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Research Article

Forage harvesting using branch pruning compromises sustainable use and conservation of *Pterocarpus erinaceus* Poir., an endangered species

Bossila Séraphin Hien[1], Loyapin Bondé[1], Mohamed Mahamoud Charahabil[2], Sié Sylvestre Da[3], Joseph Issaka Boussim[1], Oumarou Ouédraogo[1]

1 *Laboratory of Plant Biology and Ecology, Department of Plant Biology and Physiology, Université Joseph KI-ZERBO, Ouagadougou, Burkina Faso*
2 *Laboratoire d'Agroforesterie et d'Ecologie, Université Assane SECK de Ziguinchor, Ziguinchor, Senegal*
3 *West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL), Ouagadougou, Burkina Faso*
Corresponding author: Bossila Séraphin Hien (bossila.hien@ujkz.bf)

Abstract

Pterocarpus erinaceus Poir. is a leguminous tree species with huge forage value. It is subjected to heavy pruning pressure in dry season for livestock feeding, resulting in yearly decline of forage production and vulnerability of the species which is currently classified as endangered species. This study aimed at: (i) identifying factors influencing branch pruning pressure on *P. erinaceus* tree, (ii) assessing the effect of branch pruning on foliage production of the species and (iii) developing allometric equations for estimating its foliage biomass. We measured leaf biomass on representative living branches on 48 individual trees of *P. erinaceus* distributed in protected and communal areas following topography gradient. Branch size distribution and branch pruning ratio (PR) expressing human pressure on sampled trees were appreciated. Results indicated that PR was significantly (p-value < 0.001) influenced by tree morphological traits such as diameter at breast height (DBH) and crown area, and tree density around sampled tree. Linear regression highlighted the dominance of small branches on sampled trees both for pruned and living branches, suggesting a regular pruning of trees. Topography position and PR were found as main factors affecting the species leaf production ($p < 0.05$). The potential leaf biomass estimated at 15.09 ± 6.58 kg per tree is reduced by 35.98% when using branch pruning for forage harvesting. DBH and PR were the best predictor variables for estimating leaf production of the species. Allometric model developed is a useful tool for optimizing harvesting activities and secure sustainable use of the species. Based on the harvesting pressure observed on the species, the promotion of more conservative harvesting techniques such as cutting of leafy twigs for forage harvesting instead of branch pruning and preserving of heavy pruned trees from harvesting during few years are highly recommended for enabling fast renewal of branches and seed production for species regeneration. Findings and recommendations from this case study on *P. erinaceus* could be used to improve the management of tree species subjected to similar harvesting pressure across tropical regions.

Key words: Foliage production, habitat conditions, human pressure, livestock, sustainable use

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Introduction

Livestock is one of the main sectors contributing significantly to the socio-economic development of many countries worldwide (Pisani et al. 2021), including the Sahelian countries in West Africa (MRA 2010; FAO 2016). However, fodder scarcity is a perennial problem for herders in many countries (Ayele et al. 2012), but overgrazing can cause changes in plant communities' composition (Perrino et al. 2024) and threats to the conservation of plant species (Wagensommer et al. 2014). *Pterocarpus erinaceus* Poir. is a forage tree species with branches that are heavily pruned in the dry season by herders for their leaves, which are used for livestock feeding (Adjonou et al. 2019). Forage resources are limited during the dry season and increasing human pressure on the species is expressed by repeated mutilation of individual trees. Indeed, in the West African semi-arid region, individual trees of *P. erinaceus* pruned for livestock feeding are commonly observed not only in agrosystems (cultivated fields and fallows) but also in protected areas (Rabiou et al. 2015). For instance, in Burkina Faso, 96.34% and 87.80% of the trees of *P. erinaceus* are pruned for forage harvesting in agrosystems and protected areas respectively (Nacoulma et al. 2011). Estimates about forage production in the dry season are crucial data supporting the livestock sector in pasture management (Sanon et al. 2007). Therefore, allometric models were developed to estimate forage biomass available from *P. erinaceus* (Bognounou et al. 2008; Ouédraogo-Koné et al. 2008; Ganamé et al. 2020). Harvesting pressure on forage production of the species was not clearly assessed in these studies because samples were selected based on treetop accessibility or morphological health (crowns less damaged by branch pruning). Consequently, statistics generated using these models could probably overestimate forage availability from *P. erinaceus*, especially in the context of increasing pressure on the species. Harvesting pressure currently makes *P. erinaceus* the most exploited and threatened wild tree in West Africa semi-arid zones (Rabiou et al. 2017; Segla et al. 2020) and classified as an endangered (EN) species at global scale by IUCN (Barstow 2018). Many studies found that forage harvesting using destructive methods negatively affects population structure, seed production, and survival of some tree species such as *Faidherbia albida* (Delile) A.Chev., *Khaya senegalensis* (Desr.) A. Juss., and *Afzelia africana* Sm. ex Pers. (Gaoue and Ticktin 2007; Nacoulma et al. 2011, 2016; Sida et al. 2018). Regarding *Pterocarpus erinaceus*, specific works addressing how forage harvesting affects the species forage productivity and branch structure of its trees are poorly addressed while this information is essential to develop management options and harvesting methods ensuring both species sustainable use and long-term conservation. This study aimed at: (i) identifying factors influencing branch pruning pressure on *P. erinaceus*, (ii) assessing the effect of branch pruning on foliage production of the species and (iii) developing allometric equations for estimating its leaf biomass taking into account anthropogenic pressure by addressing two research questions:

a. How do tree morphological traits and habitat conditions influence herders' pressure on *P. erinaceus* trees?
b. Is branch pruning on trees operated selectively by herders?

