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Population Dynamics of *Vitex doniana* Sweet and *Vitellaria paradoxa* C.F.Gaertn. along a Rainfall Gradient in the Dosso Partial Wildlife Reserve, Niger

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

Vegetation cover is one of the most important land-use components within protected areas, which are designated for the conservation and sustainable management of natural resources. As areas of ecological and environmental value, protected areas play an important role in biodiversity conservation by providing habitats for diverse flora and fauna. The Dosso Partial Wildlife Reserve (RPFD) contains biodiversity of considerable socio-economic value, but it is currently threatened by substantial anthropogenic pressure. This study analysed the dendrometric and structural attributes of populations of two important species, *Vitex doniana* and *Vitellaria paradoxa*. An inventory was conducted in 200 plots (2,500 m² in agrosystems and 1,000 m² in natural stands). Diameter and height measurements were used to calculate density, basal area and Lorey height. The results showed that the rainfall gradient favoured the Sudanian zone, where *V. doniana* and *V. paradoxa* had densities (25.36 and 27.94 trees/ha) and mean diameters (59.26 and 67.51 cm) that were significantly higher than those recorded in the Sahelian zone. However, population structure indicated ageing stands and limited regeneration, suggesting an ecological imbalance associated with anthropogenic pressure. Sustainable management measures, including farmer-managed natural regeneration (FMNR) and stronger protection of young plants, are required to support regeneration. Effective conservation and sustainable management of these species should also promote cost-effective regeneration while encouraging the active and voluntary participation of rural communities.

Keywords: Vitex doniana; Vitellaria paradoxa; population structure; dendrometric parameters; rainfall gradient; agroforestry parklands; regeneration; Sudanian zone; Sahelian zone; protected areas; Dosso Partial Wildlife Reserve; Niger.

1. Introduction

Biological diversity encompasses the full range of life forms on Earth, including variation within species, between species and among ecosystems. Plant biodiversity is particularly significant because plants serve as primary producers and form the base of most terrestrial and aquatic food chains. Plant species diversity contributes directly to ecosystem functioning by influencing productivity, nutrient cycling and energy flow. Diverse plant communities use resources more efficiently and are better able to withstand environmental fluctuations than monocultures (Breman et al., 2021; Nayak et al., 2025). Plant biodiversity is an ecosystem component that facilitates the establishment and functioning of other organisms in various biotopes. Knowledge of the flora and plant communities of a given locality is therefore an indispensable tool for supporting sustainable development policies (Ali, 2018). The importance of biological diversity for human well-being and socio-economic development lies in its contribution to ecosystem goods and services, the enhancement of food security, health and social relations, increased incomes, sustainable land management and the mitigation of climate-change effects (Abdourhamane, 2016; FAO, 2016). According to Tankoano et al. (2015), vegetation cover is one of the most important components of land use within a protected area. Indeed, protected areas are spaces dedicated to the conservation of natural resources. They represent ecological and environmental values and constitute important reservoirs of flora and fauna biodiversity (Abdou, 2021; Ndotam Tatila et al., 2017; Fandohan et al., 2008; Kone, 2021).

Despite the numerous goods and ecosystem services that these ecosystems provide to local communities, they are increasingly threatened by a range of anthropogenic and environmental pressures. These include recurrent wildfires, the expansion of agricultural land, uncontrolled logging, the development of road infrastructure, rapid urbanisation and the adverse impacts of climate change (Diedhiou et al., 2018; Abdourhamane et al., 2013; Ngom et al., 2013). Collectively, these factors contribute significantly to the degradation and reduction of vegetation cover, thereby compromising ecosystem integrity and biodiversity conservation (Fachola et al., 2019). According to Dan Guimbo (2011), trees constitute an integral component of production systems across much of sub-Saharan Africa. This distinctive characteristic of agricultural landscapes underpins the concept of agroforestry parklands, in which trees are deliberately maintained and managed alongside crops. Within these systems, trees play a vital role in supporting food security and rural livelihoods through the provision of fruits, nuts, edible leaves and other non-timber forest products (Codjia et al., 2003). Moreover, trees contribute substantially to maintaining ecological balance, enhancing soil fertility and sustaining agricultural production systems (Ngom et al., 2018).

