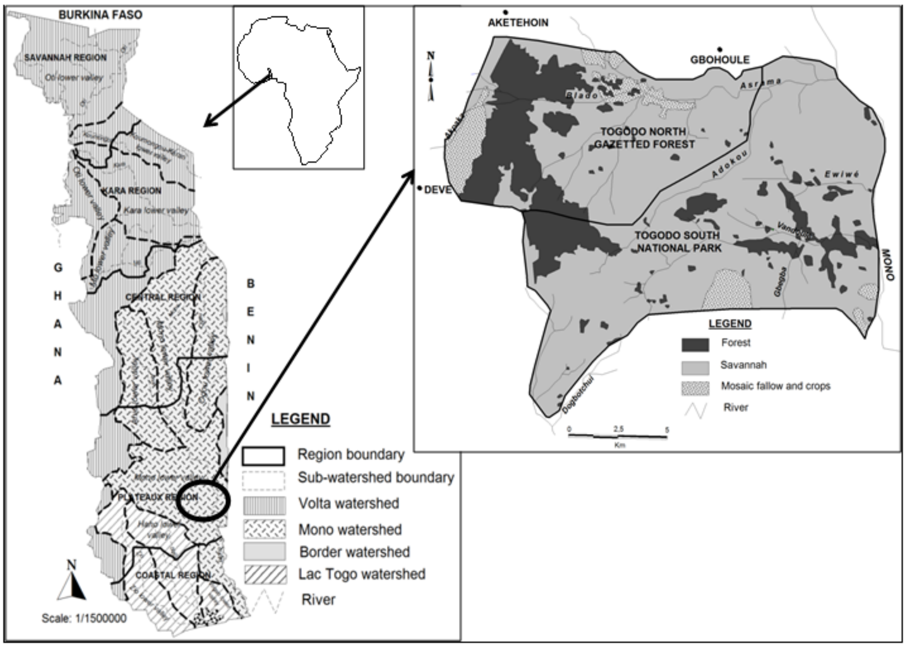


**Figure 1.** Location of the study area.

The entire area lies on a big gently rolling plain (maximum altitude 90 m above sea level). The only noticeable relief is a hill which rises to 228 m. The river system forms the Mono river sedimentary basin.

The area has a sub-equatorial climate, with a long rainy season from March to July and a short rainy season from September to November. These two rainy seasons are interrupted by a long dry season and a short dry season, giving a bimodal rainfall pattern including two maxima and two minima of unequal heights. The average annual rainfall ranges from 1000 to 1200 mm and is distributed over 70 to 80 days. The annual average temperature is around 27°C.

According to the fourth General Census of Population and Housing (RGPH4) of 2010, the population density is between 100 and 150 inhabitants/km$^2$. This population, composed of a mosaic of ethnic groups, has another important characteristic: a strong demographic increase of 3%. This population, undergoing demographic change, is mainly agricultural (22,318 urban dwellers compared to 135,108 rural dwellers). It practices extensive manual agriculture of

e-ISSN: 2347-7830
p-ISSN: 2347-7822

slash-and-burn type, based on family labor. The main crops grown are maize in the first season, from April to July, and cotton in the second season, from June to December.

### Data Collection

*Forest inventories*

In each of the land uses identified in the study area, forest inventories were conducted to gather the information needed to assess tree productivity (woody biomass). The protocols adopted for tree measurements are square plots with areas that differ from one type of land use to another, including 100 $m^2$ (10 m× 10 m) plots in crop areas and teak plantations, 400 $m^2$ (20 m× 20 m) plots in fallows and savannahs (wooded/wooded savannahs) and 2500 $m^2$ (50 m × 50 m) plots in semi-deciduous forests [19].

Within the plots in these different land uses, the inventories consist of measuring the diameter at breast height (dbh ≥ 10 cm) and the height of woody individuals. The dbh was measured at 1.30 m from the ground for trees (>5 m high) and at 0.25 m from the ground for shrubs (<5 m and >1 m) with a forest strip. Tree height was measured with a graduated plate (tree height <5 m) or a Bitterlich's relascope (tree height >5 m).

