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Allometric Models for Predicting Biomass and Carbon Pools of Boscia Senegalensis(Pers.) Lam. Ex Poir. (Capparaceae) Populations in Central Africa: A Case Study from Cameroon

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Abstract: Accurate estimates of above-ground biomass (AGB) and below-ground biomass (BGB) are essential for estimating carbon (C) balances at various geographical scales and formulating effective climate change mitigation programs. This study aimed to formulate specific allometric equations and carbon stock for *B. senegalensis* in Cameroon. Destructive sampling technique was used for harvesting and weighing the biomass of 40 individual trees. Allometric models were developed using biomass as dependent variable and tree dendrometric parameters as independent variables. The best models selected based with Adjusted coefficients of determination (Adj.R^2), residual standard error (RSE) and Akaike's information criterion (AIC) were: ln (leaf biomass) = 0.08 + 0.31*ln ($D^2 \times H \times \rho$); ln (branch biomass) = 0.14 + 0.65*ln ($D^2 \times H \times \rho$); ln (stem biomass) = 2.03 + 1.32*ln ($D^2 \times H$); ln (AGB) = 4.55 + 2.85*ln(D) and ln (BGB) =3.04 + 1.64*ln(D). The belowground biomass of *B. senegalensis* represents on average 25 % of the total aboveground biomass. Aboveground carbon ranged between 7.09 ± 0.42- 9.01 ± 0.50 tC/ha; Belowground carbon ranged between 4.37 ± 0.26 - 7.11 ± 0.35 tC/ha; litter carbon ranged between 0.50 ± 0.02 - 0.95 ± 0.04 tC/ha; herbaceous carbon ranged between 1.05 ± 0.28 - 1.86 ± 0.20 tC/ha ; dead wood carbon ranged between 3.03 ± 0.40 - 8.98 ± 0.44 tC/ha; Soil Organic Carbon Stock varies between4.33 ± 0.79 - 6.14 ± 1.05 tC/ha ;Total carbon were 33.24 ± 4.28;27.40 ± 3.35;27.27 ± 3.27and 21.18 ± 3.00 tC/ha in site 3, site 2, site 1 and site 4 respectively.The specific allometric equation developed for *B. senegalensis* can be used in similar Sudano-Sahelian savannas to implement activities to reduce emissions from deforestation and degradation (REDD+) for the benefit of local carbon trading communities.

Keywords: Allometric models, Biomass, *Boscia senegalensis*, Carbon sinks

1. Introduction

Forest biomass is the main contributor to the global carbon cycle. It acts as a carbon source when burned and also as a sink when forests are conserved [1]. To mitigate global warming, an increase in forest cover is necessary to enhance carbon sinks, particularly in regions with low forest cover and increasing populations [2,3] .Forests play a specific and important role in the global carbon-cycle, absorbing carbon dioxide during photosynthesis and storing it above and belowground [4]. The Reduction of Emissions from Deforestation and Forest Degradation (REDD+) projects are a political-effective option for the

mitigation and adaptation to climate change. One of REDD+'s goals is to estimate the car-bon reserves stored in the forests [5]. The existence of local allometric models to estimate biomass in different land uses is a fundamental part of the carbon inventories, and these are a basic requirement to develop forest projects for greenhouse gases (GHG) mitigation [6, 7, 8].Forest biomass have been studied with different purposes, among which is the nutrient cycle, for energy purposes, in forest growth assessment, for forest management purposes, environmental impact mitigation [6,7]. Obtaining economic incentives for forest preservation and the reduction of such gases [5]. Since forest cover is the main carbon sink [4].

According to [9], a statistical relationship exists between the different measurements from an individual to a population scale. Thus, from the smallest to the largest, the pro-portions between diameter and the variables height, crown size and biomass obey a rule which is identical for all living trees under the same conditions [10]. He this is the basic principle of allometry, which allows you to predict the measurement of a tree (typically its biomass) according to other measurements such as for example the density of wood, diameter, total height, etc [10-12]. Thus, allometric equations are mathematical tools de-veloped from direct measurements collected from trees and used to predict by the non-destructive method biomass or other measurements of other trees [13]. For [14], it is a formula /equation which quantitatively model the relationship between dendrometric pa-rameters and the mass of the tree. [15], for their part, recommend that the relevance of the equations allometric is based on the fact that there is a relationship of proportionality be-tween relative increases in the dimensions of an individual, for example biomass and di-ameter of a tree. However, this statistical relationship between biomass and the explana-tory variables is only valid if this relationship has a biological reality, otherwise, its use could lead to sources of error in the estimate [16].

The diameter at breast height (dbh, in cm), the wood density (ϱ, in g.cm^{-3}) and the total height (H, in m) are explanatory variables of the most common allometric models commonly used for the development of allometric equations necessary for the prediction of the biomass of standing trees [15,17-27]. Some variables have recently been introduced in models such as the diameter of the crown [28] , the basal area of the tree[29] , and the climatic index noted "E" which takes into account the prevailing environmental conditions in a given environment[30].

These ecosystems are considered as a climate change mitigation strategy at global level [31]. Allometric models make easy to estimate volume and AGB from measuring easily measurable individual tree parameters such as diameter at breast height (dbh) and total tree height (ht) in forest inventories [31]. Another important explanatory variable for the estimation of biomass is wood basic density (WD). WD is determined from wood sam-ples in laboratory as a ratio of dry mass to the green volume [31]. Literatures [32-37] list these variables according to their importance as dbh, WD, and ht in explaining tree bio-mass variations and dbh and ht for tree volume [32-37]. Among the three explanatory variables, tree dbh and ht have been often used as only explanatory variables to develop biomass allometric models [31].

Although allometric models exist for Africa [35,36,37] , these are generally limited in their applications by the dbh range used for the model calibration, uneven distribution of the dbh within the dbh range, the type and number of tree species used in developing the models, ecological zones, and the type and number of explanatory variables used [38]. Due to lack of local allometric models for some sub-Saharan African countries rely on pantropic models such as the ones developed by [30] for the estimation of local AGB and BGB. Although such pantropic models have a wide range of species from different eco-logical zones with wide calibration ranges, they are still not a panacea to the growing need for local allometric models across the continent. In view of this, more efforts are required to develop local allometric models for assessing tree carbon stock of forests to enable a better understanding of the contribution of local anthropogenic influence on atmospheric

CO_2 in Africa [39,40].The main objective of this study was to develop allometric models for accurate biomass estimation of *Boscia senegalensis* plantations. Further objective was to apply the allometric equations to derive the biomass stock of *Boscia senegalensis* plantation. The paper intends to test the hypothesis that the carbon storage potential of *Boscia senega-lensis* plantation can play significant role in climate variability and change mitigation.

2. Materials and Methods

2.1. Study area

The study occurred in Central Africa, more precisely in Cameroon, in the North region of Cameroon. This region is located between 7.2°N to 9.99°N latitude and 12.6° 'E to 15.3°E longitude (Figure 1)[4, 86,87].The relief is a vast pedi-plain between the Mandara Mountains (1442 m) to the north and the Adamawa Plateau to the south[5].The climate is of the Sudano-Sahelian type with two seasons: a dry season lasting six months (November-May) and a rainy season lasting six months (June-October) [7,87]. The average monthly temperature varies from 26°C in August to 40°C in March (extreme temperatures: 17°C to 40°C) [4]. The soil is of the ferruginous type characterized by acidity (pH = 5.5 to 6) and low cation exchange capacity [7]. The vegetation is a shrubby Sudano-sahelian savannah with a clear and degraded Savannah appearance around the villages [5]. Agriculture is the main activity of the people of the region. The population practices subsistence agriculture (corn, peanuts and millet) [5,87].The administrative North region of Cameroon comprises four subdivisions, namely, Bénoué, Faro, Mayo Louti, and Mayo Rey (Figure 1).