Among the tree species of particular socio-economic and ecological importance to rural communities are *Vitex doniana* (black plum) and *Vitellaria paradoxa* (shea tree). However, populations of these species are becoming increasingly scarce and are currently facing considerable threats. Human-induced disturbances have led to a marked decline in the abundance of several useful plant species within the RPFD and surrounding areas. In addition, numerous other species, although less frequently exploited, remain highly valued for fuelwood, energy production and various socio-economic uses, and are similarly at risk of extinction in the short to medium term owing to sustained anthropogenic pressure. Given the ongoing degradation of forest resources and the increasing vulnerability of economically and ecologically important species, comprehensive studies are urgently required to improve assessments of forest species in terms of density, regeneration capacity, population dynamics and demographic structure. Such information is essential for developing effective conservation strategies and sustainable management plans aimed at preserving forest biodiversity and ecosystem services (Ibrahima et al., 2023; Rabiou et al., 2016; Soro et al., 2011).

However, information on how the rainfall gradient is associated with the demographic structure and regeneration status of these two species in the RPFD remains limited. The present study aimed to analyse the dendrometric characteristics and population structure of *Vitex doniana* and *Vitellaria paradoxa* in order to assess their current status and support their conservation. By evaluating key parameters related to population dynamics and stand structure, the study provides insights into the ecological condition and regeneration potential of these species. The findings constitute a scientific foundation for the rational and sustainable management of these two indigenous tree species, both of which are of considerable socio-economic importance to local communities. Furthermore, the results may contribute to the development of effective conservation strategies and informed decision-making processes aimed at ensuring their long-term persistence and sustainable utilisation.

2. Materials and Methods

2.1 Study Site

The Dosso Partial Wildlife Reserve (RPFD) is situated in south-western Niger. It straddles two regions, comprising 93% of the Dosso region and 7% of the Tillabéry region (southern Kollo Department). It is bounded to the west and south-west by W National Park and the Republic of Benin; to the north by the departments of Kollo (Tillabéry Region), Boboye and Falmey (Dosso Region); and to the east by the departments of Dosso and Gaya. It is located between 13°14’23’’ and 13°27’8’’ N latitude and between 2°30’40’’ and 2°52’48’’ E longitude. It covers an area of 527,261.75 ha and belongs to IUCN Category VI. It is classified as a Ramsar site owing to the availability of surface water (wetland). It was established by Decree No. 62189/MER of 8 August 1962, creating the adjacent partial reserve known as Dosso.

2.2 Sampling

The study was conducted in five municipalities located mainly within the Dosso Partial Wildlife Reserve in order to assess current plant diversity. Administratively, these were the municipalities of Falmey, Sambera, Tanda, Gaya and Gollé. The selection was guided by the presence of *V. doniana* and *V. paradoxa* in the area. Sampling was stratified at the departmental and municipal levels but was carried out systematically using radial transects within the villages. In the commune of Falmey, four village sites were investigated: Kotaki, Sorikoira, Djabou and Rond-point. In the commune of Gaya, surveys were carried out in four village sites, namely Tombobery, Tara, Tondihinza and Tondika. In the communes of Tanda, Sambera and Gollé, surveys were conducted across ten village areas. The selection of these communes was based not only on the presence of *V. doniana* and *V. paradoxa*, as indicated by prior knowledge of the area, but also on the existence of a north-south rainfall gradient from Gollé to Gaya. Information obtained from the departmental environmental services, town halls and key informants on the distribution of *V. doniana* and *V. paradoxa* subsequently enabled the selection of the municipalities and then the village territories.