*Herbaceous biomass data*

The assessment of herbaceous biomass is carried out by cutting the herbaceous plants in 1 ml (1 m × 1 m) plots delimited at the 4 corners of the large plots. The cuts are made at 5 cm from the ground and all the plant material present in these small 1 $m^2$ plots is completely mowed. After cutting, all mowed plant material is immediately weighed using a scale and the weight of the fresh material is recorded. Then, a quantity of the fresh material is collected, weighed and returned to the laboratory in plastic bags. In the laboratory, the samples are placed in an oven for 72 hours at 70°C. Once out of the oven, they are weighed again to determine the dry mass.

*Root biomass data*

The evaluation of underground biomass is carried out by taking soil samples from different horizons with cylinders of different diameters in plots previously installed for forest inventories. Thus, for each land use, 6 samples are taken, including 3 samples with a 105 cm diameter cylinder from the surface horizon (from 0 to 10 cm deep) and the other 3 with a 95 cm diameter cylinder from the 10 to 30 cm deep in the horizon. All samples are placed in plastic bags to avoid soil contamination and soil loss and then returned to the laboratory where they are stored at a temperature of 16°C. The samples are then washed and the roots are gradually collected using 5 mm, 2 mm and then 1 mm diameter sieves. These roots are dried in an oven for 24 hours at 60°C and then weighed.

### Data Processing and Analysis

The structural analysis of forest ecosystems was based on the assessment of quantitative descriptors of the structure of the woody vegetation. To do this, quantitative forest characteristics such as density, total height, average diameter, and basal area are assessed directly by arithmetic calculation:

- Tree density is defined as the number of stems per unit area (hectare) for trees with dbh ≥ 10 cm
- The basal area (G) of a forest is the sum of the areas of the stem section of the trees in the forest. It is calculated according to the relationship $G=\Sigma \pi d^2/4$ (where d is the diameter at 1.30 m) and is expressed in $m^2$/ha. Basal area G isthe sum of the individual basal ararea G isthe sum of the individual basal ar ($G=\Sigma gi$)
- The estimation of woody biomass was based on the allometric method and involves forest inventory data. The biomass biomass is then obtained by using the following formula[20] :

$$AGB = 0.0673 \times (\rho D^l H)\ 0.976$$

Herbaceous and root biomass are bades on the weights per unit area and the weights assigned to the respective areas of each land use unit.

## RESULTS

### Demographic Structure of Ecosystems

*Forest characteristics*

The forest ecosystems studied are characterized by variability in structural parameters (Table 1). The highest tree density is obtained in teak plantations (1847 ± 343.8 N/ha), most of which are young plantations with ages ranging from

e-ISSN: 2347-7830
p-ISSN: 2347-7822

8 to 15 years. They are followed by semi-deciduous forests (955 ± 297.5 N/ha), wooded savannahs (203 ± 40.7 N/ha) and fallows (166 ± 28.5 N/ha).

**Table 1.** Main characteristics of land use units.

| Structural parameters | Land uses | | | | |
|---|---|---|---|---|---|
| | Semi-deciduous forest | Wooded savannah | Teak plantation | Fallow | Farmlands |
| Average density (N/Ha) | 955 ± 297.5 | 203 ± 40.7 | 1847 ± 343.8 | 166 ±28.5 | NA* |
| Average diameter (cm) | 16.5 ± 15.7 | 9.72 ± 6.2 | 11.36 ± 5.4 | 6.75 ± 2.1 | NA* |
| Average total height (m) | 9.8 ± 5.2 | 4.71 ± 2.7 | 9.28 ± 4.2 | 3.33 ± 1.2 | NA* |
| Basal area (m$^l$/Ha) | 38.9 | 8.6 | 24.82 | 0.65 | NA* |
| *NA: Not Available | | | | | |

In terms of performance, it is at the level of semi-deciduous forests that the largest diameter individuals are recorded with an estimated average diameter of 16.5 ± 15.7 cm and fallows constitute the land cover with the lowest average diameter (6.75 ± 2.1 cm). The same trend is observed for basal area with values estimated at 38.9 m$^2$/ha for semi-deciduous forests, 24.82 m$^2$/ha for teak plantations, 8.62 m $^2$/ha for wooded savannahs and 0.65 m $^2$/ha for fallows.