Figure 1. The geographic location of the study area in the North Region of Cameroon

2.2. Species description

Boscia senegalensis is part of the Capparaceae family. *Boscia senegalensis* is a species from the Sahelian to Sudanese areas present on dry sites with rocky, lateritic, sandy soils (dunes) and on compact sandy-clay soils [41,42,43]. Its geographic area includes Burkina Faso, Cameroon, Côte d'Ivoire, Ethiopia, Mauritania, Mali, Nigeria, Niger, Senegal, Sudan and Chad [41,42,43]. *Boscia senegalensis* a shrub or shrub ranging from 1 to 8 m in height, *Boscia senegalensis* has an ovoid crown (Figure 2). *Boscia senegalensis* has leaves during the dry season, it has an oblique trunk and drooping branches. Its different parts are characterized as follows: Its bark is smooth with a dark gray color [41,42,43]. It has a slice of pinkish yellow or oronge color. The leaves of *B. senegalensis* are alternate, simple, and glabrous (sometimes pubescent) dark green above and light below, with pubescent petioles about 2 to 6 mm long and pinnate and reticulate veins [41,42,43]. Solitary (on young twigs) or sometimes grouped (on twigs over one-year-old), they are rigid and hard with varying sizes (on the same tree), with a length of 1.5 to 5 cm or 7 and a width of 1 to 2 cm [41,42,43]. Oblong and lanceolate, their blades are obtuse at the top and wedge-shaped at the base. The Flowers are in short, dense clusters with a corymbic top forming a ball about 6 cm in diameter and have 4 sepals and 3 to 8 stamens [41,42,43]. Greenish-yellow or greenish-white in color, they have a sweet odor. They appear during the cold season [41]. The fruits of *B. senegalensis* are round and/or sphere-shaped with a diameter of approximately 1 to 2 cm [41, 42, 43, 44]. Glabrous and rough, they are grouped in clusters and arranged on a support. They have a green color which turns yellow brown when ripe and have 1 to 2 seeds. Its twigs are pubescent at first, then glabrous. Lenticellate, they are gray-brown in color [41,42].

Through its different parts, *B. senegalensis* has multiple and varied uses in medicine, food and cooking, agriculture and breeding and in industry and crafts [45,46]. *B. senegalensis* also has domestic uses [41,42,46,47,48]. In food and cooking: The leaves of *B. senegalensis* are edible and used as vegetables. The fruits (pulp) of *B. senegalensis* are edible. Walls they are eaten raw but immature they are eaten cooked [45,46]. Boiled *B. senegalensis* seeds can be used as a vegetable [45]. Also, dried these seeds give edible flour. In agriculture, pastoralism and animal health: The leaves of *B. senegalensis* are used as fodder for goats and sheep [45]. They are used as tonics in camels and horses in case of diarrhea [45,46]. They also drive away flies and fight colds and colds in horses and fever and trypanosomiasis in camels [45]. The fruits of *B. senegalensis* are purgative in camels. In industry, crafts and for domestic use: The leaves of *B. senegalensis* are used to protect cereals in granaries by hunting weevils and weevils [45]. Its roasted seeds serve as a substitute for coffee and to purify water [45]. In traditional and / or modern medicine: The bark of *B. senegalensis* is used to fight rheumatism and gastritis [45]. The leaves of *B. senegalensis* have an anthelmintic action and are used against rheumatism, stiffness, abscess, wounds, urticaria, ophthalmia, bilharzia, jaundice, gastritis, hemorrhoids, colic and neuralgia [45]. Associated with the twigs, they fight against asthenia and rheumatism [45,49,50]. The roots of *B. senegalensis* have an anthelmintic property and fight against impotence and gastritis. The fruits of *B. senegalensis* are a remedy for syphilis [45,51].

Figure 2. Individual of *Boscia senegalensis*

2.3. Data collection

2.3.1. Models biomass sampling

Forest inventory was conducted from April to July 2021. Destructive method was used to determine the biomass of each individual tree. Thus, 40 trees were harvested for estimating biomass and developing allometric models. Selection of each individual tree was based on diameter at breast height (1.30 m aboveground). The individuals were grouped into five DBH classes: 0–5 cm, 5–10 cm, 10-15 cm, 15-20 cm, 20-25 cm. For each sample tree the DBH and total height (H) of the stand trees were first recorded. Trees were felled close to ground level. The trees were selected to ensure a representative distribution of diameter classes within the sampling plots. Individuals were selected on the basis of their availability and the absence of human exploitation (traces of pruning or limping) or disease. Before the trees were felled, the diameters of the individuals with bark were determined using a tape and the total height was determined using a clinometer. The individuals were then cut 5 cm from the ground using a chainsaw and divided into compartments: the leaves; branches and trunks. The stems and large branches were cut into small pieces, and bagged and weighed with a scale in the field.

All 40 trees selected for destructive sampling were excavated for belowground tree component analysis. Once excavated, the main tree components were treated as by [52] as follows: (i) Root crown was cleaned to remove soil and weighed for green weight. (ii) All broken roots (roots not excavated) were measured for top diameter at breakage point on the root crown. Tap root was followed to the point where its diameter was nearly equal to the top diameter of the largest side root, and its weight was included to the weight of root crown. (iii) From each sample tree, 3 main roots (small, medium and big) were selected and traced to minimum diameter of 1 cm. The top diameter and weight of each sample root were measured and recorded. When main roots enter obstacles (stone or another tree) the end point diameter was measured.

A sample from each compartment was taken and dried in an oven for 48 hours, at a temperature of 70 °C for the leaves and 105 °C for the stem, branch discs. The water contents of the samples of leaves, branches and trunks will be calculated according to the following formula:

$$WC\ (\%)\ =\ ((WM - DM)\ /\ DM)\ *\ 100 \tag{1}$$

Where: WC is the water content of the samples in percentage,
WM and DM are respectively the wet mass (Kg) and the dry mass (Kg) of the sample.
From the water content of the samples, the total dry masses of the fractions were calculated as follows:

$$TDM\ =\ 100\ *\ TWM\ /\ (100\ +\ WC) \tag{2}$$

Where: TDM is the total dry mass
TWM is the total wet mass (Kg).
The total dry masses are called biomass and expressed in Kilograms (Kg).

The wood density of *B. senegalensis* was determined later by harvesting with a chainsaw a few pieces of wood from different parts of the stems and branches. These wood samples were immediately weighed to the ground using a sensitive balance. Subsequently, they were kept in bags, labeled and marked and from the part removed, placed in the shade and protected from heat in the laboratory. These wood samples were then soaked in water contained in a graduated cylinder, placed on a previously calibrated balance to finish determining the volume of wood [53]; all this with respect for Archimedes' principle. These samples were then dried in an oven at a constant temperature of 105 ° C [54] for about 72 hours depending on the plant material. From the third day of drying, each compartment was weighed every six hours using a very sensitive electric balance until a constant weight was obtained [55]. When the weight becomes constant, it is deduced while all the water contained in the material is totally evaporated. The data of each weighing has been saved. The density of the wood was obtained using the dry weight to volume ratio according to the formula of [53] below: WDi = DWi / Vi; where WD is the wood density i, DWi the dry weight of species i and Vi the volume of water of species.

