Leaf biomass modeling, carrying capacity and species-specific performance in aerial fodder production of three priority browse species *Afzelia africana*, *Pterocarpus erinaceus* and *Daniellia oliveri* in Benin

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Abstract

Browse plants play an important role in feeding ruminants especially in dry seasons when herbaceous forage is unavailable. This paper aim at developing models for leaf biomass estimating for their rapid evaluation and the planning of the rational use conditions. For each of the three main browse species, 25 trees were sampled. Dendrometric measurements such as girth at breast height, total height, stem height, crown diameter and crown height were performed on each tree before harvesting the entire leaf biomass which is then weighed. A sample of 200 g of leaves was taken per tree to estimate the dry matter. Kruskal-Wallis test was performed to compare plant traits among the three species. Relationship between plant traits and aerial fodder biomass was examined using a stepwise multiple regression. Carrying capacity was determined for the dry season in the study area.

Aerial fodder production varied among species. The best models that estimated leaf biomass production of *Afzelia africana* and *Pterocarpus erinaceus* were obtained with diameter at breast height, a plant trait not directly affected by pruning as predictor. For *Daniellia oliveri* the best model uses the crown height as estimator parameter. Globally, the carrying capacity of each species is about 0.05 to 0.09 TLU/ha/year for *Afzelia africana*; 0.03 to 0.08 TLU/ha/year for *Pterocarpus* *erinaceus* and 0.04 to 0.79 TLU/ha/year for *Daniellia oliveri* inin the dry season. The number of animal that can sustainably be fed in the study area was 38497. The introduction of these fodder tree species in afforestation/reforestation activities can improve the availability of leaf biomass to feed animals.

Keywords: *carrying capacity, fodder, models, pastoralism, production*

Introduction

In regions where drought reduces availability of food resources for herbivores feeding, fodder trees are under high pressure. Fodder deficit was previously reported, as a major problem in many countries of Africa, Asia, and Latin America, especially during the dry seasons (Bille 1980; Egan 1997; Upreti and Shrestha 2006; Hassen et al 2011; Ghimire et al 2013; Pariyar et al 2013; Mboko et al 2017). Under such circumstance, survival of transhumance and sedentary herds depends mainly on fodder trees. Hence, the carrying capacity (i.e., number of animals that can be fed) of resident pasture lands becomes a function of the production of overhead forage. In a sustainable management context, the assessment of tree forage harvests must take into account the rangelands productivity. In this regards, it is very important to know the relationship between the leaf biomass production and the level of animal feeding needs. This will make it possible to appreciate the sustainability of the leaf biomass uses as fodder and to avoid a spiral of degradation. Leaf biomass modeling is useful for the rapid evaluation of aerial fodder in order to project the number of animal that can be sustainably fed. Ravichandran (2003) reported that pruning is an essential agronomic practice in the production of leaves for the manufacture of black tea as it leads to enhanced branching and hence a greater number of tender leaves. But some studies have noted that by reducing the leaf biomass of a tree or shrub in the pruning or lopping, it directly reduces the surface of the crown whereas the trunk circumference and often the height of the plant remain unchanged (Bognounou et al 2008). Ghimire et al (2013) reported that leaves commonly harvested in the year, contain more concentrated nutrients than those of the trees whose cutting frequency is lower. The repeated and severe pruning reduce or totally hypothec fruit production and tend to obscure the effects linked to the season, site or tree size of *Faidherbia albida* (Depommier 1998). Gaoue and Ticktin (2010) noted that the bark and foliage harvest of *Khaya senegalensis* reduced its stochastic population growth rates. The highest total polyphenol concentration was observed in unpruned plants while the lowest was observed in apically pruned plants (Maudu et al 2010). Maudu et al (2010) also noted no significant difference in tannin and antioxidants content between unpruned, apically pruned and middle pruned of cultivated bush tea. Ortega-Vargas et al (2013) reported that the date of pruning of *Guazuma ulmifolia* during the rainy season affects the availability, productivity and nutritional quality of forage during the dry season. But the effect of the pruning on the leaf biomass modeling is not yet documented. In fact, pruning affect some morphological trait on the trees such as crown diameter, crown height whereas diameter at breast height, bole height are plant traits not directly affected by pruning. The question is to know what can be the objective measure of the tree forage and the carrying capacity of these regularly pruned trees?