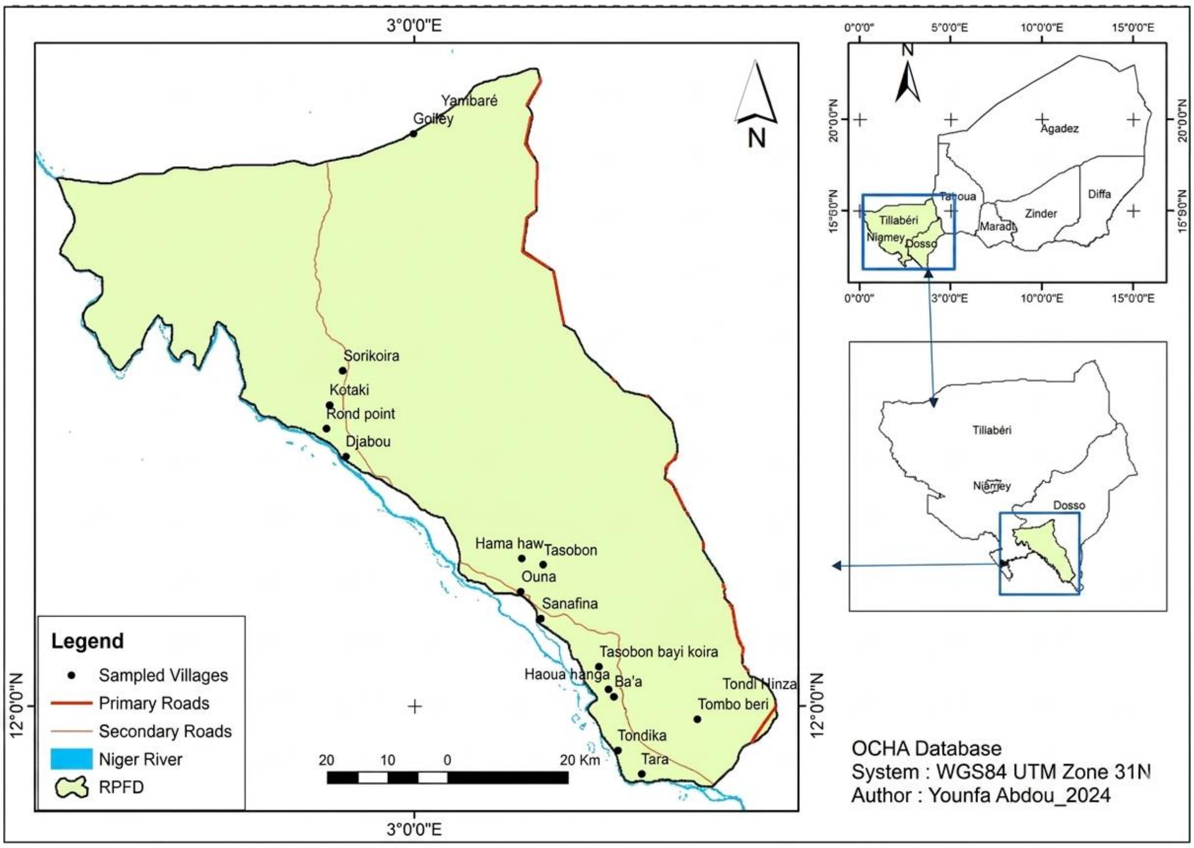

Fig. 1. Map showing the location of the study sites

2.3 Data Collection

The forest inventory enabled data to be collected for the assessment of tree species diversity. Sampling was methodically designed around four radial transects, each selected on the basis of the presence of the two target species. Transects were established in the four directions from each village. Sampling was carried out by establishing radial transects from the village exit in four directions (east, west, north and south). As part of this study, plots were established along each transect according to land-use type. Thus, 2,500 m² plots were allocated to agrosystems and 1,000 m² plots to contracted formations (Mahamane & Saadou, 2008). These plots were spaced 500 m apart and were placed according to site accessibility, giving a total of 16 plots per village. However, villages with natural constraints or land-use limitations were excluded from the study. The phytogeographic inventory, which recorded woody flora, covered 200 plots. A comprehensive count of woody individuals was carried out in each plot. Measurements were taken on tree specimens. These measurements included diameter at breast height, measured at a height of one metre, and the two crown diameters along two perpendicular axes. The total height of each individual was also recorded. Height and diameter measurements were taken only for stems or trunks with a diameter of 2 cm or more.