*Diameter class distribution*

The distribution of trees by diameter class in semi-deciduous forests indicates an exponentially decreasing distribution (Figure 2) marked by the predominance of small diameter individuals with a value of c equal to 1 (Figure 2A and 2C). For the wooded savannah and fallows, an inverted "J" distribution is obtained (Figure 2B and 2D). The shape parameter of the Weibull distribution gives for these two distributions values lower than 1 characteristic of multi-species stands with a predominance of small diameter individuals. In these two ecosystems, individuals in the 5-10 cm dbh class are the most represented, followed by those in the 10-20 cm dbh class.

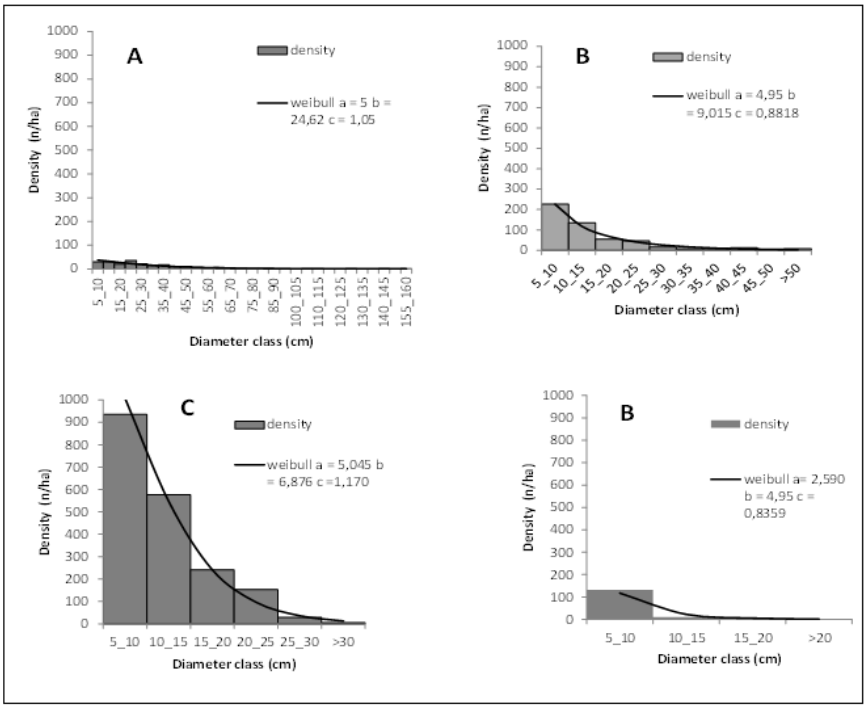


**Figure 2.** Diameter class distributions for each land uses: A: semi-deciduous forest; B: wooded savannah; C: teak plantation; D: fallow.

The same pattern is observed in teak plantations (inverted "J" distribution) except that the value of c is between 1 and 3.6 and reflects that this distribution is characteristic of monospecific populations with a predominance of young or small

e-ISSN: 2347-7830
p-ISSN: 2347-7822

diameter individuals. The Kolmogorov-Smirnov test (performed for each structure) indicates a good fit observed with the Weibull distribution (p>0.001).

### Plant Biomass of the Different Land Uses

The quantification of the productivity of the different ecosystems in the area shows a difference in the spatial distribution of plant biomass within land uses, particularly between semi-deciduous forests, teak plantations, wooded savannahs, fallows and crop areas. Occupations with a fairly dense vegetation cover with a high tree density and a high proportion of large-diameter trees have the highest total biomass values estimated at 266.24 ± 14.37 t/ha and 183.04 ± 20.44 t/ha for teak plantations and semi-deciduous forests respectively (Table 1 and Figure 3).