The carrying capacity which is defined as the ability of a given area to support a number of animals on a continuing basis (De Vos 1969) may be affected by long and short term variations in climate parameters particularly precipitations (Phillipson 1975). It refers to the total number of animals that may be safely supported by a rangeland in the long term (Caltabiano 2006). The concept of carrying capacity is based on the assumption that plants and animals are in a state of balance or equilibrium. Two different notions of carrying capacity can be identi?ed (Hiernaux 1982; Behnke et al 1993). The ecological carrying capacity is reached ‘‘when the production of forage equals the rate of its consumption by animals, and the livestock population ceases to grow because limited feed supplies produce death rates equal to birth rates'' (Behnke et al 1993). The economic carrying capacity, on the other hand, sets a theoretical limit, which marks the number of livestock units that pastoral resources in a certain area can support in order to attain a certain management objective (e.g., optimal meat or milk production). In this article, the carrying capacity is the number of animal expressed by Tropical Livestock Unit per ha (TLU/ha) that the trees' forage of a unit rangeland can feed sustainably in one year. The Tropical Livestock Unit (TLU) or " *UnitÃ© de BÃ©tail Tropical*" (UBT) is an animal of 250 kg live weight (Hans 1982). This author also reported that the Tropical Cattle Unit (TCU) is less commonly used and is supposed to be the equivalent of a bovine of 175 kg live weight which, on the aggregate level; which is assumed to represent the average live weight of a bovine. The carrying capacity can be quickly determined with a reliable biomass models.

Plant allometric equations allow managers and scientists to quantify the biomass contained in associated vegetation communities without having to cut down large numbers of plants (Penderis and Kirkma 2014). But in several biomass studies, forage from trees is often ignored because of the lack of methods to estimate their biomass according to the regions and species. However, the destructive methods (CissÃ© 1980; Zabek and Prescott 2006) and those non-destructive (Andrew et al 1976; Montes et al 2000; Mizoue and Mascitani 2003; Savadogo and Elfving 2007) and the semi-destructive methods (Bognounou et al 2008; 2013) were used to estimate the biomass of several browse species in Africa. Leaf biomass equations were determined in Sahelian zone for some species such as *Acacia senegal* (Poupon 1976), *Pterocarpus lucens* (CissÃ© 1980), *Daniellia oliveri* (Bognounou et al 2008), *Afzelia africana* and*Pterocarpus erinaceus* (Bognounou et al 2008), *Khaya senegalensis* and *Pterocarpus erinaceus* (OuÃ©draogo-KonÃ© et al 2008). The semi-destructive method is less expensive in terms of human resources and equipment with minor damage on trees (Bognounou et al 2008). For different parts of plants, a variety of methods have been developed for biomass estimation, ranging from aerial photography and imagery to destructive sampling. However, direct measurements involving destructive sampling are usually preferred for accurate estimations (Lehtonen 2005), partly because browsed biomass depends on many interacting environmental factors (Grote 2002; Maraseni et al 2005; Balehegn et al 2012). Several models to estimate plant biomass exist (Brown 1976; Rutherford 1979; Zabek and Prescott 2006; OuÃ©draogo-KonÃ© et al 2008; Bognounou et al 2008). But no one of them takes into account the pruning effect on the accuracy of the leaf biomass models. However, although fodder trees in the Guineo-Congolese / Sudanian transition zone of Benin are exploited by transhumants from Niger, Burkina Faso, Nigeria and local population, very little is still known about leaf biomass production and estimation (Laamouria et al 2002). To fill in this gap, this paper aims to determine leaf biomass models to predict fodder production of three browse species identified as main fodder trees for conservation (SÃ¨wadÃ© et al 2016). The following questions are addressed:

1. Does the repetitive foliage harvesting by pastoralists suppress species-specific performance in aerial forage production?

2. Are plant traits not directly affected by pruning (diameter at breast height, bole height) more accurate in predicting leaf biomass production than traits modified after defoliation by pastoralists (crown height, crown diameter)?

3. What is the carrying capacity of rangelands in the dry season when tree defoliation is the main forage source for cattle?

Material and methods

Study area

Three forest reserves namely Monts KouffÃ© (179920 ha), Wari Maro (107500 ha) and OuÃ©mÃ© SupÃ©rieur (177442 ha) in the Guineo-Congolese / Sudanian transition zone of Benin were surveyed (Figure 1). The study sites were located between latitudes 8^{o} 28' and 9^{o} 47' North and between longitudes 1^{o} 40' and 2 ^{o} 28' East, within the Guineo-Congolese / Sudanian transition zone of Benin transition zone (White 1983). It is characterized by one rainy season from May to October (1247 mm per year on average) and one dry season (November to April). The annual mean temperature varies between 26 to 27Â° C with extremes ranging from 21Â° C (December-January) to 40Â° C (February-April). The relative humidity is low (10 to 40 %) in December and January, but high (85 to 98 %) from July to August. The natural vegetation consists of gallery forests, woodlands, wood and shrub savannas generally established on tropical lateritic and ferruginous soils. During the dry season, the study area receives transhumant herds from North Benin, Nigeria, Niger and Burkina Faso (Teka et al 2007).