Materials and methods

Study area

This study was conducted in the Mouhoun province in the Sudano-Sahelian climatic zone. Data collection was carried out in the classified forest of Toroba (protected area) and adjacent communal areas represented by fallows and croplands (Fig. 1). During the last two decades, this zone has been characterized by an average rainfall of 892.25 mm per year with a duration of 4 to 5 months and by a temperature between 18 and 39 °C (National Meteorological Agency). The main soil types are represented by less developed soils, eutrophic brown soils, and leached ferruginous soils (Traoré and Anne 2010). Vegetation formations are characterized by savannahs, gallery forests, and agroforestry parks (Sambaré et al. 2011). The woody flora is dominated by Sahelian and Sudanian species such as *Vachellia seyal* (Delile) P.J.H. Hurter, *Vachellia sieberiana* (DC.) Kyal. & Boatwr., *Combretum micranthum* G.Don, *Combretum glutinosum* Perr. ex DC., *Combretum nigricans* Lepr. ex Guill. & Perr., *Guiera senegalensis* J.F.Gmel., *Anogeissus leiocarpa* (DC.) Guill. & Perr., *Burkea africana* Hook., *Daniellia oliveri* (Rolfe) Hutch. & Dalziel, *Diospyros mespiliformis* Hochst. ex A.DC., and *Isoberlinia doka* Craib & Stapf (Traoré et al. 2012 ; Nacoulma et al. 2019).

Study species

Pterocarpus erinaceus Poir. is a woody tree species from the Fabaceae family that can grow up to 15 m high, with a stem that is straight and cylindrical, reaching 1 m in diameter. Its bark is cracked, blackish, and very flaky with a brown edge striped with red threads. The branches have long shoots that bend downwards. The 10–20 cm long leaves are alternate, imparipinnate with rather polymorphous leaflets emarginate at the top, with a rounded base, glabrous above, and slightly pubescent below (Arbonnier 2019). The natural distribution area of the species extends from West Africa to Central Africa (Adjonou et al. 2020; Alaba et al. 2020). It is found in semi-arid to sub-humid wooded savannahs in regions with annual rainfall between 600 and 1200 mm and an average annual temperature of 32 °C. *P. erinaceus* leaves are highly valued and preferred by livestock, especially during the dry season as fodder (Bognounou et al. 2008; Rabiou et al. 2015). This leads to strong pastoral exploitation during this period of the twigs development during the previous wintering season. This overexploitation of branches locally threatens the species with extinction as it excludes all flowering and fruiting of the pruned branches (Nacoulma et al. 2011; Arbonnier 2019).

Data collection

Tree sampling design was based on two factors: topography (lowland, upland) and treetop pruning degree (four degrees). The four degrees of pruning considered are those adopted by Schumann et al. (2010): no-pruning (0% of crown pruned); low-pruning (1–25% of crown pruned), medium-pruning (25–50% of crown pruned) and heavy-pruning (> 50% of crown pruned). Each factor combination was sampled with 6 repetitions, resulting in 2 × 4 × 6 = 48 sampled trees. Topography is considered as ecological factor affecting the diversity,