2.4 Data Analysis

- **Dendrometric parameters:** To establish the structure of the tree layer, the following dendrometric parameters were calculated:
- **Tree density (N):** The density (N, expressed as number of trees/ha) of mature tree stands was calculated as the ratio of the total number of trees measured to the total area (in ha) under consideration. The frequency of seedlings considered as regeneration was defined as individuals with diameter ≥ 2 cm.

$$N = \frac{n}{s}$$

N is the number of trees recorded, and S is the area in hectares (ha).

- **Basal area:** Basal area is the sum of the cross-sectional areas of all stems measured in the plot, normalised to one hectare:

  $G = \frac{\pi}{40000S} \sum_{i=1}^{n} di^2$

- **Mean diameter (D, in cm):** This is the diameter of trees with the mean basal area.

  where n is the number of trees in the plot and d is the diameter of the i-th tree in cm.

- Contribution to basal area:

  $Cst = 100 \frac{Gp}{G}$

  Gp is the basal area of trees of a given species, and G is the basal area of all trees.

- **Stand cover:** Stand cover was calculated using the equation below and is expressed in m²/ha (Guihini et al., 2021).

  Where $Sc = \Sigma\, \pi \times D^2 / 4$

  Sc is the crown area (m²/ha); D is the average crown diameter (East/West and North/South); Σ is the sum; and $\pi = 3.14$.

- **Average Lorey height:** Lorey's mean height (HL), expressed in metres (m), is the mean height of individual trees weighted by their basal area (Rondeux, 2021).

  $HL = \frac{\sum_{i=1}^{n} gihi}{\sum_{i=1}^{n} gi}$ where $gi = \frac{\pi}{4} di^2$

  where gi is the basal area of individual i, hi is the height of individual i (expressed in metres), and di is the diameter of individual i (in cm).

- **Analysis of population structure:** The demographic structure of the tree stands was analysed by dividing individuals into diameter classes of 15 cm width, with a minimum threshold of 2 cm. To characterise this distribution, the three-parameter Weibull probability density function was fitted to the observed data using Minitab 14 software.

  The Weibull distribution is recognised for its great flexibility, enabling it to model a wide range of forest structure types (Thiombiano et al., 2016). Its probability density function is defined as follows:

- $f\,(x) = \frac{c}{b}\left(\frac{x-a}{b}\right)^{c-1} exp\left[-\left(\frac{x-a}{b}\right)^{c}\right]$

  Where:

  - x: diameter, circumference or height of the trees;
  - a: location parameter (threshold value, here cm);
  - b: scale parameter (linked to the central value of tree dimensions);
  - c: shape parameter (characterises the shape of the distribution).

The Weibull distribution can take several forms depending on the value of the shape parameter, as shown in Table 1. An analysis of variance was performed for the dendrometric variables of the individuals. Where the conditions for applying ANOVA were not met (normality and homogeneity of variances), the non-parametric

Kruskal-Wallis test was used to test the significance of differences in the relevant dendrometric parameter within each group.

Table 1. Shape of the Weibull distribution according to the values of the parameter c

C < 1	'Inverted J' distribution, characteristic of multi-species or uneven-aged stands.
C = 1	Exponentially decreasing distribution, characteristic of endangered populations.
1 < *C* < 3.6	Positive asymmetric or right-skewed distribution, characteristic of monospecific stands with a predominance of young or small-diameter individuals.
C = 3.6	Symmetrical distribution; normal structure, characteristic of even-aged or monospecific stands of the same cohort.
C > 3.6	Negatively skewed or left-skewed distribution, characteristic of monospecific stands dominated by older trees.