Because the grassy forage is no more available after vegetation fires during the dry season, pastoralists defoliate wood fodder species (e.g.*Khaya senegalensis*, *Daniellia oliveri*, *Pterocarpus erinaceus* and *Afzelia africana)* toto feed cattle (Teka et al 2007; Gaoue and Ticktin 2008, 2010; Gaoue et al 2013; SÃ¨wadÃ© et al 2016).

Figure 1. Location of the study area

Data collection

Data were collected on three woody fodder species:*Afzelia africana, Daniellia oliveri* and *Pterocarpus erinaceus*. These three species are among the top five most defoliated trees that provide aerial fodder to animals in the region (SÃ¨wadÃ© et al 2016). The other two species which are not included in this study are *Khaya senegalensis* and*Vitellaria paradoxa.* Particularly *Khaya senegalensis* is rare in the three forest reserves while *V*. *paradoxa* is used to feed sheep. Previous studies on biomass production by defoliated trees in tropical Africa used a sample size of 6 - 30 individuals per species (Bognounou et al 2008; Balehegn et al 2012; Goodman et al 2014; Penderis and Kirkma 2014; Laminou Manzo et al 2015). In the current study, 25 trees were sampled per species as follows.

In the field, 42 plots (50 m x 50 m) were established to count the number of individuals with a diameter at breast height (DBH) bigger than 10 cm and assess the variability of DBH within each species. Then, 25 individuals were sampled per species to reflect the variation in DBH. However, when the leaves of the species are under high pruning or lopping pressure, the model becomes less accurate and less reliable. Sampled trees were selected so as to account for this aspect in order to have representative trees categories.

The following traits were measured on the sampled trees: DBH, bole height (BH), crown height (CH) and crown diameter (CD). Stem traits (DBH, bole height) are not directly modified by defoliation while pruning to harvest leaves reduced crown diameter and height. Once a tree was measured, its branches were cut into pieces following the herder practice. The leaf biomass and edible twigs (<5 mm diameter) (Rutherford 1979) of each sampled tree were handpicked from January to March. After their harvest, they were weighed in bags whose weight ranged between 10 and 12 kg. The total weight of the fresh material (WFM) of each sampled tree is obtained by summing the weight of the obtained bags per tree. After a good homogenization of the content of each bag, a 200 g sample was taken every time. All samples of 200 g obtained from the different bags on the same tree were mixed again and well homogenized before taking a final sample of 200 g used to later quantify the dry matter content in the laboratory. After drying the samples in an oven at 60^o C to constant weight, the dry matter content (DMC) per sample was calculated using the formula:

The total dry matter (TDM) of the leaf biomass per tree was determined by the formula:

WFM is the total Weight of Fresh Biomass per sampled tree.

Data analysis

With the measured Circumference (C, cm), the Diameter at Breast Height (DBH, cm) was calculated for each tree using the formula:

All statistical analyses were performed using the R software (R Core Team 2016). After testing for the normality of data (Shapiro-Wilk test), the analysis of variance (crown diameter, crown height) or a Kruskal-Wallis test (DBH, bole height) was performed to compare plant traits among the three species. The relationships between plant traits and aerial fodder biomass were examined using a stepwise multiple regression within the R software environment. The correlation between plant traits (DBH, bole height, crown diameter, crown height) were computed to avoid collinearity in the initial models. The final models only include significant predictors. These models were ranked using the coefficient of determination (R^2) and Akaike's Information Criterion (AIC) as recommended by Sileshi (2014). The carrying capacity was computed per species by considering the daily forage need of a Tropical Livestock Unit (TLU, 6.25 kg of dry matter) and the duration of the dry season when trees are defoliated (180 days). To avoid over exploitation with subsequent impacts on life-history traits (Gaoue et al 2013) and recruitment of seedlings (Bufford and Gaoue 2015), the carrying capacity was obtained by assuming a harvesting pressure equaling to the half of the produced aerial fodder biomass.