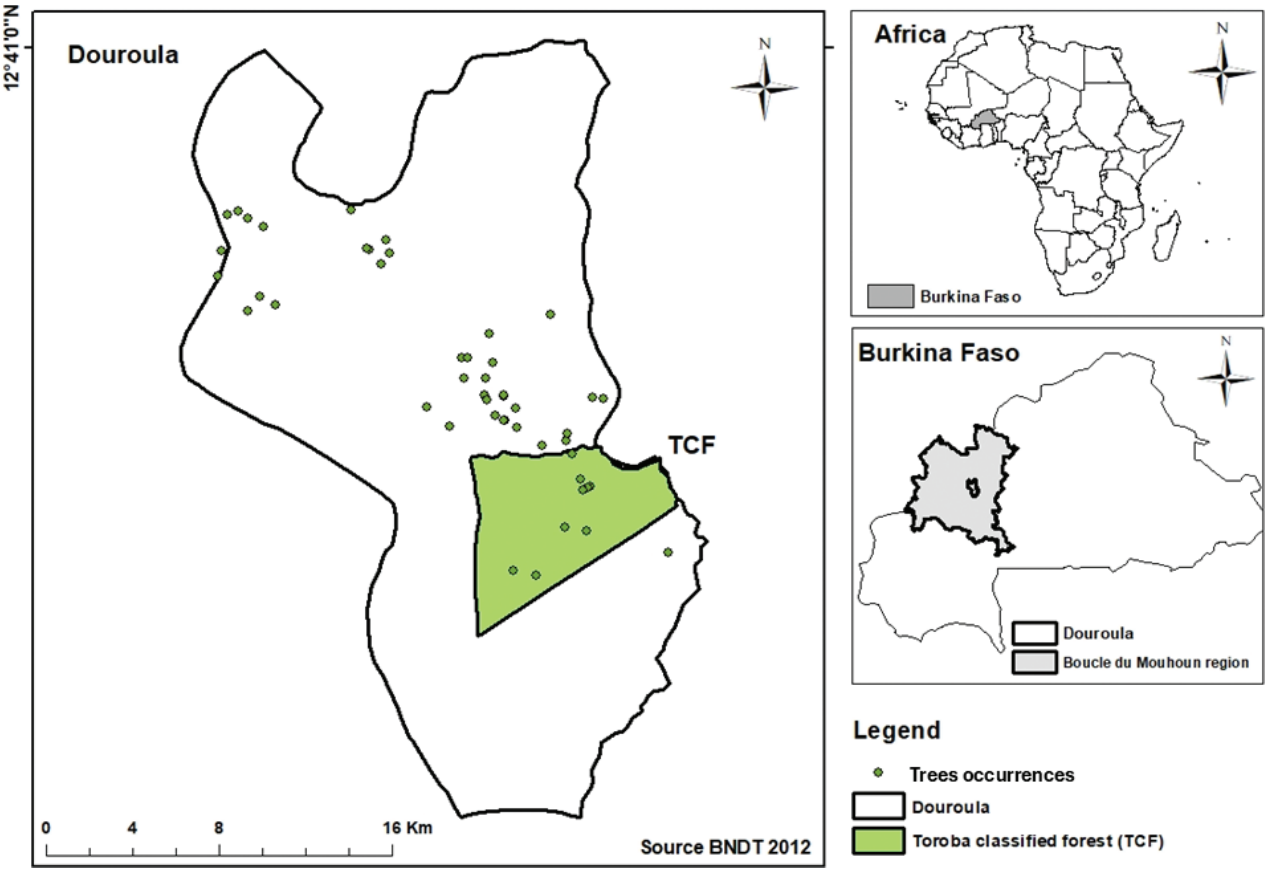

Figure 1. Map of study area presenting sampled *P. erinaceus* occurrences.

morphological traits, and productivity of woody species (Lamien et al. 2007; Bondé et al. 2013). Sampled trees were georeferenced with a minimum distance of 100 m between each individual to minimize interdependence of observations and to sample individuals that are genetically different. For each sampled tree, the following variables were measured:

- stem diameter at 1.3 m aboveground (DBH);
- crown diameter;
- tree height;
- number and diameter at the base of branches (pruned and unpruned);
- number of adult trees from all species growing around the sampled tree. Trees were counted within a circular plot with a radius of 25 m to account for nutrient competition on foliage production of *P. erinaceus* (Bondé et al. 2019);
- individual foliage biomass of three (03) branches.

To assess the foliage biomass of branches, leafy twigs of each sampled branch were cut and leaves were harvested and weighed using an electronic balance (5 g precision). The three sampled branches were randomly selected per tree to reduce damage from cutting twigs during biomass assessment. In total, 144 branches were used for biomass estimation (3 branches × 48 trees). Data collection was carried out at the end of the dry season (May-June 2021) which corresponds to the full leafing period for *P. erinaceus* (Ouédraogo-Koné et al. 2008) and the exploitation of leafy branches for animal feeding

(Hien et al. 2021). The assessment of *P. erinaceus* foliage production was limited to fresh biomass. The fresh leaves of the species are used as green forage and food supplements for their livestock in the dry season when herbaceous grazing becomes scarce (Gandon 2003).

Data analyses

Histogram was generated to illustrate branch class distribution on the sampled trees both for pruned and unpruned branches. The method of Condit et al. (1998) was applied to class distribution data for exploring the relationship between branch diameter classes on trees, as an indicator of branch disturbance by herders. For this purpose, linear regression was performed using the median value of the diameter classes as the independent variable and the number of branches per class as the dependent variable. Regression parameters, especially slope value, coefficient of determination (r^2), and p-value of the model were considered as indicators of the goodness of relation between branch diameter classes (Obiri et al. 2002). A negative slope indicates the dominance of small branches on sampled trees while a positive slope indicates the dominance of large branches. High r^2 associated with a significant p-value ($p < 0.05$) indicates a strong correlation in branch class distribution on sampled trees. Branch pruning ratio (PR) expressing human pressure on trees was calculated for each sampled tree using Equation (1).