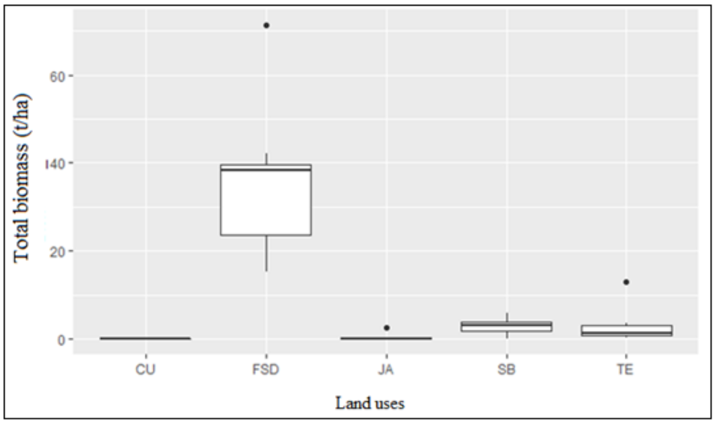


**Figure 3.** Total biomass variability through land uses.

Analysis of the productivity values of the different land uses shows a very high variability across them and a significant difference (p<0.001) in total biomass between the different ecosystems (Figure 4 and Table 2). This difference between total biomasses is mainly due to the clear differences that exist between these land occupations in terms of their aerial biomasses. Apart from the cultivated areas, fallow land has the highest rate of herbaceous plants, followed by wooded savannahs. In teak plantations and semi-deciduous forests, the herbaceous biomass is very low compared with woody biomass. When we know that these two land uses have the highest biomass values followed respectively by wooded savannahs, fallows and cropping areas (Table 2 and Figure 3), it is obvious that most of the biomass is produced by woody species in these ecosystems. Thus, the higher the rate of woody matter in an ecosystem, the greater its biomass increases.

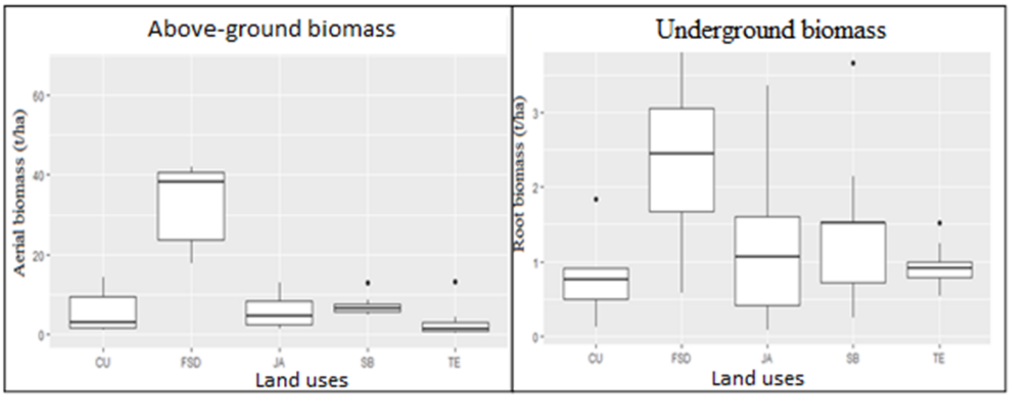


**Figure 4.** Total biomass across the two compartments. FSD: Semi Deciduous Forest; TE: Teak Plantation; SB: Wooded Savannah; JA: Fallow; CU: Farm Land.