2.3.2. Sample Plots and Inventory Design

Quadrats of 20 m x 20 m were installed on four stands of *B. senegalensis* according to the criteria of densities, areas, topographies and each quadrat is spaced 5 m apart. A total of 25 quadrats were installed, for a total sampling area of 1 ha per site. Sampling bands were established using the compass, decameter, GPS and rope. At the ends of each strip, the stakes were planted at an equidistant distance of 20 m. Along the quadrat, all woody plants with Dbh> 5 cm were inventoried. Along the sub-quadrat, all the woody plants have been inventoried. All the trees were systematically counted and measured. The dendrometric data related to the measurement of dbh (Diameter at breast height) and total height were determined using a clinometer. Thus, the circumferences of the woody plants were measured using a tape measure at 1.30 m from the ground. The circumference values were then converted to diameter (dhp) according to the formula: C = πD, with C = circumference, D = diameter and π = 3.14. To characterize the vegetation structure of the stands, the density and the basal area were calculated.

2.3.2.1. Herbaceous and litter biomass

The classical clear cut method was used for the quantification of herbaceous biomass. On each elementary plot (400 m²), 05 frames of 1 m x 1 m were installed for the collection of herbaceous plants using the secateurs. The herbaceous collection took place from May-August. A total of 5 samples were taken per 20 m x 20 m boring unit, which corresponds to a total of 20 samples per stand. A total of 80 samples (4 site x 5 samples x 4 replicates x 1 area) for the four sites studied. For the estimation of the carbon stock in the litter, about twenty square quadrats of 0.5 x 0.5 m² each, spaced 20 m from each other were installed randomly inside each site following the method of quadrats. The biomass of the litter is collected monthly from January-February. A total of 5 samples were taken per 20 m x 20

m boring unit, which corresponds to a total of 20 samples per site. A total of 80 samples (4 site x 5 samples x 4 replicates x 1 area) for the four sites studied.

To determine the moisture content, the samples are returned quickly to the laboratory where they are reweighed, dried at 65°C to constant weight and then reweighed. The samples of litter and herbaceous plants dried in an oven at 65°C for 72 hours to constant weight, then reweighed and then ground for the determination of organic carbon by the calcinations method. The carbon was determined by incineration in an oven at 525°C, after passing in an oven at 105°C for 48 hours.

2.3.2.2. Deadwood biomass

On each elementary plot (400 m²), strips of 20 m x 20 m were installed for the collection of dead wood. In these bands, only dead wood in the interior was measured. Unmarked dead wood from outside the plot that fell inside it was not measured, while unmarked dead wood from inside the plot that is fallen outside of it was measured.

2.3.2.3. Soil samples and laboratory analysis

Soil samples are taken from December-January. In each 400 m² survey, soil samples were taken in 0.25 m x 0.25 m frames. These samples are taken at 0-10 cm, 10-20 cm, 20-30 cm, 0-30 cm depths on the four elementary plots. Each depth of soil level was collected with a machete and trowel and then immediately put in a sealed bag in a cooler, in the shade to prevent evaporation. In total, 3 samples were taken per sampling unit, which corresponds to a total of 12 samples per site and then homogenized to obtain an aggregate sample. A total of 48 samples (4 site x 3 depths x 4 replicates x 1 area) for the four sites studied, then were dug into the ground to a depth of 30 cm**.** The organic carbon of the soil was determined by the method of Walkley & Black [58] which is an oxidation with potassium bicarbonate ($K_2Cr_2O_7$) in an acidic medium (H_2SO_4) according to NF ISO 14235 [59]. The assay was done by calorimetry. The organic matter content was obtained by multiplying the organic carbon rate by the Sprengel factor which is 1.724 for cultivated soils and 2 for non-cultivated soils.

The bulk density at the various research sites was determined by the cylinder method. It consists of taking a soil sample using a hollow metal cylinder of 100 cm³ volume. The soil extracted with the cylinder is levelled at the ends. The volume of soil removed is equal to that of the cylinder. The soil is then removed and dried at 105°C or 48 hours, it was weighed again.

Bulk density (BD) = (weight of dried soil-weight of empty cylinder)/ (Volume of the core) with BD (g/cm³); weight of dried soil (g); empty cylinder (g); volume of the core (cm³).

The granulometric analysis was carried out by the Robinson pipette method on airdried soil samples sieved at 2 mm. The organic matter was previously destroyed by hydrogen peroxide attack. The soil was then dispersed by rotary agitation in flasks after the addition of sodium hexametaphosphate (NaPO3)6. The different particle size fractions were determined by pipetting for the clay and silt fractions and by sieving for the sand. The textural classes were found by using the FAO Textural Triangle, once the proportions of the different textural fractions were calculated.

2.4. Data Analysis

2.4.1. Biomass equations

Biomass equations using DBH, H and WD as the independent variable were developed and were regressed against the leaves, branches, stem, above and below ground Biomass allometric model of individual trees were derived from 40 sample trees in the North region of Cameroon.

We first used the distance of Cook's residuals to identify outliers of explanatory and response variables [37]. We then examined the theoretical relationship between the response variable and the explanatory variables, testing the linear, logarithmic, exponential and power regression models. The response variable is the biomass expressed in kg and the explanatory variables are the diameter at breast height (DBH) and tree height (H). The best theoretical model retained to develop the equations for predicting the biomass of leaves, branches, stem, AGB and BGB of the tree for this species is the power model:

$$B = a * Db \tag{3}$$

where B is the biomass, D is the diameter and, a and b, the coefficients of regression [6, 16, 37].

The following models were considered for estimating Biomass (*B*, kg dry weight) from DBH, H and WD where *a, b, c, d* and e are coefficients [13, 15, 21, 22, 23, 25, 28, 30]:

$$\ln(B) = a + b \times \ln(D) \text{ (Eq. 1)} \tag{4}$$

$$\ln(B) = a + b \times \ln(D \times H) \text{ (Eq. 2)} \tag{5}$$

$$\ln(B) = a + b \times \ln(D \times \rho) \text{ (Eq. 3)} \tag{6}$$

$$\ln(B) = a + b \times \ln(D^2 \times H) \text{ (Eq. 4)} \tag{7}$$

$$\ln(B) = a + b \times \ln(D^2 \times \rho) \text{ (Eq. 5)} \tag{8}$$

$$\ln(B) = a + b \times \ln(D^2 \times H \times \rho) \text{ (Eq. 6)} \tag{9}$$

$$\ln(B) = a + b \times \ln D + c \times (\ln(D))^2 \text{ (Eq. 7)} \tag{10}$$

$$\ln(B) = a + b \times \ln(D) + c \times \ln(\rho) \text{ (Eq. 8)} \tag{11}$$

$$\ln(B) = a + b \times \ln(D) + c \times \ln(H) \text{ (Eq. 9)} \tag{12}$$

$$\ln(B) = a + b \times \ln(D^2 \times H) + c \times \ln(\rho)) \text{ (Eq. 10)} \tag{13}$$

$$\ln(B) = a + b \times \ln D + c \times \ln H + d \times \ln(\rho) \text{ (Eq. 11)} \tag{14}$$

$$\ln(B) = a + b \times \ln(D) + c \times \ln(D^2 \times H) + d \times \ln(\rho) \text{ (Eq. 12)} \tag{15}$$

$$\ln(B) = a + b \times \ln D + c \times \ln D^2 + d \times \ln D^3 + e \times \ln(\rho) \text{ (Eq. 13)} \tag{16}$$

The logarithmic transformation of the data generally leads to a bias in the estimation of Biomass [21, 37, 56]; a correction is therefore necessary and consists in multiplying the estimated Biomass by a correction factor (CF) which is calculated as follows:

$$CF = \exp(RSE^2/2)$$

CF is a number always greater than 1 [23].

Three criteria were used to test the robustness and precision of the models in the estimation of above-ground biomass. They are in order of importance:

Adjusted coefficient of determination (Adjusted. R^2).

AIC or Akaike Information Criterion obtained by the following formula:

$$AIC = -2\ln(L) + 2p \tag{18}$$

(L "Likelihood" or Probability at which the predicted model is correct to the unknown true and p: Total number of parameters of the model) [57].