The number of branch diameter classes (NDC) was defined using Equation (2) (Sturges 1926) and the amplitude of classes (AC) using Equation (3). Therefore, all the 144 sampled branches were ranged into eleven branch diameter classes with an amplitude of 0.95 cm as follows: < 1.9; [1.9–2.85] [2.85–3.8]; [3.8–4.75]; [4.75–5.7]; [5.7–6.65]; [6.65–7.6]; [7.6–8.55]; [8.55–9.5]; [9.5–10.45]; ≥ 10.45 cm. The same method was also applied to determine the number of tree diameter size classes.

$$PR = \frac{\text{Pruned branches}}{\text{Unpruned branches} + \text{Pruned branches}} \times 100 \quad (1)$$

$$NDC = 1 + 3.3 \log (N) \quad (2)$$

$$AC = \frac{\text{Maximal diameter} - \text{Minimal diameter}}{\text{Number of diameter class}} \quad (3)$$

with N representing the total number of sampled branches.

Allometric models using linear regression were developed to estimate foliage biomass both for individual branches and whole trees. For branch models, diameters at the base of branches (D) were treated as explanatory variables, and corresponding foliage biomasses as response variables. Both variables were transformed using the logarithm function or root square to improve regression quality and meet the main regression assumptions (normality, homoscedasticity, and independence of model residuals). Then, the best branch model with the lowest value of prediction error was selected. To this end, 75% of the data was used for model fitting and 25% for model evaluation using Equation 4. Allometric models are validated by evaluating their predictions using observations that are independent of the data used to fit the model (Picard et al. 2012). The best-performing equation was applied to all living branches of individual sampled trees to estimate their foliage biomass observed (FBO). The same model was applied to diameters at the base of pruned branches of each sampled tree to estimate foliage biomass loss (FBL) from branch pruning carried out by herders to feed their livestock. Potential foliage biomass (PFB) per sampled tree was calculated by summing FBO and FBL.

For the tree allometric model, tree morphological traits (DBH, crown area, total height) combined with branch pruning ratio were treated as explanatory variables, and foliage biomass per tree as the response variable. To get an accurate estimation of foliage biomass, it was essential to include the branch pruning ratio in model development as leafy branches of the species are constantly pruned to feed livestock. Single and multiple linear regressions were run to improve model quality and those that meet linear regression assumptions as indicated above were selected as best fitted equations. Then, models with the lowest prediction errors were considered as final best estimating models. To this end, 75% of data were randomly selected for model fitting and 25% were used for model validation. Correction factors (CF), as indicated in Equation 5, were used to correct the errors introduced by the logarithmic transformation. The prediction error (PE) was calculated by using Equation 4 to determine the prediction error of models.

$$PE = \frac{\text{Predicted biomass} - \text{Observed biomass}}{\text{Observed biomass}} \times 100 \quad (04)$$

$$CF = \exp(RSE^2 / 2) \quad (05)$$

where RSE is the residual standard error obtained from the allometric model regression.

GLM (family = Poisson, link = log) was performed to test whether human pressure on trees depends on tree morphological traits and/or habitat conditions. Tree morphological traits considered were DBH, total height, and crown area while tree density around sampled trees and topographic position represented habitat variables. Branch pruning ratio expressing human pressure was used as response variable while tree morphological traits and habitat variables were used as explanatory variables. Topographic positions (lowland, uplands) were treated as categorial factors and the other explanatory variables as co-variables in model fitting. GLMs (family = Gamma, link = log) were also performed to test the effects of branch pruning ratio, tree morphological traits, and habitat conditions on foliage production. GLMs based on the Poisson distribution are useful for modelling count data (Crawley 2007) and those based on the Gamma distribution are useful for modelling positive continuous data (Dunn and Smyth 2018). All statistical analyses were performed with R 3.6.1 (R Core Team 2019).

Results

Factors determining human pressure on *Pterocarpus erinaceus* trees

The branch pruning ratio was significantly (p-value < 0.001) influenced by specific tree morphological traits (DBH and crown area) and habitat conditions, especially tree density in the surrounding habitat of sampled trees (Table 1). The pruning pressure (Fig. 2) increased with DBH ($z > 0$). However, this pressure increased with decreasing crown area and tree density around the sampled

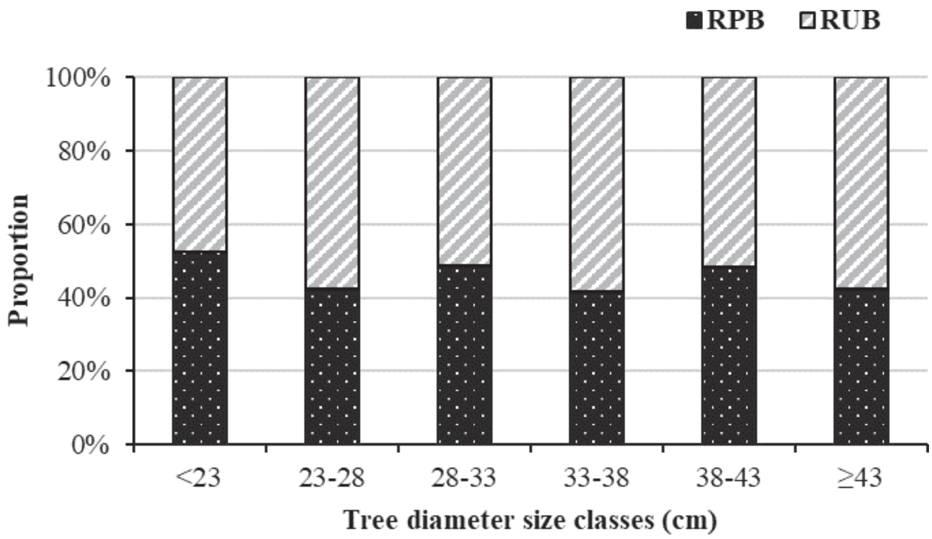

Figure 2. Variation in branch pruning ratio according to tree size (RPB: ratio for pruned branches; RUB: ratio for unpruned branches).