**Table 2.** Estimation of plant biomass in land uses.

| Type of biomass | Land uses | | | | | Probability (p-value) |
|---|---|---|---|---|---|---|
| | FSD | TE | SB | JA | CU | |
| Aerial biomass (t/ha) | 153,49 ± 16,04a | 250,41 ± 12,27 a | 83,32 ± 9,32a | 65,01 ± 3,62a | 43,71 ± 5,09a | <0,001 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Underground biomass (t/ha) | 26,55 ± 0,99 a | 15,83 ± 0,24 b | 16,57 ± 0,90b | 14,87 ± 1,06b | 6,09 ± 0,54a | <0,001 |
| Total biomass (t/ha) | 183,04 ± 20,44 a | 266,24 ± 14,37 a | 99,89 ± 11,15a | 79,88 ± 3,38a | 49,80 ± 4,25a | <0,001 |
| FSD: Semi-Deciduous Forest; TE: Teak Plantation; SB: Wooded Savannah; JA: Fallow; CU: Farm Land; a: Significant difference for these values; b: Not significant difference for these values | | | | | | |

#### Variability of Biomass across Compartments

Two compartments are considered, namely the above-ground compartment and the underground compartment. The total above-ground biomass is composed of woody and herbaceous biomass, while the total underground biomass represents the root biomass obtained from different horizons.

Analysis of the total biomass values obtained in the two compartments of the different ecosystems indicates a significant difference between the values ($p<0.001$) **(Table 2 and Figure 4)**. As far as the aerial biomass is concerned, the semi-deciduous forest differs significantly from other ecosystems **(Figure 5)**. This is not the case for groundwater biomass, which varies significantly from one ecosystem to another ($p<0.001$) **(Table 2)**.

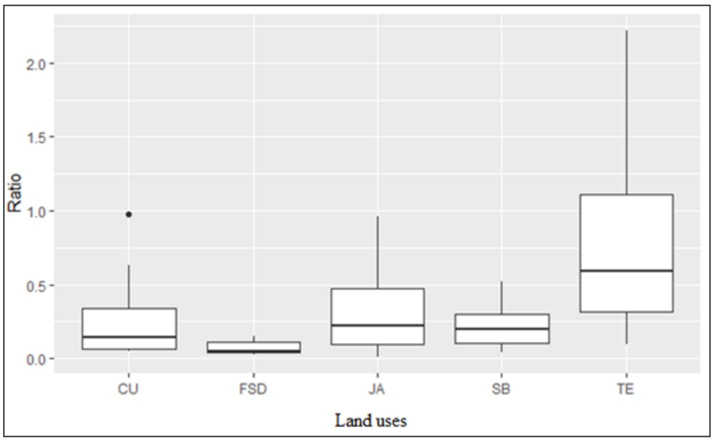


**Figure 5.** Ratio of underground to aerial biomass across land uses patterns. FSD: Semi-Deciduous Forest; TE: Teak Plantation; SB: Wooded Savannah; JA: Fallow; CU: Farm Land.

In addition, the evaluation of the ratios between underground and above-ground biomass indicates that, with the exception of crop areas where the ratio is largely in favour of the underground biomass and fallows where this ratio is equitable (on average equal to 1). Other ecosystems have a biomass ratio in favour of above-ground biomass **(Figure 5)**. This equitable ratio in the fallows reflects the transient nature of this ecosystem between cropping areas and other ecosystems, in this case, forested wooded savannahs.

As for the values of underground biomass in the different ecosystems studied **(Figure 4)**, there is no significant difference (the values are not exclusive to these ecosystems) although the average in semi-deciduous forests is still slightly higher than in the other land uses. In general, it can be deduced that the amount of above-ground and below-ground biomass is a function of the type of land use identified in the study area.

Through field observations, it appeared that there are no woody plants in the crop areas and the surveys carried out for biomass calculation only concern herbaceous plants. As a result, the value of the ratio of herbaceous to woody biomass is infinite for this ecosystem and cannot be represented.