The carrying capacity (CC, TLU/ha) of each species was computed using the following formula:

The total aerial fodder biomass for each species is computed as density (tree ha^{-1}) times the mean aerial fodder biomass per tree (kg DM).

The Equivalent Rangeland Area (ERA, ha/TLU) is the area of rangeland needed to feed one TLU in the year. It is calculated by the formula:

The size of livestock (N, TLU) that each species can feed during the dry season was computed as:

Results

Variation of plant traits across species and species-specific response to repetitive defoliation

Table 1 summarizes the variation of plant traits across the three tree fodder species. No probability associated with mean comparison was significant. No difference exists between the tree species according to the measured traits.

Table 1. Variation of plant traits (mean Â± Standard error mean) across species defoliated during the dry

Plant traits	Defoliated tree species		
	Afzelia africana	*Pterocarpus erinaceus*	*Daniellia*
Stem descriptors*			
Diameter breast height, cm	30.3	23.4	31.1
Bole height, m	4.71	3.91	3.80
Crown descriptors**			
Crown diameter, m	6.15	5.85	6.52
Crown height, m	7.30	7.92	7.90
Plant performance*			
Aerial forage biomass, kg)	11.4	10.6	19.1

**Krukal-Wallis test and **ANOVA test*

However, the intra-class correlation (ICC) computed to quantify the existence of species-specific performance in aerial fodder production was 0.22, a sizeable value and far from 0. Thus, there was a correlation between observations coming from the same species. It confirmed the existence of species-specific performance in aerial fodder production despite repetitive defoliation of fodder trees.

Importance of stem traits versus crown descriptors in modeling aerial forage production

The initial variables of the models were derived from the correlation among tree traits (Table 2). The initial models excluding collinear variables were DBH + BH and CD + CH + BH. The first one only included stem descriptors while the last one encompassed crown and stem traits.

Table 2. Correlation between plant traits

Tree traits	**Diameter at breast height**		**Bole height**		**Cr**
	Correlation	***p***	**Correlation**	***p***	**Corre**
Bole height	0.07	0.55			
Crown height	0.62	0.00	-0.12	0.32	
Crown diameter	0.39	0.00	0.11	0.34	0.

Following variable selection, the final models (Table 3) only included stem traits (diameter at breast height) or crown descriptors (crown diameter and crown height).

Table 3. Regression models for aerial forage biomass production in relation to stem and crown traits

Defoliated tree species	**Models/prameters**	**Estimate**	**SE**	**t value**	***p* (>|t|)**	**R^2**	**AIC**
Afzelia africana	**Unique model**						
	(Intercept)	2.13	2.24	0.95	0.35	0.42	-

	Diameter	0.31	0.07	4.30	0.00		
Pterocarpus erinaceus	**Model 1**						
	(Intercept)	4.87	1.42	3.42	0.00	0.42	118
	Diameter	0.25	0.06	4.29	0.00		
	Model 2						
	(Intercept)	5.47	1.96	2.80	0.01	0.21	125
	Crown height	0.65	0.24	2.75	0.01		
Daniellia oliveri	**Model 1**						
	(Intercept)	5.79	4.01	1.45	0.16	0.34	181
	Diameter	0.43	0.12	3.66	0.00		
	Model 2						
	(Intercept)	1.29	4.65	0.28	0.78	0.40	178
	Crown height	2.25	0.55	4.09	0.00		

Model 3							
	(Intercept)	-0.74	6.99	-0.11	0.92	0.24	185
	Crown diameter	3.04	1.04	2.94	0.01		

AIC: Akaike's Information Criterion

Regarding the R^2 values and the comparison of the AIC values for *Pterocarpus erinaceus* on the one hand and *Daniellia oliveri* on the other, one model seems the best fit for each species. In the case of *Pterocarpus erinaceus* the model 1 including diameter at breast height is the best (AIC = 118; R^2 = 0.42) whereas in the case of *Daniellia oliveri* the model 2 realized with the crown height fits better than the other models (AIC = 180; R^2 ? 0.40). For *Afzelia africana* only one model elaborated with the diameter at breast height is obtained with R^2 = 0.42.

Figure 2. shows the relationship between diameter at breast height and aerial fodder biomass production for *Afzelia africana* and *Pterocarpus erinaceus*.

Figure 2. Relationship between diameter at breast height and aerial fodder biomass production. Points represent
the scatter plot of the diameter-biomass relation. The prediction lines for the biomass produced by each
of the two forage tree species (*Afzelia africana* and *Pterocarpus erinaceus*) are drawn based
on the intercept and slope of diameter taken from the regression models.