Table 1. Factors influencing harvesting pressure on *Pterocarpus erinaceus* trees.

	Estimate	Std. Error	z value	Pr(>|z|)
Intercept	3.833	0.220	17.426	< 0.001 ***
Crown area	-0.019	0.003	-6.355	< 0.001 ***
DBH	0.032	0.004	7.873	< 0.001 ***
Height	-0.059	0.030	-1.950	0.051
Density	-0.015	0.001	-14.644	< 0.001 ***
Topography (upland)	-0.057	0.057	-0.990	0.322

Significant levels: * P < 0.05; ** P < 0.01; *** P < 0.001.

trees ($z < 0$). Tree height and topographical position had no significant influence on PR (p-value > 0.05). Linear regression based on branch class distribution showed that sampled trees are dominated by small diameter branches, which is highlighted by the negative values of slopes (Fig. 3). The high values of the coefficient of determination ($r^2 > 0.5$) and their significant p-value (< 0.01) showed that there is a strong relationship in branches distribution among different diameter classes on *Pterocarpus erinaceus* trees (Fig. 3).

Allometric equation for estimating foliage production of *Pterocarpus erinaceus*

Three models were selected to estimate foliage biomass both for *P. erinaceus* branches and entire trees respectively. All models were significant ($p < 0.0001$) with r^2 values ranging from 0.29 to 0.33 and from 0.54 to 0.55 for branches and trees, respectively. For branches, equation B1 was selected as the best predictive model (Table 2) and was used for estimating the foliage biomass of the species. Concerning models that take into account tree DBH and PR (pruning pressure), the equation T1 was considered as the best predictive model (Table 3). All allometric equations were significant coefficients and satisfied the condition of linear regressions.

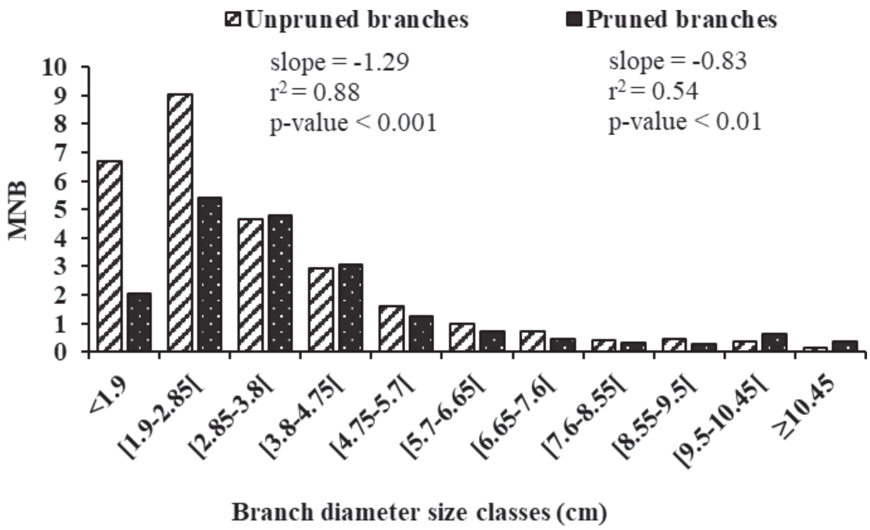

Figure 3. Mean number of branches (MNB) distribution on *Pterocarpus erinaceus* trees and regression parameters.

Table 2. Allometric equations for *P. erinaceus* branch foliage biomass production.

N°	Allometric models	Standard error	R²	PE (%)	CF
B1	$\ln(Bio) = -2.32 + 0.47(D) - 0.03(D^2)$	0.51	0.29	-11.91	1.14
B2	$\ln(Bio) = -2.12 - 0.23(D) + 1.54 \ln(D)$	0.49	0.33	-17.64	1.13
B3	$\ln(Bio) = -2.12 - 0.23(D) + 0.77 \ln(D^2)$	0.49	0.33	-17.64	1.13

Bio = branch foliage biomass; R² = coefficient of determination; CF = correction factor; D = branch diameter; PE = prediction error.

Table 3. Allometric equations for *P. erinaceus* tree foliage biomass production.

N°	Allometric models	Standard error	R²	PE (%)	CF
T1	$Bio = 19.27 - 0.04\sqrt{DBH \times PR^2}$	3.64	0.54	-8.02	–
T2	$Bio = 64.12 - 5.07 \ln(DBH \times PR^2)$	3.66	0.54	-9.01	–
T3	$LnBio = 9.46 - 0.69 \ln(DBH \times PR^2)$	0.49	0.55	-13.92	1.13

Bio = Tree foliage biomass; R² = coefficient of determination; CF = correction factor; DBH = diameter at breast height; PE = prediction error; PR = branch pruning ratio.