#### Influence of Climatic Parameters on Biomass Distribution Across Land Uses

As part of this study, the effect of land-use type and season type was tested to show their impact on the distribution of different biomass categories. With regard to the type of season, the average above-ground biomass and the average below-ground biomass do not seem to show any difference. The variance test carried out confirms that there is no significant difference ($p>0.05$) between the biomass values in the two compartments during the two seasons considered (high rainy season and low rainy season). However, there is high variability in above-ground biomass regardless of the season.

e-ISSN: 2347-7830
p-ISSN: 2347-7822

In addition, it is generally noted that herbaceous biomass is slightly more abundant in ecosystems during the high rainy season than during the low rainy season (Figure 6). Although overall, this difference is not significant between the two seasons, fallows are still the ecosystems with the greatest seasonal variability of herbaceous to woody ratio. They are followed successively by wooded savannahs, teak forests and semi-deciduous forests. This result obtained at the fallow level could be explained by the intermittency or instability of this ecosystem. The greater presence of herbaceous plants during the main rainy season is because this season follows the main dry season.

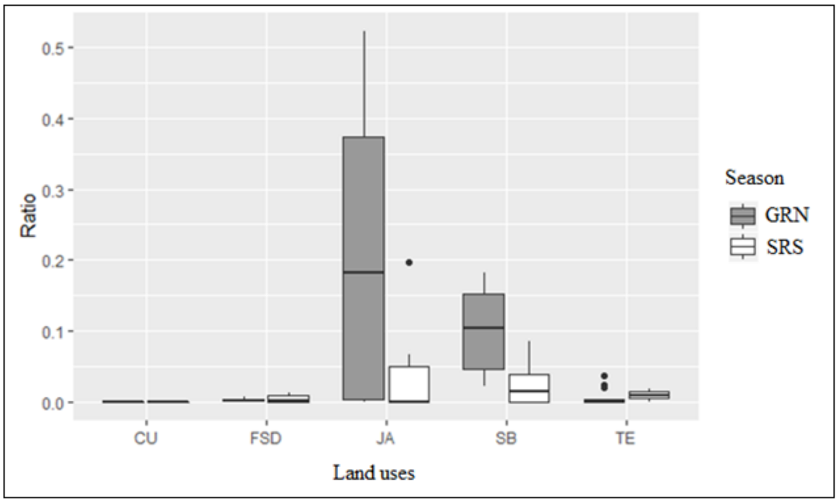


**Figure 6.** Ratio of herbaceous biomasses to woody biomass according to seasons and by land uses. FSD: Semi-Deciduous Forest; TE: Teak Plantation; SB: Wooded Savannah; JA: Fallow; CU: Farm Land; GRN: Great Rainy Season; SRN: Small Rainy Season.

Indeed, during the dry season, fires burn and the landscape becomes open. The high rainfall of the high rainy season, which occurs after the passage of fires, allows the herbaceous mat to be installed quickly and to constitute an important part of the biomass. This share is all the more important when the ecosystem under consideration has burned better and is more open. As a result, semi-deciduous forests and teak forests, which are less exposed to fires, do not produce as much herbaceous material as fallows and wooded savannahs. The woody plants present in these last two ecosystems will then rapidly increase their above-ground biomass during the high rainy season and gradually prevent the growth of herbaceous plants by making the environment more closed during the low rainy season.

## DISCUSSION

Plant biomass productivity is an important variable to assess the functionality and health of ecosystems but also for assessing the potential for mitigating climate change through the reduction of greenhouse gas emissions. A better understanding of biomass production through land uses is essential for assessing the resilience of systems and the capacity to provide ecosystem services [13]. Thus, the assessment of biomass across different land uses in the Togodo protected area complex and its peripheral area revealed a high spatial variability between different land uses. Natural forests such as semi-deciduous forests indicate total biomass significantly higher than that of other land uses such as forest plantation, wooded savannah, fallow and cropland ($p<0,001$). The values obtained for total biomass stocks at the level of the different land uses in this study are in the same orders of magnitude as those found by other authors for forest ecosystems in tropical Africa. In a similar study in Ekiti State in Nigeria, the values obtained to follow the same trends and are estimated at 331.09 t/ha for natural forests, 171.01 t/ha for forest plantations, 87.59 t/ha for wooded savannahs, and 75.18 t/ha for cultivated areas [21].