RSE or Residual standard error obtained by the following formula:

$$RSE = \sqrt{\frac{\sum(AGB_{obs} - AGB_{pred})}{n-2}} \tag{19}$$

Where RSE: Residual standard error; AGB obs: Measured above-ground biomass; AGB pred: Predicted above-ground biomass, n= data points in population.

Several goodness-of fit were combined to evaluate the developed allometrics models performance. Thus, the lowest residual standard error (RSE), Akaike information criterion (AIC), and the highest adjusted R^2 values indicated the best models [16, 30].

Eventually, root to shoot ratio was calculated as ratio of below ground biomass to aboveground biomass.

$$R: S = BGB/AGB \tag{20}$$

Where; (R: S): Root to shoot ratio, BGB: Below ground biomass, AGB: Above ground biomass.

2.4.2. Vegetation structure

Density calculation
Densities (D) of individual trees were estimated using the formula according to [7]:

$$D = n/S \tag{21}$$

Where D= Density (stems/ha), n = total number of individuals in a sample plot; S = area of the sample plot (ha).

Basal area calculation
The Basal area (Ba) of individual trees was estimated using the formula according to [7]:

$$BA = \frac{\pi}{4}D^2 \tag{22}$$

Where Ba = Basal area (m^2), D = dbh (cm) and π = 3.142 (constant)

2.4.3. Biomass and carbon stock estimation

2.4.3.1. Estimation of above (AGB) and below ground biomass (BGB)

The determination of the amount of carbon present in the different components of the tree and in each plantation was made based on the allometric equations developed Table 4 according to the carbon stock models for the different tree components.

According to [83], the content of carbon in woody biomass of any forest is generally 50% of the tree total volume. Therefore, the weight of carbon in the tree was calculated by multiplying the dry weight of the tree by 50%.

2.4.3.2. Herbaceous and litter biomass

$$DM = (DW/WW) * 100 \tag{23}$$

Where DM = Quantity of dry matter (%); DW = dry weight of the sample after three days in the oven at 65°C (g); WW=wet weight of the sample measured in the field (g) [7].

$$B = (TWW * DM)/100 \tag{24}$$

Where: B = biomass (g); TWW = Total wet weight in measured in the field (g); DM = percentage of dry matter (%)[7].

2.4.3.3. Dead wood biomass

Calculating dead wood biomass was done using the formula used by[7,84] :

$$V = \pi^2 (\Sigma di^2) / 8L \tag{25}$$

Where dead wood biomass (m³/ha); Di: diameter of each wood debris sampled (m); L: length of the quadrat (m) = 20 m in the case of our study.

Translating the results obtained from the bulk volume was made by setting the value of wood density to 0.47 KgMS.m$^{-3[7, 84]}$.

The portion of the dry mass of carbon stock is made by the following equation [7]:

$$DWCS = (DM) \times FC \tag{7}$$

Where DWC= Dead wood carbon stock (tC/ha), DM= Quantity of dry matter (%); FC= Factor conversion=0.5 [7, 84]

2.4.3.4. Soil organic carbon

$$SOCS = \%\,C \times BD \times d \tag{26}$$

Where: SOCS= Soil organic carbon stock per unit area (tC.ha^{-1}), %C= Carbon concentration (%), d= Soil depth (cm), and BD: Bulk density (g.cm^{-3}) [61].

2.4.3.5. Total carbon

$$TC = AGC + BGC + LC + HC + DWC + SOCS \tag{27}$$

Where AGC= Aboveground carbon stock (tC.ha^{-1}), BGC= Belowground carbon stock (tC.ha^{-1}), LC=Litter carbon stock (tC.ha^{-1}), HC= Herbaceous carbon stock (tC.ha^{-1}), DWC=Dead wood carbon stock (tC.ha^{-1}), SOC= Soil organic carbon stock (tC.ha^{-1}) and TC=Total carbon (tC.ha^{-1}).

2.4.3.6. Atmospheric CO_2 equivalent stock

With regard to the sequestered atmospheric CO_2 stock, it is recognized that the atomic mass of Carbon is 12 and the one Oxygen is 16. Consequently, the molecular mass of CO_2 is 44. Thus, the ratio of the combination of carbon (C) and oxygen (O_2) is 3.67. The equivalent atmospheric CO_2 stock (VCO$_2$eq) is estimated by multiplying the carbon stock from biomass by 3.67 [7].

$$\textbf{Atmospheric CO}_2 \textbf{ equivalent stock} = \text{Total carbon} \times 3.67 \tag{28}$$

2.5. Statistical analysis

The data were encoded in EXCEL software and then analyzed using STAT-GRAPHICS plus 5.0 and R software. Analysis of variance (ANOVA) was used to test the existence or not of a significant difference in the difference parameters. Duncan test at 0.05 was used to compare parameter means.

3. Results

3.1. Dendrometric characteristics and correlation between dendrometric parameters and biomass

The average values of the diameter, height and wood density are 15.28 cm, 3.09 m and 0.58 g.cm^{-3} respectively (Table 1). Pearson's correlation showed that AGB and BGB are significantly correlated only with diameter, while leaves, branches biomass are significantly correlated with diameter, height and wood density. So the stem biomass was significantly correlated only with diameter and height (Table 2).

Table 1. Dendrometric characteristics of sampled trees

Item	DBH (cm)	H(m)	WD or ϱ (g.cm^{-3})
Minimum	5.76	1.60	0.28
maximum	24.80	4.58	0.88
Mean	15.28	3.09	0.58

Dbh: Diameter at Breast height, H: Height, WD or ϱ: wood density.

Table 2. Correlation between Diameters (Dbh), Height (H), wood density (WD) with Biomass

Item	Dbh (cm)	H (m)	WD or ϱ (g.cm^{-3})
Leaves	0.95***	0.88***	0.88***
Branches	0.90***	0.73***	0.73***
stem	0.87***	0.55*	0.28ns
AGB	0.96***	0.23ns	0.23ns
BGB	0.85***	0.35ns	0.35ns

*: Significant, **: Very significant, ***: Highly significant, ns: no significant

3.2. Developed allometric equations

Table 3 presents the allometric models developed for *B. Senegalensis*. The regression coefficients were statistically significant (p <0.001) for all models. These coefficients varied between the same models developed in all compartments, with RSE and AIC ranging from 0.400 - 0.598 kg and 6.82-22.04 kg respectively, while their Adj.R^2 varies from 0.44 - 0.97 (Table 3).

Table 3. Models parameters and performance criteria for biomass estimation

Compartments	Models	Regressions coefficients					Adj.R^2	RSE	AIC	FC
		a	b	c	d	e				
	1	1.04**	0.38 **				0.75	0.445	8.75	1.10
	2	0.52***	0.011*				0.74	0.433	7.88	1.09
	3	2.45**	0.29**				0.76	0.487	7.98	1.12
	4	0.82***	0.09***				0.87	0.401	6.87	1.08
	5	0.44**	0.64 **				0.85	0.445	10.01	1.10
	6	0.08 ***	0.31*				0.88	0.400	6.82	1.08
Leaf	7	1.92**	2.09**	0.71**			0.76	0.473	11.06	1.11
	8	0.80***	2.02***	0.31**			0.67	0.438	9.87	1.10
	9	3.08**	1.50**	0.01**			0.65	0.459	10.42	1.11
	10	3.15***	1.11*	0.78**			0.74	0.483	9.73	1.12
	11	1.02**	0.40**	0.31**	0.15**		0.76	0.487	7.96	1.12
	12	3.21***	0.22***	0.10**	0.82**		0.77	0.408	10.97	1.08
	13	1.04**	0.84**	0.10**	0.02**	0.38**	0.85	0.445	11.05	1.10
	1	2.54**	0.88**				0.73	0.425	10.04	1.09
	2	0.92***	1.11*				0.78	0.411	12.08	1.08
Branch	3	0.72**	0.94**				0.83	0.438	10.41	1.10
	4	0.53***	1.79***				0.75	0.451	10.05	1.10