Regardless of these species, the diameter at breast height had a positive effect on the performance of trees in biomass production. Figure 3 illustrate the relationship between crown height and the leaf biomass production.

Figure 3. Relationship between crown height and aerial fodder biomass production of *Daniellia oliveri*. Points represent
the scatter plot of the crown height-biomass relation. The prediction line for the biomass produced is drawn
based on the intercept and slope of crown height taken from the regression models.

Carrying capacity of rangelands in the dry season

The carrying capacity was high for *Daniellia oliveri*, and very low for *Afzelia africana (Table 4).*

Table 4. Carrying capacity (TLU/ha/year) and cattle charge that tree fodder species can feed during

the dry season

Forest reserves	Area (ha)	Species	Density (trees/ha)	Biomass per tree (kg DM)	Total Biomass (kg DM)	Car cap (TLU/h
Monts KouffÃ©	179920	*Afzelia africana*	1.33	10.80	14.37	0
		Pterocarpus erinaceus	5.78	9.88	57.01	0
		Daniellia oliveri	9.33	19.08	178	0
Wari-Maro	107500	*Afzelia africana*	1.55	12.34	19.13	0
		Pterocarpus erinaceus	5.55	11.14	61.82	0
		Daniellia oliveri	6.22	15.47	96.21	0
OuÃ©mÃ© SupÃ©rieur	177442	*Afzelia africana*	1.07	10.38	11.01	0
		Pterocarpus erinaceus	1.60	11.71	18.74	0
		Daniellia oliveri	3.47	19.08	66.02	0

The mean Equivalent Rangeland Area was two to eight times higher for *Afzelia africana* than *Pterocarpus erinaceus* and *Daniellia oliveri*. Globally, one TLU needs for its annual nutrition based on the exploitation of each species 159 ha of *Afzelia africana;* 67.3 ha for *Pterocarpus erinaceus* and 19.5 ha of *Daniellia oliveri*.

Considering the cattle carrying capacity, this is lower for *Afzelia africana* than for *Pterocarpus erinaceus.* But the highest value was noted for *Daniellia oliveri.* The same tendency is observed respectively for the forest reserves in the order Wari-Maro, OuÃ©mÃ© SupÃ©rieur and Monts KouffÃ©. The study area can sustainably support 38497 TLU with the three fodder trees species.

Discussion

Species-specific performance in aerial forage production

Our question was to know whether repetitive foliage harvesting by pastoralists suppresses species-specific performance in aerial forage production. In this study species-specific performance in aerial fodder production (intra-class correlation (ICC) greater than 0) was not affected by repetitive defoliation by herders. Species-to-species differences could be imputable to intrinsic post stress regrowth capacity of target species (Geta et al 2014). Observed species-to-species discrepancies could also result from specific micro-climatic conditions, anthropogenic regimes disturbance life stories of censused trees, genetic traits, exposure to fire and foraging pressures, etc. (Bognounou et al 2013). Exploitation stresses, even on non-reproductive plant parts significantly affect physiology, growth, survival, and population dynamics of trees (Snyder and Williams 2003, Ticktin 2004, Gaoue et al 2011). Improving our understanding of process underlying observed differences and accuracy of developed models would however require further endeavors towards testing influence of these specific factors.