3. Results

3.1 Dendrometric Characteristics of the Populations

Table 2 compares the dendrometric parameters of *Vitex doniana* and *Vitellaria paradoxa* according to the rainfall gradient. For *Vitex doniana*, the mean diameter was significantly higher in the Sudanian zone (59.26 cm) than in the Sahelian zone (47.19 cm) (P = 0.032*). Mean height and Lorey height were greater in the Sudanian zone, but the differences were not statistically significant (mean height: P = 0.162; Lorey height: P = 0.072). Density was significantly higher in the Sudanian zone (25.36 ind/ha) than in the Sahelian zone (7.68 ind/ha) (P = 0.0001***). Basal area was also significantly higher in the Sudanian zone (8.02 m²/ha) than in the Sahelian zone (1.43 m²/ha) (P = 0.001**). Variability (CV %) was generally higher in the Sudanian zone for all parameters, particularly basal area (67.71% versus 52.27%), suggesting greater stand heterogeneity in this zone. Regarding *Vitellaria paradoxa*, the mean diameter was significantly higher in the Sudanian zone (67.51 cm) than in the Sahelian zone (56.91 cm) (P = 0.011*). For mean height and Lorey height, there was no significant difference between the two zones (mean height: P = 0.398; Lorey height: P = 0.228). Density was significantly higher (P = 0.003**) in the Sudanian zone (27.94 ind/ha) than in the Sahelian zone (9.42 ind/ha), as was basal area, which was significantly higher (P = 0.045*) in the Sudanian zone (7.86 m²/ha) than in the Sahelian zone (3.62 m²/ha). As with *Vitex doniana*, variability (CV %) was considerably higher in the Sudanian zone for basal area (93.81% versus 63.73%), also indicating a high degree of heterogeneity in shea stands (Table 2).

Table 2. Dendrometric parameters of the populations

	Sahelian zone		**Sudanian zone**		**P-value**
	***Vitex doniana* population**				
Parameters	**Mean**	**AVG (%)**	**Average**	**CV (%)**	
Average diameter (cm)	47.19	26.83	59.26	38.41	0.032*
Average height (m)	8.97	20.94	9.6	28.74	0.162
Lorey height (m)	9.39	16.36	10.54	21.35	0.072
Density (trees/ha)	7.68	36.31	25.36	25.23	0.0001***
Basal area (m^2/ha)	1.43	52.27	8.02	67.71	0.001**
	***Vitellaria paradoxa* population**				
Parameters	**Mean**	**CV (%)**	**Mean**	**CV (%)**	
Average diameter (cm)	56.91	30.72	67.51	38.41	0.011*
Average height (m)	12.09	22.34	11.68	28.74	0.398
Lorey height (m)	12.64	15.18	11.97	16.84	0.228
Density (trees/ha)	9.42	37.38	27.94	39.12	0.003**
Basal area (m²/ha)	3.62	63.73	7.86	93.81	0.045*

Key: CV (%): coefficient of variation (measure of relative variability)
P-value: probability that the observed difference is due to chance
*Statistical significance: *** = very highly significant (p < 0.001); ** = highly significant (p < 0.01); * = significant (p < 0.05)*
(No symbol) = not significant (p≥ 0.05); Test used: Student's t-test for independent samples; Significance threshold α= 0.05

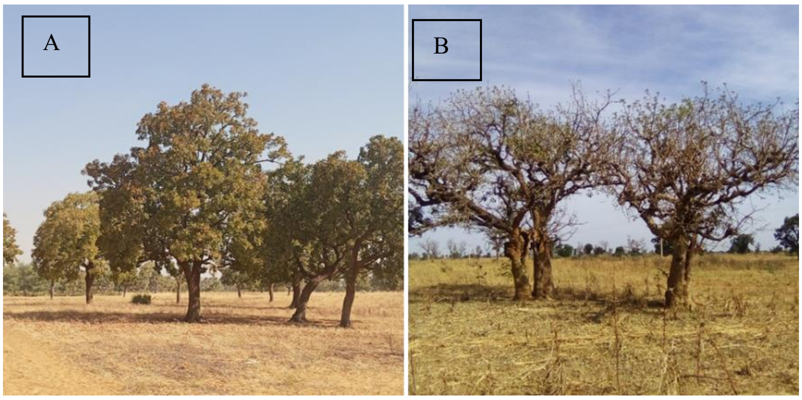

Fig. 2. Agroforestry park A: *V. paradoxa* at Djabou and B: *V. doniana at Gollé*

3.2 Diameter and Height Structure of the Two Species

The distribution of individuals in the *Vitex doniana* and *Vitellaria paradoxa* populations by diameter class followed a bell-shaped curve (Fig. 3). It fitted the theoretical Weibull distribution with a shape parameter c ranging from 2.51 to 2.89 (1 < c < 3.6). This parameter took values of 2.51 for *V. doniana* and 2.89 for *V. paradoxa. These values reflect a positively skewed (or right-skewed) distribution, characteristic of populations with limited regeneration potential. This situation is often attributable to exogenous pressures that restrict recruitment in the small-diameter classes.*

Furthermore, the height structure also exhibited a bell-shaped curve, but with a shape parameter c greater than 3.6. This indicated a negative (or left-skewed) distribution, typical of stands dominated by mature or old individuals (Fig. 3).