Effect of tree morphological traits, human pressure, and habitat conditions on *Pterocarpus erinaceus* foliage production

The GLM results showed that tree morphological traits (DBH, tree height, crown area) and habitat conditions (tree density, topography position) have specific responses on foliage production respectively (Table 4). Foliage production was significantly influenced by the DBH of trees (p-value < 0.05) while no significant effect was observed with tree height and crown area. Foliage biomass increased with tree DBH ($z > 0$). For habitat conditions, only topography exhibited a significant effect on the foliage production of *P. erinaceus*. The high foliage biomass was recorded in the lowlands with a mean value estimated at 11.45 ± 4.83 kg per tree and the low biomass (7.87 ± 5.04 kg per tree) in uplands (Fig. 4). Foliage production was significantly affected by human pressure, with branch pruning ratio negatively correlated with foliage biomass (Table 4).

Table 4. Result of the GLM showing the effect of tree morphological traits, human pressure, and habitat conditions on foliage production.

	Estimate	Standard Error	t value	Pr(>|t|)
Intercept	2.771	0.480	5.772	< 0.001 ***
Crown area	-0.006	0.006	-0.890	0.378
DBH	0.027	0.009	3.099	< 0.01 **
Height	-0.028	0.065	-0.437	0.664
Ratio	-0.025	0.003	-8.921	< 0.001 ***
Density	-0.002	0.001	-1.607	0.116
Topography (upland)	-0.397	0.115	-3.458	< 0.01 **

Significant levels: * P < 0.05; ** P < 0.01; *** P < 0.001.

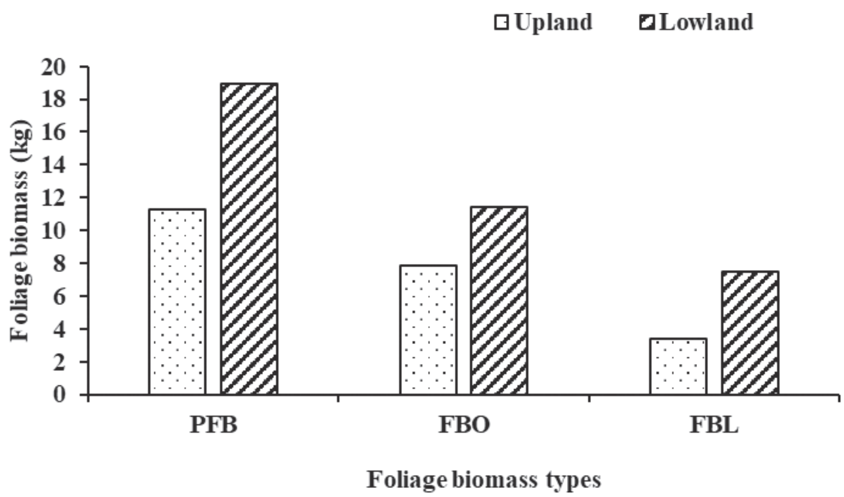

Figure 4. Mean values of potential foliage biomass (PFB), foliage biomass observed (FBO), and foliage biomass loss (FBL) production according to topography position.

When considering the loss of foliage production related to pruned branches on trees, the results indicated that foliage biomass (loss) was significantly different according to pressure degree (branch pruning ratio), tree size, topography, and tree density (Table 5). Biomass loss was negatively correlated with pruning ratio, topography, and tree density and positively correlated with tree DBH. The potential foliage biomass estimated at 18.93 ± 5.6 kg per tree in lowlands is reduced by 7.48 ± 6.22 kg (39.51%) when using branch pruning. In upland, biomass loss was estimated at 3.33 ± 2.57 kg per tree (29.98%) for a potential of 11.20 ± 5.11 kg. Variation in foliage production according to human pressure is presented in Fig. 5.

Discussion

Variation of human pressure according to trees morphological traits and habitat conditions

Pruning pressure on *P. erinaceus* was significantly influenced by tree DBH, crown area, and tree density. Tree size (DBH, Crown area) was positively correlated with branch pruning ratio, indicating that human pressure on trees increases with tree size. Large trees have more branches and leaves than small trees,

Table 5. Result of GLM showing the factors that influence *P. erinaceus* trees foliage production loss.

	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	0.195	0.561	0.348	0.729
Crown area	-0.004	0.007	-0.527	0.601
DBH	0.029	0.010	2.861	< 0.01 **
Height	0.013	0.076	0.174	0.862
Ratio	0.027	0.003	8.157	< 0.001 ***
Density	-0.004	0.002	-2.139	< 0.05 *
Topography (upland)	-0.523	0.134	-3.899	< 0.001 ***

Significant levels: * P < 0.05; ** P < 0.01; *** P < 0.001.