Establishing reliable biomass models

The established models in this study revealed the R^2 values ranged from 0.40 to 0.42 (best fitted for each species). Savadogo and Elfving (2007) reported also for *Acacia dudgeoni* a value of R^2 less than 0.50. Many biomass estimation models and particularly leaf estimation models were performed on shrubs and bushes in other countries (Bognounou et al 2008; OuÃ©draogo-KonÃ© et al 2008). The morphology of these shrubs and bushes facilitates leaves harvesting and the data collection on several samples with a limited human resources, material and financial support. With the same mean the number of sampled trees that can be covered is very limited. This illustrates the difficulties we would have if we take a large number of sample trees per species. Bognounou et al (2008) noted that in an ecosystem facing seasonal bush fires, different methods and estimation models of leaf biomass of some fodder tree raise problems. These authors also reported that the bole of these trees are quite delicate, making the use of some measurements very subjective (e.g. tree mutilation). Indeed, accounting for difficulties to access the leaves of the great and height trees, Bognounou et al (2008) limited the height of their sampled trees to 0.5-5 m (shrubs, bushes) with a number of trees between 6 and 30. But in the context of our study, 25 trees for each species were considered, with an average height of 12 m. This mean that the obtained results from this study could be deemed as more reliable as a sufficient number of sampled fodder trees were used. Biomass estimation models also depend on species as well as ecological growing conditions (Bognounou et al 2013). Several studies reported the role of human pressure on species, soil, and climatic conditions in the variation of biomass estimation models (Devineau 1999; Sanon et al 2007; Bognounou et al 2008; Bognounou et al 2013). Strong relationships between the foliage biomass and the physical parameters of trees such as circumference of the crown for other agro ecological zones have been linked with the form of the canopy, thus the foliage (OuÃ©draogo-KonÃ© et al 2008). In contrast, the weak R^2 observed in our finding should be an indicator of the perturbation faced by the sampled trees used in this study. It also leads to the idea that they are other predictive covariates that were not taking into account in our models. Similar trends (small R^2 values) were reported in several leaves biomass estimating models (Petit and Mallet 2001; Sinsin et al 2004). Anthropogenic factors are supposed to have influenced the current morphological characteristics of the crown and the height. Among several potential factors (e.g. water, diseases, nutrient availability, light, and human disturbances) (Hiernaux et al 1994; Devineau 1999; Seghieri and Simier 2002; OuÃ©draogo-KonÃ© et al 2008) that could affect the relationship between foliage biomass and the physical parameters of the tree, the human disturbances seem to be the principal factor of the used trees to build the leaf biomass. In fact, Crown traits (CD and CH) affected directly by leaves harvesting (pruning) could lead to a less accurate leaf biomass models. In the present study, best leaf biomass estimation models of the three fodder species were linear models and very simple to apply, i.e., each of them included one predictive parameter (DBH, not affected directly by defoliation). In Burkina Faso, Bognounou et al (2008) developed exponential equations and obtained the best predictive power for leaf biomass with the crown area of *Afzelia africana*, *Daniellia oliveri*, *Ficus sycomorus* subsp. *gnaphalocarpa* and *Pterocarpus erinaceus*, with trunk circumference of *Ficus sycomorus* subsp. *gnaphalocarpa*; with the total height of *Sterculia setigera* and *Pterocarpus erinaceus*. These differences may be related to the morphology of trees. The use of a single dendrometric parameter to build the estimation models of forage biomass in this study corroborate the work of Brown (1976) on several fodder shrubs that showed that basal diameter was a good predictor of shrubs leaf biomass production. Rutherford (1979) reported that stem diameter was highly correlated with plant biomass of *Burkea africana, Terminalia sericea* and other species, whereas Laamouria et al (2002) found that basal diameter was enough to establish a significant linear model to predict *Acacia cyanophylla* biomass production in North-West Tunisia. But pruning activities can modify some of these plants traits with a possible influence on the model accuracy.