The spatial variability of the observed biomass could be explained by the variability and performance of the structural parameters of these ecosystems, in particular the proportion of large diameter trees. Field investigations have shown that in semi-deciduous forests, there is a relatively higher frequency of trees with a diameter greater than 50 cm. Consequently, the total biomass appears to be higher in this ecosystem. As other types of ecosystems have relatively less efficient structural variables, the biomass calculated in them, therefore, appears to be relatively lower. Several other authors have also demonstrated that there are significant spatial variations in biomass within different types of tropical forests particularly in tropical Africa [22-25]. These variations are believed to be due to the higher frequency of over 70 cm diameter trees in paleotropical forests [23,24] indicate that spatial variations in above-ground biomass between evergreen and semi-deciduous forests in Cameroon are explained by differences in floristic composition, forest structure (stem density per hectare and basal area) and height-diameter allometry. Similarly, Bastin JF et al. [25] noted that these biomass differences would be explained by the high presence of hyperdominant species in Central Africa, which contribute to

e-ISSN: 2347-7830
p-ISSN: 2347-7822

more than 50% of biomass stocks. These authors explain these variations by structural differences related to anthropogenic disturbances and/or edaphic and altitudinal gradients. However, floristic composition and structural variables (basal area, height-diameter allometry, etc.) explain a larger part of the spatial variation in biomass in African tropical forests [22,26,27].

Other factors that can also influence above-ground biomass include biotic factors (vegetation cover, species richness and uniformity) and abiotic factors (soil texture properties and topographic factors). But biotic factors can be the dominant factor in determining the variability of ecosystem biomass productivity variability because they can better predict above-ground biomass, probably because of their small spatial scale [28]. In the Togodo Protected Area Complex, human activities such as slash and burn agriculture and forest exploitation put pressure on natural ecosystems and lead to land-use changes at different spatial and temporal scales and continuous habitat degradation. Thus, as in the entire sub-Saharan African region, forest land is gradually being transformed and converted to agricultural land with shorter and shorter fallow periods in order to meet the needs of growing populations [8].

In the study area, natural landscapes are therefore converted to cultivated lands in an agricultural system that conserves few trees on agricultural land and clearing and burning systems that destroy the woody component of ecosystems. Human activities, including slash-and-burn agriculture and forest exploitation, inevitably affect biomass and carbon stocks [29,30]. Depending on the type and intensity of land-use change, ecosystems reflect different structures, functions, and dynamics, creating new and complex interactions between vegetation, soil and nutrients. Land-use change and land degradation reduce biomass productivity, influencing biodiversity and the general state of ecosystems [13,31].

However, it is important to remember that in this study, some components were not considered for the assessment of total biomass at the land cover level. These include coarse woody debris, dead trees, and litter. These important components could also form a large part of the total biomass in the different types of ecosystem and therefore the contributions of the different biomass storage compartments (above-ground and below-ground biomass) could be revised. Another component that could induce changes in biomass assessment is the seasonality of herbaceous productivity. Productivity in herbaceous ecosystems such as wooded savannahs and fallows is strongly influenced by the seasons. In certain periods of the year, these herbaceous plants are completely burned by wildfires. The biomass of these ecosystems is therefore directly influenced by climate change due to changes in the seasonal distribution of precipitation and increasing temperatures [32,33].

Although not determined using the IPCC default method, the values obtained in this study can be considered a reference for the Togodo Protected Area Complex and its peripheral area. Indeed, the methodology adopted for the data inventory follows a sampling plan that takes into account the different land uses that are accepted as one of the main schemes used to estimate biomass and forest carbon stocks at the country level [34,35]. The biomass values obtained are calculated using regression models or allometric equations coupled with herbaceous and root weights. However, it should be noted that the use of the allometric equations proposed by [20] in biomass estimation in this study may lead to underestimating compared to the IPCC calculation methods. Concerning regression models or allometric equations, many authors recommend developing specific equations for the species most commonly found at the sites studied in order to improve the reliability of the results [36,37]. However, at present, no equation has yet been developed for Togo. Although some models have been generated in other sub-Saharan African countries, such as Benin, Burkina Faso, Cϕte d'Ivoire, Mali [17], unfortunately, very few species inventoried in this study have been found and the biophysical and ecological conditions for establishing the available equations are not similar to those in this study area.