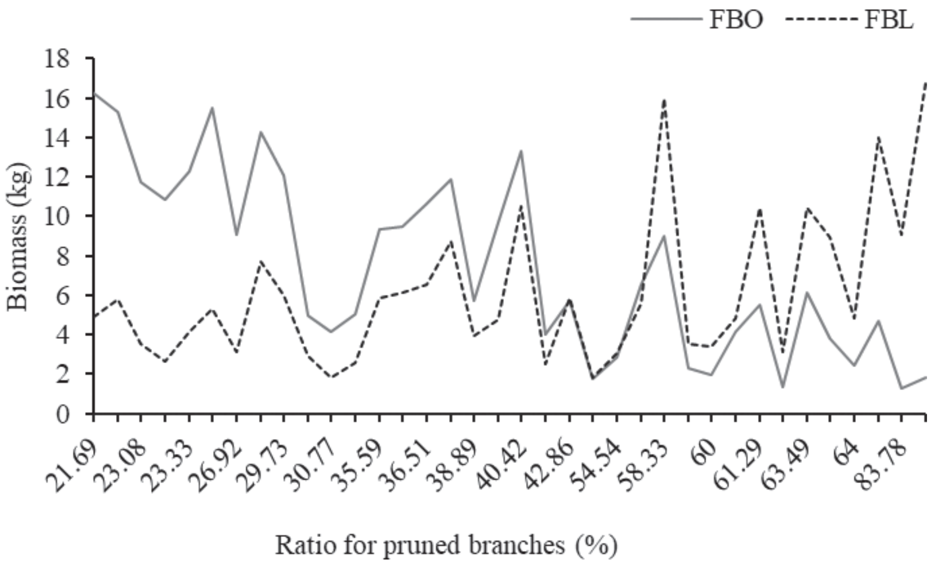

Figure 5. Variation of *Pterocarpus erinaceus* foliage production according to human pressure levels; FBO (foliage biomass observed), FBL (foliage biomass loss).

which are indicators to easily track the species on the field. Similar results were found on *Khaya senegalensis* in West Africa where pruning pressure was higher on large trees compared to small trees (Gaoue and Ticktin 2007). In contrast, Nacoulma et al. (2016) found in the same region that pruning pressure was higher on small trees than on large trees of *Afzelia africana*, suggesting that human pressure on forage trees is species-related. Tree density in the surrounding habitats of sampled trees was negatively correlated with the branch pruning ratio, indicating that herders' pressure on *P. erinaceus* trees increases with low tree density. In fact, habitats with poor tree density provide comfortable conditions for pruning activities on trees compared to the ones with high density where some actions are practically difficult to operate. In this study, all sampled trees with low pruning ratio (0–25%) were only found in classified forests where the density of adult plants is higher. The branch pruning ratio was not influenced by topographic position, suggesting that trees from both uplands and lowlands are subjected to the same herder pressure for forage harvesting.

The dominance of small diameter branches (pruned and unpruned) and the strong correlation between branch classes indicate that branches of *P. erinaceus* are subjected to heavy and regular pruning by herders to feed their livestock.

In the West African Sahelian zone, the leaves of the species constitute one of the main sources of green food for livestock during the dry season (Segla et al. 2020), which increases harvesting intensity on the species to a high degree when the delay in the onset of the rainy season is pronounced enough (Gangon 2003). Therefore, renewal branches are regularly pruned at short intervals to meet dry season fodder needs, so that large branches are rare on trees. Petit and Mallet (2001) found that the branches pruned by herders were small, ranging from 1 to 3 cm diameter. Indeed, this could explain the predominance of small diameter branches in the *P. erinaceus* sampled trees. When tree branches are pruned, it may take several years before they can produce fruit. Therefore, studies carried out in East and West African regions found that frequent pruning of *Afzelia africana* and *Faidherbia albida* branches for forage compromise fruit production and seed availability for species natural regeneration (Nacoulma et al. 2016; Sida et al. 2018). In South Asia, Varghese et al. (2015) found that the high fruit harvest intensity decreased the proportion of *Terminalia chebula* Retz. saplings. Similarly, in the same area, parts of dry deciduous forests that are subject to heavy Non-Timber Forest Product (NTFP) harvesting are characterized by a reduction in species richness and basal area, as well as in the number of individuals in the lower size classes, compared with the same type of plant formation where NTFP harvesting is less intensive (Murali et al. 1996).

Allometric equation for estimating fruit production of *Pterocarpus erinaceus*

The DBH and branch pruning ratio (pruning pressure) were the tree variables that were used to predict *P. erinaceus* foliage biomass in this study. This combination would minimize the overestimation of foliage biomass that could result from using DBH as the only dendrometric variable, especially in the uncontrolled exploitation context of NTFP-providing tree species. Picard et al. (2012) found that tree DBH was the best predictor of tree biomass when developing allometric models. The use of intensive branch pruning as a harvesting method disturbs the architecture of *P. erinaceus*, leading to a change in the size (crown diameter, total height) and reduce foliage production of this species (Fig. 6). The application of the prediction equation developed by Ganamé et al. (2020) overestimates the foliage biomass of *P. erinaceus* trees by 7.68% compared to the equation (T1) developed in the current study. Consequently, the use of equations developed in this study allows the anthropogenic pressure (ratio) related to branches pruning for forage harvesting to be taken into account in the estimation of *P. erinaceus* foliage biomass for optimizing harvesting activities and secure sustainable use of the species in Sahelian ecosystems.