Impact of pruning on the accuracy of the leaf biomass modeling

The second specific question aimed to know whether plant traits not directly affected by pruning (diameter at breast height, bole height) are more accurate in predicting leaf biomass production than plant's traits that are directly modified after defoliation by herders (crown height, crown diameter). Our expectations were confirmed by results. Established models with DBH which is a stem traits unmodified directly by leaf harvesting were more accurate for *Afzelia africana* (R^2 = 0.42 and AIC value not evaluated because only one model was significant); and for *Pterocarpus erinaceus (*R^2 = 0.42 and AIC value = 118.21) than the models including crown height which is a plant trait directly modified after pruning (R^2 = 0.21 and AIC value = 125). Contrary to that, the most accurate model to estimate leaf biomass of *Daniellia oliveri* was obtained with the crown height. This can be explained by the variability of the pruning methods. For example, SÃ¨wadÃ© et al (2016) observed in the study area that different intensities of pruning are applied while harvesting aerial forage for animal feeding. As such, species like *Daniellia oliveri* are pruned after herders have finished using available forages of *Afzelia africana, Pterocarpus erinaceus* and *Khaya senegalensis*. Conversely, Gaoue and Ticktin (2009) noted that, in order to facilitate foliage regrowth, certain Fulani people use to leave on the *Khaya senegalensis* trees the meristems called "*sopoodo*" representing regrowth organ in Fulani culture. Other sociolinguistic groups (Bariba and Nago) suggested regulating pruning to a maximum harvest limit of 25-50 % of foliage pruned every two or three years in the Guineo-Congolese / Sudanian transition region of Benin (sÃ¨wadÃ© et al 2016). But in the Sudanian region, herders did not mention any speci?c percentage canopy pruning that would be necessary for sustainability; they pointed out reducing the pruning frequency per tree (Gaoue and Ticktin, 2009). Yet, recently, SÃ¨wadÃ© et al (2016) reported that 41 % of Fulani people assert pruning all the available leaves on the trees whereas 45 % of them removed 75 % of the total leaf biomass. All this illustrate the variability on the threat faced by the fodder trees and its impact on the variability of plant traits that are directly affected after pruning. Wittig et al (2002) noted that trees species forage harvesting method consist mainly of slaughtering young subjects or pruning young branches. Young shoots are also directly grazed by animals and all this combined with the high frequency of wildfires especially late fires prevent fruiting (Sinsin 1993), thereby compromising species regeneration (Teka et al 2007; Gaoue and Ticktin 2008). This situation can be due to the intensity, the frequency and the regular pruning of the trees to feed animals particularly in the dry season. OuÃ©draogo-KonÃ© et al (2008) noted also that probable previous pruning of the trees could partly explain the weak relationship obtained with the circumference of the trunk and the height of the *Afzelia africana* and *Pterocarpus erinaceus* trees in the biomass estimating models. Bognounou et al (2008) had established to *Afzelia africana* an estimating equation of leaf biomass from the total height. In this study, no model for estimating leaf biomass has integrated the total height. The lack of relationship between leaf biomass and height of some species is explained by the fact that these trees are severely trimmed, often headless for livestock feeding (Bognounou 2004). Height is not suitable in estimating leaf biomass of a species whose crown is severely and regularly exploited. However, when the crown is not severely exploited, a strong relationship between leaf biomass and total height has been obtained for *Sterculia setigera* and *Daniellia oliveri* (Bognounou et al 2008); *Balanites aegyptiaca* (L (L.) Del (Cisse 1980). An accurate leaf biomass modeling is a tool for the carrying capacity determination.

Role of the carrying capacity in rangeland management

The carrying capacity observed in this study depended on the species and forest reserves. This carrying capacity derived from the produced biomass for each species. *Daniellia oliveri* had highest aerial forage production, whereas *Afzelia africana* had the lowest. Similar trends were noticed for size of livestock (N, TLU) that each species can support during the dry season. Genetically driven intrinsic differences could partially explain some of these results. However, human pressure and environmental factors could accentuate observed variability in fodder production. Depending on the severity of the dry season, with the possibility of two cuts of the same tree in the year, total biomass production may vary. It seemed to be the case of *A. africana, P. erinaceus* and *K. senegalensis*. Ghimire et al (2013) showed that trees whose leaves are harvested quarterly in the dry season give a total production of leaf biomass higher than those whose leaves are harvested by half in the same period of time. Similarly, these authors noted that leaves commonly harvested in the year contain more concentrated nutrients than those of the trees whose cutting frequency is lower. Thus, the second or the third cut made by some Fulani herders in the study area could help secure good nutrients supply for their livestock.

In some pastoral systems in Africa, it is suggested to adapt animal number to vegetation condition but the ecological conditions of the vegetation make their responses more complex than equilibrium models would suggest (Vetter 2005). The importance of carrying capacity is associated with the ecological regulation between the leaf biomass production and its sustainable utilization by the herders. The need for livestock keepers to adhere to a de?ned carrying capacity in order to conserve rangeland resources and to achieve economic development remains an institutionalized fact (Benjaminsen et al 2006). They also need to be sensitized on the necessity to define a rational policy in the fodder trees utilization based on the carrying capacity of their rangelands. This can be done by evaluating the quantity of aerial fodder needed to feed each animal and the number of animal the global leaf biomass production should feed normally and durably.

Limit of the study

The use of 180 days as the length of the dry season when aerial fodder is supposed to be used is a pessimist scenario because, at the beginning of the dry season, herders use crop residues or available dry herbaceous fodder to feed their animals. Because of climate variability, herders began using herbaceous fodder when rainfall precocity make them available. Other limit is that leaf biomass estimating models established in this paper did not take into account plants whose diameter at breast height are less than 10 cm even if they can be consumed by animals without pruning. However, due to their state of development, the amount of leaf biomass produced by these plants are usually very small. Some Fulani herders, especially the trans-border transhumant, entirely defoliate the tree of K. *senegalensis* (Gaoue et al 2007), *A. africana, P. erinaceus, D.* oliveri. This behavior directly affects the leaf biomass production and reduces the potential capacity of trees to produce seed because the critical biomass production required to initiate the seed production will not be reached before the next pruning (Gaoue et al 2007; SÃ¨wadÃ© et al 2016). Gaoue and Ticktin (2010) noted that the bark and foliage harvest of *Khaya senegalensis* reduced its stochastic population growth rates.