	5	1.04**	0.49**				0.84	0.409	9.88	1.08
	6	0.14***	0.65*				0.89	0.403	8.53	1.08
	7	-0.03**	-1.89**	0.61**			0.77	0.418	10.07	1.09
	8	0.40***	0.92***	-0.01**			0.74	0.415	8.97	1.08
	9	3.08**	0.50**	0.01**			0.84	0.411	10.24	1.08
	10	0.15***	-0.11*	-0.08**			0.71	0.417	9.05	1.09
	11	1.02**	0.40**	0.31**	0.15**		0.82	0.418	10.00	1.09
	12	-0.88***	0.02***	-0.10**	0.82**		0.68	0.415	10.11	1.08
	13	-2.94**	0.33**	0.10**	0.02**	0.08**	0.76	0.423	10.94	1.09
Stem	1	0.04**	-1.88**				0.86	0.487	9.70	1.12
	2	-0.30***	2.81*				0.87	0.426	10.07	1.09
	3	-2.72**	0.04**				0.85	0.445	10.00	1.10
	4	2.03***	1.32***				0.95	0.401	8.04	1.08
	5	-5.04**	0.98**				0.86	0.412	9.06	1.08
	6	0.47***	-5.65*				0.88	0.421	10.07	1.09
	7	-6.03**	-1.05**	-6.61**			0.80	0.407	9.76	1.08
	8	-7.40***	2.92***	-0.81**			0.90	0.428	10.89	1.09
	9	0.08**	-0.90**	0.31**			0.83	0.415	11.01	1.08
	10	-3.15***	-0.11*	-0.08**			0.91	0.403	10.48	1.08
	11	0.92**	-7.40**	0.01**	0.75**		0.86	0.407	9.03	1.08
	12	-4.01***	0.23***	-0.43**	0.01**		0.93	0.418	10.99	1.09
	13	2.04**	-0.54**	-1.19**	0.22**	0.07**	0.76	0.405	13.03	1.08
AGB	1	4.55**	2.85**				0.97	0.408	10.07	1.08
	2	2.92***	-4.11*				0.85	0.445	10.65	1.10
	3	0.72**	0.94**				0.94	0.433	10.94	1.09
	4	-4.53***	0.09***				0.76	0.487	10.76	1.12
	5	-2.04**	0.01**				0.87	0.468	10.57	1.11
	6	0.14***	-0.05*				0.86	0.487	10.76	1.12
	7	-5.03**	-1.00**	1.01**			0.80	0.438	10.85	1.10
	8	2.00***	-6.92***	-0.98**			0.65	0.445	10.65	1.10
	9	-7.33**	0.77**	0.63**			0.93	0.431	10.94	1.09
	10	0.05***	-8.02*	2.06**			0.78	0.480	10.70	1.12
	11	1.09**	-0.80**	2.31**	-6.50**		0.67	0.452	10.63	1.10
	12	-3.08***	1.11***	0.76**	1.02**		0.77	0.489	10.36	1.12
	13	1.31**	0.03**	-2.18**	0.58**	0.12**	0.91	0.422	10.15	1.09
BGB	1	3.04**	1.64**				0.85	0.500	8.05	1.13
	2	0.92***	1.11*				0.44	0.598	22.04	1.19
	3	0.72**	0.94**				0.73	0.587	20.90	1.18
	4	0.53***	1.79***				0.47	0.508	10.07	1.13
	5	1.04**	0.49**				0.50	0.567	19.03	1.17
	6	0.14***	0.65*				0.57	0.518	10.07	1.14

						Adj.R²	CF	RSE	AIC
7	-0.03**	-1.89**	0.61**			0.65	0.525	11.65	1.14
8	0.40***	0.92***	-0.01**			0.64	0.503	11.44	1.13
9	3.08**	0.50**	0.01**			0.80	0.557	18.32	1.16
10	0.15***	-0.11*	-0.08**			0.67	0.508	10.07	1.13
11	1.02**	0.40**	0.31**	0.15**		0.76	0.527	10.76	1.14
12	-0.88***	0.02***	-0.10**	0.82**		0.70	0.528	10.07	1.14
13	-2.94**	0.33**	0.10**	0.02**	0.08**	0.75	0.525	10.65	1.14

The coefficients at $p < 0.001$ are significantly different from zero; *: Significant, **: Very significant, ***: Highly significant, AGB: Aboveground biomass, BGB: Belowground biomass, D: Diameter, H: Height, WD: Wood density, Coefficient of regression model (a, b, c, d and e), coefficient of determination adjusted (Adj.R²), correction factor (CF), residual standard error (RSE) and Akaike information criteria (AIC).

3.2. Best Models selected across

Predicted parameters varied between tree compartments. DBH accurately predicted the AGB and BGB (Table 4). Stem biomass were better predicted with $D^2 \times h$ (Table 4). The leaves and branches biomasses were better predicted with $D^2 \times H \times \varrho$. These best equations are shown in Table 4 and Figure 3 shows their adjustments.

Table 4. Selection of the Best Models

Models	Adj.R²	RSE	AIC	CF
ln (leaf biomass) = 0.08 + 0.31*ln ($D^2 \times H \times \varrho$)	0.88	0.400	6.82	1.08
ln (branch biomass) = 0.14 + 0.65*ln ($D^2 \times H \times \varrho$)	0.89	0.403	8.53	1.08
ln (stem biomass) = 2.03 + 1.32*ln ($D^2 \times H$)	0.95	0.401	8.04	1.08
ln (AGB) = 4.55 + 2.85*ln(D)	0.97	0.408	10.07	1.08
ln (BGB) = 3.04 + 1.64*ln(D)	0.85	0.500	8.05	1.13

AGB: Aboveground biomass, BGB: Belowground biomass, ln: logarithmic, D: Diameter, H: Height, ϱ: wood density, Coefficient of determination adjusted (Adj.R²), residual standard error (RSE) and Akaike information criteria (AIC).
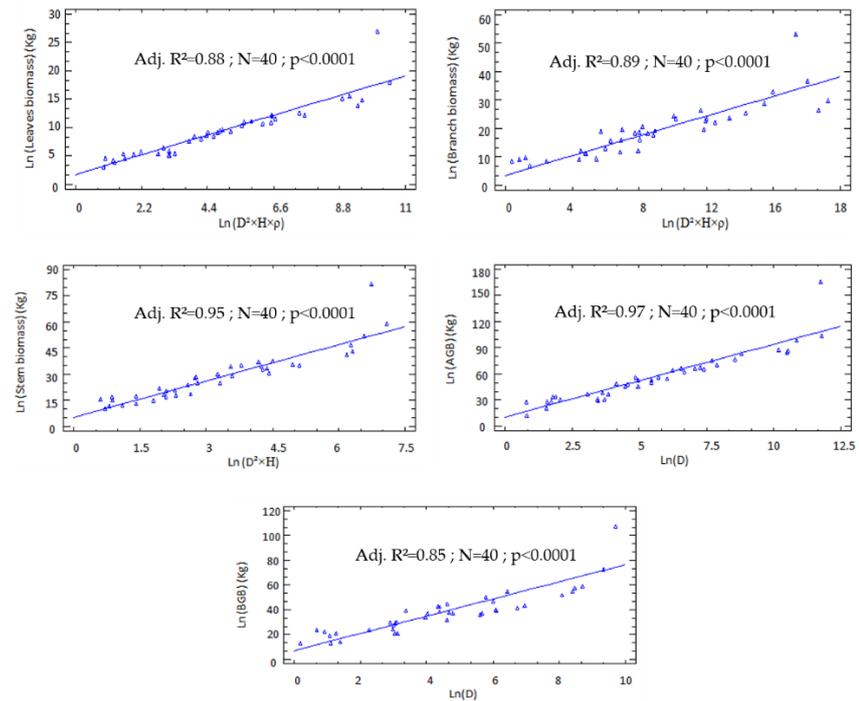
Figure 3. Linear regressions between parameter (D, H and ρ) with leaves biomass (a), branch biomass (b), stem biomass (c), aboveground biomass (AGB) (d) and belowground biomass (BGB) (e)

3.3. Ratios between belowground Biomass, Biomass from other above-ground compartments and Total aboveground Biomass

The average ratios of root biomass to other parts of the tree (ratio) were evaluated (Table 5). The average ratio of root biomass to other tree components ranges from 0.25 to 1.88. However, the most important biomass in the estimates is the total biomass (Table 5).