Despite these uncertainties in the approaches to allometric equations adopted for biomass estimates, it is important to remember that the results obtained in this study area (local level) provide essential data for extrapolating biomass stocks to ecosystems throughout the region or even across the country under the same biophysical conditions. This information is also very useful for modeling the ecosystem's carbon cycle, as well as reliable estimates of emissions under a land-use change scenario [14]. Although most of the deforestation and forest degradation and resulting emissions have occurred in tropical developing countries, little or no direct quantification of the effects of land-use change on biomass stocks in these land-use systems has been carried out [21].

In addition to this information, the distribution of biomass stocks across different land uses is also assessed. The availability of this informations for this part of Togo is an important step in the development of activities as part of the implementation of the Measurement, Reporting, and Verification (MRV) system as part of the reducing emissions from deforestation and Forest Degradation (REDD+) strategy to which Togo has committed itself in recent years. Indeed, the United Nations framework convention on climate change has examined the possibility of reducing greenhouse gas emissions through the international REDD+ initiative. The REDD+ mechanism aims to encourage developing countries to preserve forest areas through financial compensation from carbon credits [38]. However, its implementation depends on an MRV system for estimating biomass and carbon stocks in forest ecosystems [39-41].

e-ISSN: 2347-7830
p-ISSN: 2347-7822

## CONCLUSION

The study helps to understand the spatial variability of biomass stocks across different land uses and compartments (above and below-ground biomass) and identifies the main factors determining the spatial distribution of biomass in ecosystems. Based on existing allometric models and weighing of herbaceous and root samples, the study presented biomass stock values close to those estimated in previous work on the assessment of average biomass stocks in tropical ecosystems in relation to land uses. The results obtained for the different land uses reflect a high variability in the average total biomass, i.e. 266.24 ± 14.37 t/ha, 183.04 ± 20.44 t/ha, 99.89 ± 11.15 t/ha, 79.88 ± 3.38 t/ha and 49.80 ± 4.25 t/ha respectively for teak plantations, semi-deciduous forests, wooded savannahs, fallows, and cultivated areas. For Togo do protected area complex and its peripheral zone, the main factors influencing the variability of biomass stocks through land use include land use and management patterns, biotic factors (vegetation cover, woody richness and structural parameters within each land use) and climatic factors that mainly influence herbaceous biomass.

These results can be used to establish the baseline situation for biomass stock accounting in Togo, taking into account the particularities of the study area because it contains a complex of protected areas and a peripheral area with different forms of land use. This knowledge of the contribution of the Togo do protected areas complex and its peripheral area to biomass storage will make it possible to put in place appropriate management systems for relatively well-conserved ecosystems in order to protect stocks and increase the sequestration and resilience of these ecosystems. Future work will monitor changes in biomass storage to determine periodic stock changes related to land use. On the other hand, further work is needed to develop specific allometric equations by conducting sampling in the country, which would allow more accurate values of biomass stocks to be obtained.

It appears that it is the use of land with a high vegetation cover, which concentrates most of the biomass stock and can, therefore, play a significant role in the fight against climate change. Initiatives to increase carbon sequestration capacity in forest ecosystems, including the conservation of forests and forest resources, afforestation and reforestation initiatives, should, therefore, be encouraged. Agroforestry, therefore, appears to be an important approach as a carbon sequestration strategy at the level of agricultural land, and can also play an important role in climate change mitigation.

## ACKNOWLEDGMENTS

The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7) under grant agreement n° 244240 (Clim Africa project).

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e-ISSN: 2347-7830
p-ISSN: 2347-7822
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