The environmental, seasonal, and climatic variations could have some influence on foliage growth and so could have some effect on the validity of the leaf biomass estimating model established. Thus, the biomass of the sampled trees used in this study depended on the climate conditions and the use story faced by the trees, and other factors that determine their current biomass production level. In fact, when the duration of the dry season is long, the pressure on the fodder trees could be high as they are then the only source of fodder. Finally, the determination of the size of livestock and the carrying capacity concerned only the three fodder trees which cannot express the total leaf biomass production potential of the study area. Although this study presents the above mentioned limitations, it provides a very useful models to evaluate rapidly, the fodder production potentiality of some rangelands. It also takes into account the real use conditions of the forage harvesting as herder practices were applied to collect leaf biomass data. This leads to some tools which have implications for the fodder resources evaluation and the planning of the rangelands sustainable management.

Implications

The knowledge of browse species production is important for a sustainable management and exploitation of rangelands. An excessive carrying capacity can lead to an overgrazing and degradation of the rangeland (Abel 1993), but the herders' strategy within non-equilibrium systems is to sequentially move their livestock across different environments (Behnke et al 1993). Herd management must aim at responding to alternate period of high and low productivity, with an emphasis on exploiting environmental heterogeneity rather than manipulating the environment to maximize stability and uniformity (Behnke et al 1993). The local and cross-border transhumance accentuated that situation in the Guineo-Congolese / Sudanian rangelands of Benin. However, the herders' awareness on the possibilities of fodder trees production and rational use will permit them to take into account the limits and the availability of the aerial biomass to use in the dry season. This will decrease the pressure of overexploitation of natural resources. Biodiversity will be better off handled through its rational exploitation.

Leaf biomass estimation models of fodder trees can help estimate the total aerial forage production with easily measurable biomass predictors. Management strategy can focus on species that are quite available (e.g. *Daniellia oliveri*) and limit to a restrictive use of the fodder trees such as *Afzelia africana* and *Pterocarpus erinaceus* for livestock feeding. Prediction of potential carrying capacity depend on uncertain events in the future such as forest exploitation and climate change phenomenon. One possible application of the trees' browse biomass estimates can be the quantification and the monitoring of carbon sequestration in the context of global climate change as reported by Penderis and Kirkma (2014).

We suggest (i) sensitizing local herders and identify with them further steps to ensure rational use of the three priority browse species; (ii) helping to situate herders responsibilities of non-compliance in the restrictive use of fodder tree species such as *Afzelia africana* and *Pterocarpus erinaceus,* and the possibility of a zoning of the rangeland areas to be entrusted to groups of herders; (iii) the use of priority species in afforestation, reforestation, and plantation activities for its better production of aerial forage of priority browse species in the rangeland.

However, cross-border (foreign) transhumance could upset the natural course of use strategy, hence the need to strengthen surveillance measures for the strict respect of the herd's corridors. Herders could manage forage deficits created by restrictions on use of the two priority browse species by selecting other lower priority species.

Conclusion

- The results of this study indicated that in the contest of regular use, fodder trees' leaf biomass can be modeled using dendrometric parameters directly measurable as predictors. For each species, simple linear model is obtained in the leaf biomass estimation. The best models were obtained with Stem traits namely DBH which is not directly affected by pruning. So diameter at breast height was the best predictor parameter of *Afzelia africana* and *Pterocarpus erinaceus* whereas the crown height suit more for *Daniellia oliveri* in the leaf biomass estimating modeling. The models obtained respectively with crown height of *Pterocarpus erinaceus*; diameter and crown diameter of *Daniellia oliveri* were less accurate. Despite the low power (R^2 =0.42), the models constitute a primary way to evaluate nondestructively the availability of fodder for animal feeding in the studied region. Our leaf biomass estimation models will allow to determine the overall aerial forage production by measuring only the DBH of *Afzelia africana, Pterocarpus erinaceus* trees and the crown height of *Daniellia oliveri*. The calculation of the number of animal based on the Carrying Capacity is a useful sustainable rangeland management tool.

- In order to ensure growth level needed to produce seed for regeneration in the natural environment, herders should adopt a rotary leaf biomass harvesting of each tree. It will also be good to take into account, especially in the Guineo-Congolese / Sudanian transition zone of Benin, the feed potential of fodder trees in order to ensure their sustainable use by developing more realistic management plans.

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