Table 5. Average ratios according to the compartments

Ratios	BGB /LB	BGB /BB	BGB/SB	BGB /TAGB
Mean (STD)	1.88 (0.83)	0.68 (0.32)	0.66 (0.21)	0.25 (0.12)

BGB: Belowground biomass, LB: Leaves biomass, BB: Branch Biomass, SB: Stem biomass, TAGB: Total Aboveground biomass, STD: Standard deviation.

3.4. Root-shoot ratio

The calculated root / stems ratio (R: S), for all samples of *B. senegalensis* destroyed had the overall mean of 0.24, for all diameter classes. In addition, the trend shows that, R: S, increases with increasing diameter class rate, and tend to decrease at a diameter of 15-20 cm to 20-25 cm (Table 6). The calculated R: S varies significantly in all the classes of Dbh (p <0.05).

Table 6. Root shoot ratio

			R:S Ratio			
Variables Dbh class (cm)	n	mean	minimum	maxi-mum	Standard deviation
0-5 cm	5	0.23ab	0.05	0.41	0.02
5-10 cm	9	0.26b	0.08	0.45	0.03
10-15 cm	11	0.34c	0.04	0.65	0.04
15-20 cm	15	0.20ab	0.02	0.38	0.02
20-25 cm	20	0.17a	0.09	0.25	0.01

Between the columns,Values assigned the same letter are not statistically different ($p > 0.05$; Duncan's test)

The difference in rainfall could explain the rooting in the two types of soil. In areas with insufficient rainfall, species tend to develop deep rooting [14,15].

3.5. Vegetation structure

The average density of four sites is 335.75 ± 25.89 individuals / ha. The highest density was recorded in site 4 (535 ± 41.85 individuals / ha). The analysis of variance shows that there is a significant difference in density between the four sampled sites ($p < 0.05$) (Table 7).

The mean basal area of four sites is 5.77 ± 1.16 m² / ha. The highest basal area was recorded in site 3 (10.88 ± 2.62 m² / ha). Analysis of variance shows that there is a significant difference in basal area between the four sampled sites ($p < 0.05$) (Table 7).

Table 7. Density and basal area in the four sites

Sites	Density (individuals/ha)	Basal area (m²/ha)
Site 1	395 ± 30.05c	3.93 ± 0.65b
Site 2	285 ± 21.02b	5.55 ± 1.05c
Site 3	128 ± 10.65a	10.88 ± 2.62d
Site 4	535 ± 41.85d	2.74 ± 0.35a
Mean	335.75 ± 25.89	5.77 ± 1.16

Between the columns,Values assigned the same letter are not statistically different ($p > 0.05$; Duncan's test)

3.6. Estimation of Carbon stock

3.6.1. Carbon pools

The Aboveground carbon vary from $7.09 \pm 0.42 - 9.01 \pm 0.50$ tC/ha with a higher value in site 3. The analysis of variance does not show a significant difference in the aboveground carbon between the four sites studied ($F = 0.05$; $P = 0.53 > 0.05$) (Table 8).

Table 8. Estimation of Carbon pools for compartments within sites

Sites	Aboveground					Belowground	
	Leaf(t/ha)	Branch(t/ha)	Stem (t/ha)	TAGB(t/ha)	AGC (tC/ha)	BGB (t/ha)	BGC (tC/ha)
Site 1	2.54 ± 0.11a	4.87 ± 0.27a	7.87 ± 0.39a	15.28 ± 2.98a	7.64 ± 0.42a	9.45 ± 1.42a	4.72 ± 0.28a
Site 2	3.87 ± 0.13a	4.79 ± 0.25a	8.87 ± 0.43a	17.53 ± 3.10a	8.76 ± 0.45a	10.83 ± 1.45a	5.41 ± 0.30a
Site 3	4.00 ± 0.14a	5.05 ± 0.28a	8.98 ± 0.44a	18.03 ± 3.12a	9.01 ± 0.50a	14.22 ± 1.50a	7.11 ± 0.35a
Site 4	2.09 ± 0.10a	4.56 ± 0.20a	7.54 ± 0.40a	14.19 ± 2.90a	7.09 ± 0.42a	8.74 ± 1.42a	4.37 ± 0.26a
Mean	3.12 ± 0.12	4.81 ± 0.25	8.31 ± 0.41	16.25 ± 3.02	8.12 ± 0.44	10.81 ± 1.44	5.40 ± 0.29

Aboveground biomass (AGB), belowground biomass (BGB), Aboveground Carbon contents (AGC) and belowground Carbon contents (BGC).Between the columns,values assigned the same letter are not statistically different (p > 0.05; Duncan's test)

The belowground carbon vary from 4.37 ± 0.26 - 7.11 ± 0.35 tC/ha with a higher value in site 3. Analysis of variance does not show a significant difference in the belowground carbon between the four sites studied (F = 0.08; P = 0.62> 0.05) (Table 8).

The litter carbon vary from 0.50 ± 0.02 - 0.95 ± 0.04 tC/ha with a higher value in site 3. The analysis of variance does not show a significant difference in the litter carbon between the four sites studied (F = 0.38; P = 0.298> 0.05) (Table 9).

Table 9. Estimation of Carbon litter, herbaceous and dead wood within sites

Sites	LC(t/ha)	HC(t/ha)	DWC (t/ha)
Site 1	0.65 ± 0.01a	1.80 ± 0.27a	7.65 ± 0.39c
Site 2	0.87 ± 0.03a	1.69 ± 0.25a	5.87 ± 0.43b
Site 3	0.95 ± 0.04a	1.05 ± 0.28a	8.98 ± 0.44a
Site 4	0.50 ± 0.02a	1.86 ± 0.20a	3.03 ± 0.40d
Mean	0.74 ± 0.02	1.60 ± 0.25	6.63 ± 0.41

Litter Carbon (LC), herbaceous Carbon (HC), dead wood Carbon (DWC). Between the columns,values assigned the same letter are not statistically different (p > 0.05; Duncan's test)

The herbaceous carbon vary from 1.05 ± 0.28 - 1.86 ± 0.20 tC/ha with a higher value in site 4. The analysis of variance does not show a significant difference in the herbaceous carbon between the four sites studied (F = 0.104; P = 0.105> 0.05) (Table 9).

The dead wood carbon vary from 3.03 ± 0.40 - 8.98 ± 0.44 tC/ha with a higher value in site 3. The analysis of variance does not show a significant difference in the dead wood carbon between the four sites studied (F = 0.098; P = 0.25> 0.05) (Table 9).

3.6.2. Soil Physical Characteristics

The Bulk densities vary between sites. The highest value is recorded in site 1 (1.60 ± 0.02 g/cm³). The analysis of variance does not show a significant difference in the Bulk density between the four sites studied (F = 0.03; P = 0.563> 0.05) (Table 10).