Effect of tree morphological traits, human pressure, and habitat conditions on foliage production

Foliage biomass observed on sampled trees was significantly influenced by the topography. Foliage biomass of trees located in lowlands was higher than those of trees located in uplands. In general, the aboveground biomass of trees decreases from the low to the high slope in an environment (Tateno et al. 2004). The total biomass was higher in the lowlands than the uplands

Figure 6. *P. erinaceus* tree under heavy pruning pressure.

positions. In a semi-arid environment, the ecological conditions (temporarily flooded environment and sandy-silty soil) in lowlands allow individual trees to obtain more water and nutrients for foliage production. According to a study carried out by Bond-Lamberty et al. (2002) in North America, foliage production of tree species is very sensitive to light, water, nutrients, and soil conditions. The branch pruning ratio was negatively correlated with foliage biomass, indicating that human pressure reduces foliage production of the species.

The potential production is reduced by 35.98% and showed that forage harvesting using branch pruning in previous years limits the availability of this resource for the next few years. Indeed, Kamissoko et al. (2001) found that repeated pruning of *P. erinaceus* and *P. lucens* Lepr. ex Guill. & Perr. branches dangerously reduces the sustainability of their foliar production. The density of trees in the habitat does not have a significant influence on foliage biomass observed in *P. erinaceus*. In general, high tree density leads to high intra- and inter-competition between individual trees for water and nutrients (Bognounou et al. 2009; Rabiou et al. 2017). Therefore, some studies in West Africa have found that tree density in habitat negatively affects the fruit production of *Lannea microcarpa* Engl. & K.Krause and *Vitellaria paradoxa* C.F.Gaertn. (Haarmeyer et al. 2013; Bondé et al. 2019). In this study, the non-sensitivity of the species to tree density in terms of foliage production could probably suggest that its adult trees have strong competition ability making them productive in any habitat regardless of tree density. In contrast, as mentioned above, high tree density in the habitat reduces harvesting pressure on *P. erinaceus*, which explains why the loss of foliage biomass was negatively correlated with tree density.

Regarding tree size, results showed that the tree DBH significantly influenced foliage biomass. Trees with large diameters presented a higher foliage biomass than trees with small diameters. This could be explained by the great ability of large trees to capture more nutrients and reduce water stress due to their well-developed crown and root systems (Rosa et al. 2014; Kabré et al. 2022). Positive correlations have previously been found between tree morphological traits and foliage biomass of *P. erinaceus* (Ouédraogo-Koné et al. 2008).

Conclusion and implication for conservation

This study highlighted the impact of branch pruning pressure on *Pterocarpus erinaceus* foliage production in semi-arid areas. This pruning pressure on the species was associated with trees' morphological traits and trees' density in their habitats and highlighted by the dominance of small branches on trees. Branches of individual trees are subjected to frequent pruning from year to year with an estimated 35.98% loss of potential forage production. Consequently, sustainable use and long-term conservation of the species are compromised if effective harvesting methods combined with alternative management options are not developed and promoted. In addition to reducing forage resources, heavy branch pruning negatively affects seed production and seed quality, which compromises the species recruitment in natural conditions. The allometric model developed for estimating forage production from the species is a useful tool for optimizing harvesting activities and securing the sustainable use of the species. Based on the harvesting pressure observed on the species, the promotion of more conservative harvesting techniques such as cutting leafy twigs for forage harvesting instead of branch pruning and preserving heavily pruned trees from harvesting in a few years is highly recommended, which will enable fast renewal of branches and seed production for species regeneration. Promoting forage crops in dry season including planting of tree forage species could be an alternative management option to limit human pressure on *P. erinaceus*. People's awareness about the negative effects of the use of destructive methods for forage harvesting on the species also needs to be raised at a large scale to stimulate changes in people's behaviors in favor of its sustainable use and management. Findings and recommendations from this case study on *P. erinaceus* could be used to improve the management of tree species subjected to similar harvesting pressure across tropical regions.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

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Author contributions

Conceptualization: OO, LB. Data curation: BSH. Formal analysis: LB, BSH. Funding acquisition: LB. Methodology: BSH, LB. Project administration: LB. Supervision: OO. Validation: OO, IJB, MMC. Writing - original draft: BSH. Writing - review and editing: MMC, IJB, OO, SSD, LB.

Author ORCIDs

Bossila Séraphin Hien https://orcid.org/0000-0003-1651-9002
Loyapin Bondé https://orcid.org/0000-0002-9399-8644
Mohamed Mahamoud Charahabil https://orcid.org/0000-0002-5711-0548
Sié Sylvestre Da https://orcid.org/0000-0001-8284-4589
Oumarou Ouédraogo https://orcid.org/0000-0002-0440-2766

Data availability

All of the data that support the findings of this study are available in the main text.

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