Table 10. Variation in bulk density as a function of depth under different sites

Depth (cm)	Site 1	Site 2	Site 3	Site 4
0-10	1.64 ± 0.02a	1.06 ± 0.00a	1.31 ± 0.01a	1.49 ± 0.02a
10-20	1.45 ± 0.01a	1.63 ± 0.03a	1.22 ± 0.00a	1.34 ± 0.01a
20-30	1.72 ± 0.03a	1.41 ± 0.02a	1.35 ± 0.02a	1.65 ± 0.04a
Mean	1.60 ± 0.02	1.36 ± 0.01	1.29 ± 0.01	1.49 ± 0.02

Between the columns,values assigned the same letter are not statistically different (p > 0.05; Duncan's test)

The granulometry distribution made it possible to distinguish 2 textural classes including sandy and sandy clay. The soils studied are predominantly sandy. Data analysis for the textural fractions of the soils (Clay: P-value = 0.068; Silt: Pvalue = 0.078 and Sand: P-value = 0.084) show that there is a variation in the textural composition of the soils at different depths between the four sites studied (Table 11).

Table 11. Soil texture under the different sites

Textural fractions	Site 1	Site 2	Site 3	Site 4
% Sand	48 ± 5.50b	88 ± 9.52b	50 ± 5.75c	45 ± 5.03b
% Silt	12 ± 1.54a	5 ± 1.51a	10 ± 2.05a	14 ± 2.10a
% Clay	40 ± 5.48b	7 ± 1.76a	40 ± 4.43b	41 ± 5.00b
Textural classes	Sandy clay	Sandy	Sandy clay	Sandy clay

Between the columns,values assigned the same letter are not statistically different (p > 0.05; Duncan's test)

3.6.3. Soil organic carbon stock

The Soil Organic Carbon Stock varies between sites. The highest value is recorded in site 3 (6.14 ± 1.05 tC/ha). The analysis of variance does not show a significant difference in the Soil Organic Carbon Stock between the four sites studied (F = 0.085; P = 0.38> 0.05) (Table 12).

Table 12. Estimation of S0C within sites

sites	0-10 cm	10-20 cm	20-30 cm	Total (0-30 cm)
Site 1	2.64 ± 0.38a	1.45 ± 0.30a	0.72 ± 0.19a	4.81 ± 0.84a
Site 2	1.76 ± 0.34a	1.63 ± 0.35a	1.41 ± 0.28a	4.80 ± 0.80a
Site 3	2.81 ± 0.40a	2.22 ± 0.38a	1.11 ± 0.23a	6.14 ± 1.05a
Site 4	1.69 ± 0.32a	1.34 ± 0.28a	1.30 ± 0.26a	4.33 ± 0.79a
Mean	2.22 ± 0.36	1.66 ± 0.32	1.13 ± 0.24	5.02 ± 0.87

Between the columns,values assigned the same letter are not statistically different (p > 0.05; Duncan's test)

3.6.4. Total carbon and CO_2 equivalent stock

The Total Carbon varies between sites. The highest value is recorded in site 3 (33.24 ± 4.28 tC/ha). The analysis of variance does not show a significant difference in the Total Carbon between the four sites studied (F = 0.03; P = 0.508> 0.05) (Table 13). The sequestered atmospheric CO_2 stock varies between sites. The highest value is recorded in site 3 (121.99 ± 10.44 tCO₂eq.ha⁻¹). The analysis of variance does not show a significant difference in the sequestered atmospheric CO_2 stock between the four sites studied (F = 0.37; P = 0.08> 0.05) (Table 13).

Table 13. Total carbon and Atmospheric CO_2 equivalent stock

sites	Total Carbon (tC/ha)	Atmospheric CO_2 equivalent stock (tCO₂eq.ha⁻¹)
Site 1	27.27 ± 3.27a	100.08 ± 8.39a
Site 2	27.40 ± 3.35a	100.55 ± 8.43a
Site 3	33.24 ± 4.28a	121.99 ± 10.44a
Site 4	21.18 ± 3.00a	77.73 ± 6.40a
Mean	27.27 ± 4.47	100.08 ± 8.41

Between the columns,values assigned the same letter are not statistically different (p > 0.05; Duncan's test).

4. Discussions

The study established allometric equations for estimating the above-ground and below-ground biomass of *B. senegalensis* in the diameter range between 5.76 and 24.80 cm

with mean (15.28 cm). This result is not similar to those of [60] (2.87 ± 1.18 cm) for *B. senegalensis* in Senegal. The allometric models developed vary from one compartment to another. The choice of method and mathematical model for adjusting the parameters must be considered judiciously in estimating the biomass of woody plants [37]. The leaf biomass, branch biomass, stem biomass, aboveground biomass (AGB) and belowground biomass (BGB) of individuals were fitted using the linear form of the power model. This mathematical model has been widely used in the literature for the prediction of standing biomass of woody species in Africa [11, 23, 24, 34, 37]. The sample size was 40 individuals. Indeed, the size of the sample in the development of allometric models is variable in the literature and takes into account the resources and time allocated to the study [6]. Some allometric biomass equations have been constructed from a limited number of individuals, 20 trees [62], 38 trees [63] , 17 trees [6] , 20 trees [64], 15 and 43 trees [60].

The average base wood density calculated for *B. senegalensis* in this study is 0.58 g/cm^3. This result is similar to those of [65] reported an average value of 0.58 g/cm^3 for 129 trees of *Aglaia argentea* in South-East Asia (tropical), [65] reported an average value of 0.58 g/cm^3 for 43 trees of *Aglaia cucullata* in South-East Asia (tropical), [65] reported an average value of 0.58 g/cm^3 for 16 trees of *Aglaia lawii* in South-East Asia (tropical).This result is not similar to those of [66] (0.50 g/cm^3) for *Anacardium occidentale* in Benin and [67] (0.52 g/cm^3) for *Mangifera indica* in tropical Africa. The wood density in this study is lower than the values reported for *Tectona grandis* plantations (0.70 g/cm^3) by [80]. In addition, [68] reported an average value of 0.54 g/cm^3 from 123 species in the tropical forest of Panama and [19] reported an average value of 0.60 g/cm^3 for 470 species from tropical America. The differences between the estimates obtained in this study and the values in the database suggest that the wood density from the databases may introduce errors in the biomass estimates. The wood density from field measurements can therefore greatly improve the precision of allometric equations compared to using estimates from the literature.

Indeed, power models generally remain extrapolable with good reliability because they are based on a fractal allometric model which is invariant at all scales [16]; which explains their wide use in biomass prediction equations for the benefit of logarithmic or polynomial models. The logarithmic transformation of the variables carried out in this study remains necessary to reduce the deviations that may exist in a real environment, and to satisfy the conditions of normality and homoscedasticity of the residuals [21]. The precision of the measurement of the explanatory variables is very decisive in the development of allometric equations [16]. DBH can be easily measured in the field with greater accuracy than other dendrometric parameters. In addition, this variable is always available in the inventory data. Numerous studies have also shown that DBH is the explanatory variable most commonly used for predicting the biomass of different compartments of woody species [10, 11, 36, 69].

However, the use of this variable alone did not allow an optimal prediction of the biomass of leaves and branches. The incorporation of total height and wood density was therefore necessary to improve the quality of prediction of the biomass of leaves and branches of *B. senegalensis* in the zone studies. Some authors believe that the use of DBH alone as an explanatory variable would lead to an increase in the predicted biomass [21, 36]. Previous studies have shown that incorporating height as a second variable improves the prediction performance of elaborate equations [10, 26, 36, 70] and has the advantage of increasing the potential of applicability of the equations to different sites [71]. Biomass prediction models vary according to different tree compartments. The results of these studies are similar to those obtained by [11, 32, 37, 71, 72] who showed a variation in allometric equations depending on the parts of the tree. In this study, the use of this variable DBH accurately predicted the AGB and BGB. Stem biomass were better predicted with D^2 × h. The leaves and branches biomasses were better predicted with D^2 × H × ϱ.

The logarithmic CF is a simple and straightforward statistical tool for eliminating systematic biases produced by converting the estimated logarithmic value to the original

untransformed scale [6]. However, previous studies indicated that CF are generally small compared to the variation generated by the biomass estimate and therefore can be omitted [34]. In the present study, the CF values for all component biomass equations were relatively low. Therefore, our results indicate that few errors were introduced when using the logarithmic transformation to fit allometric equations to biomass data.

The ratio established in our study is in line with other results found in the literature such as those of [34]. We did not find results for *B. senegalensis* in particular, but for woody plants in general, [10] determined a ratio of 0.28 which is close to the value found in our study. The small difference observed could be due, on the one hand, to the architectural forms [6] between the species used in this study and those studied by [6] and on the other hand, to the environmental conditions which are different in the two studies. The calculated root / stems ratio (R: S), for all samples of *B. senegalensis* destroyed had the overall mean of 0.24, for all diameter classes. These results are slightly low, comparable to those reported by [52] where R:S of 0.4 but higher than that of [73] where R: S of 0.18. However, these differences could have been attributed by site conditions, wood properties and management regimes.

The highest density was recorded in site 4 (535 ± 41.85 individuals/ha). This high value would reflect appreciable regeneration within the stands. Indeed, the importance of regeneration in the plots studied is the fact that it promotes land protection by preventing rainwater from having a beating effect through foliage and root systems [74]. This result is superior to those [60] in *B. senegalensis* (42 ± 7.3 ind/ha) and *S. birrea* (6.1 ± 3.4 ind/ha) , [75] in *Gmelina arborea* stands (sites 2 = 182 ± 4.57 individuals/ha and site 3 = 98 ± 2.01 individuals/ha), [73] in Cashew plantation (168 ± 22.65 individuals/ha). The difference in density of the site studied with the other authors could be related to the ecological characteristics of the study environments, Montag including soil types, topography, climate, and cover. These results are also superior to those of [76] who reported average TOF tree density of 156 individuals/ha under communal tenure, [77] who studied TOF in Mali reported less. They came with low densities of 8-20 stems/ha in village fields that had been cultivated and from [78] who reported a higher tree density of 250 individuals/ha in forestry operations in Kenya. The higher value of basal area observed in the site 3 (10.88 ± 2.62 m²/ha). The highest basal area in the site 3 indicated the large tree specimens. Among the species of its undergrowth, some have a high shade rate. This may explain the high proportion of species that can provide shade in any season. These results are not close to those [4,5,74]. Variation in stand and basal area can be caused by a number of factors such as site productivity and silvicultural management.

The highest aboveground carbon was recorded at site 3 (9.01 ± 0.50 tC/ha). Several factors could explain the spatial variability of carbon stocks recorded in the different site studied. [74] also point out that structural variables explain more of the spatial variation of biomass in tropical African forests. In fact, air carbon stock tends to increase with the increase of certain structural parameters such as basal area [79]. Then it may be noted that the most significant differences between carbon stocks between the studied orchards could lie in the importance of their basal areas and their resources dbh. The highest belowground carbon was recorded at site 3 (7.11 ± 0.35 tC/ha). The main change factors agroforestry soil carbon stocks are the climate, the dominant species, in connection with the type of humus, and qualitative characteristics (pedogenetic type) and quantitative soil (clay content and soil depth) [74,85].

The litter carbon varies from 0.50 ± 0.02 - 0.95 ± 0.04 tC/ha with a higher value in site 3. This variation could be explained by main reasons: because the litter in the site 3 comes in addition to crops, timber left standing, which adjoins the latter and the resulting wasteland debroussaged above its set up.

The herbaceous carbon varies from 1.05 ± 0.28 - 1.86 ± 0.20 tC/ha. This is explained by the fact that the closure of the forest negatively influences the carbon reservoir in the stratum herbaceous [7]. Thus, forest dynamics increasing carbon stocks in the tree and shrub layer at the expense of the herbaceous stratum [5].

The dead wood carbon vary from 3.03 ± 0.40 - 8.98 ± 0.44 tC/ha with a higher value in site 3. The differences in carbon stocks in dead wood could explain rated by [4] who point out that carbon stocks in dead wood vary between sites and study methods. The reason site 4 store more carbon in this component is certainly due to the fact that farmers have very little involvement in this type of system.

The Soil Organic Carbon Stock vary from 4.33 ± 0.79 - 6.14 ± 1.05 tC/ha. The carbon storage dynamics in agroforestry soil depends on changes in land use (deforestation, afforestation, etc.), climate and silvicultural practices mineralisatry increasing the activity of microorganisms in the soil (plowing, drainage, fertilization)[7, 85].

The highest total carbon was recorded in site 3 (33.24 ± 4.28 tC/ha).These values are within the range reported in forest farms in the Philippines by [81] where the carbon figures ranged from 0.98 tC/ha to 63.94 tC/ha, but are not within the range reported in the three agroforestry systems by [82] where the net carbon accumulation figures ranged from 17 to 18 tC/ha.The site 3 are great sinks of CO_2 ((121.99 ± 10.44 $tCO_2eq.ha^{-1}$).), this explains the absence of anthropogenic emissions of greenhouse gas effects [85].

5. Conclusions

This study shows that the allocation of tree biomass varies depending on the compartment of *B. senegalensis* in the North region of Cameroon. Power-type allometric models fit well to the above-ground and below-ground biomass of the different compartments of *B. senegalensis*. The study also highlighted the specificity of allometric equations according to the parts of the tree. DBH accurately predicted the AGB and BGB of *B. senegalensis*. Stem biomass were better predicted with (D^2 × h) of *B. senegalensis*. The leaves and branches biomasses were better predicted with (D^2 × H × ϱ) of *B. senegalensis*. All the models developed have a fairly good predictive capacity with regard to the small differences observed between the values observed and those predicted. The established allometric models can be used to estimate the biomass of *B. senegalensis* by component under similar environmental conditions. Density ranged between 128 ± 10.65 - 535 ± 41.85 individuals/ha; Basal area between 2.74 ± 0.35 -10.88 ± 2.62 m²/ha; Aboveground carbon ranged between 7.09 ± 0.42- 9.01 ± 0.50 tC/ha; Belowground carbon ranged between 4.37 ± 0.26 - 7.11 ± 0.35 tC/ha; litter carbon ranged between 0.50 ± 0.02 - 0.95 ± 0.04 tC/ha; herbaceous carbon ranged between 1.05 ± 0.28 - 1.86 ± 0.20 tC/ha ; dead wood carbon ranged between 3.03 ± 0.40 - 8.98 ± 0.44 tC/ha; Soil Organic Carbon Stock varies between4.33 ± 0.79 - 6.14 ± 1.05 tC/ha; Total carbon were 33.24 ± 4.28;27.40 ± 3.35;27.27 ± 3.27and 21.18 ± 3.00 tC/ha in site 3, site 2, site 1 and site 4 respectively. This makes of the *B. senegalensis* contributory lungs to mitigate the mitigations of climatic disturbances. Finally, these results are also an important economic, ecological and dynamic informative value to serve as a basis for guiding any program of action aimed at the conservation and sustainable management of this species. It is recommended that the Sudano-Sahelian savannah stand management policy encourage the use of marginal or already degraded lands for the establishment of *B. senegalensis* in order to reduce the pressure on the areas better supplied with trees.

Conflict of Interest

The author declares that there is no conflict of interest regarding the publication of this manuscript.

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