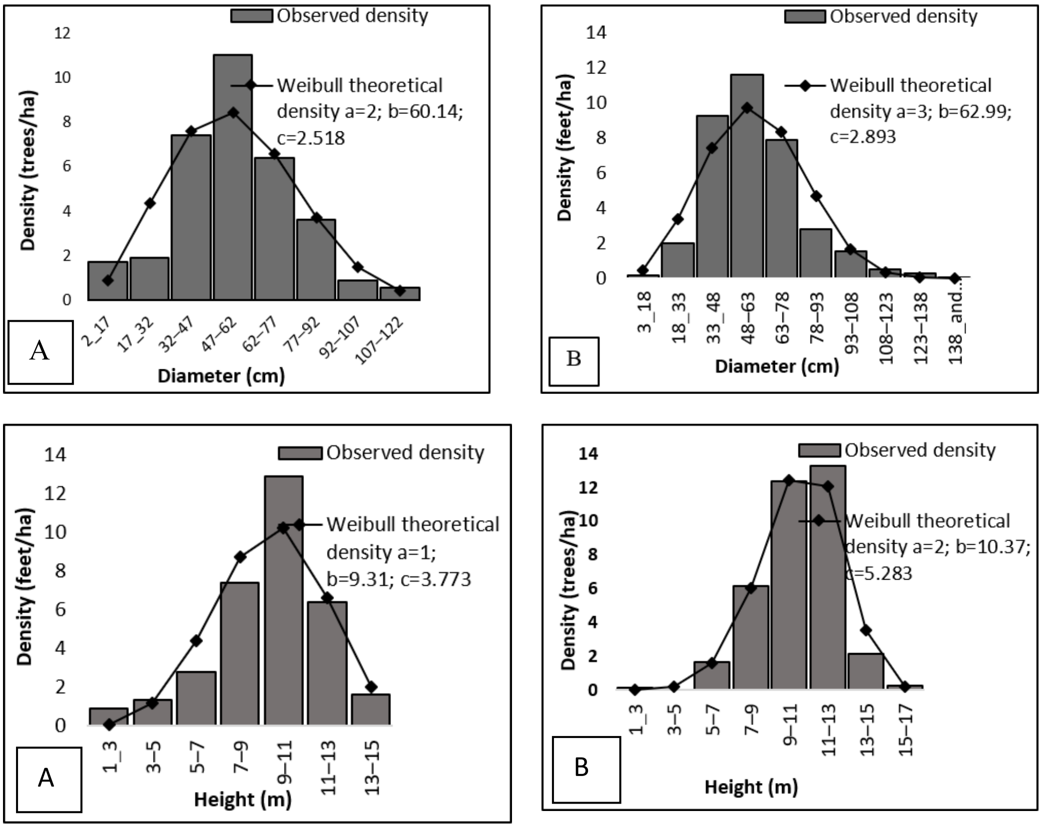

Fig. 3. Diameter (A) and height (B) structure of *Vitex doniana* and *Vitellaria paradoxa* populations

3.3 Height-diameter Relationship

Analysis of the allometric relationships between diameter at 1.30 m (X) and total height (Y) of *Vitex doniana* and *Vitellaria paradoxa* individuals showed a very satisfactory fit to a simple linear regression model (y = ax + b). The scatter plots (Fig. 4) revealed a strong positive correlation between these two dendrometric parameters, confirmed by very high coefficients of determination (R^2). The models obtained were as follows: for *Vitex doniana* (Fig. 4A), Y = 0.1192x + 2.86 (R^2 = 96.8%); and for *Vitellaria paradoxa* (Fig. 4B), Y = 0.094x + 6.024 (R^2 = 93%).

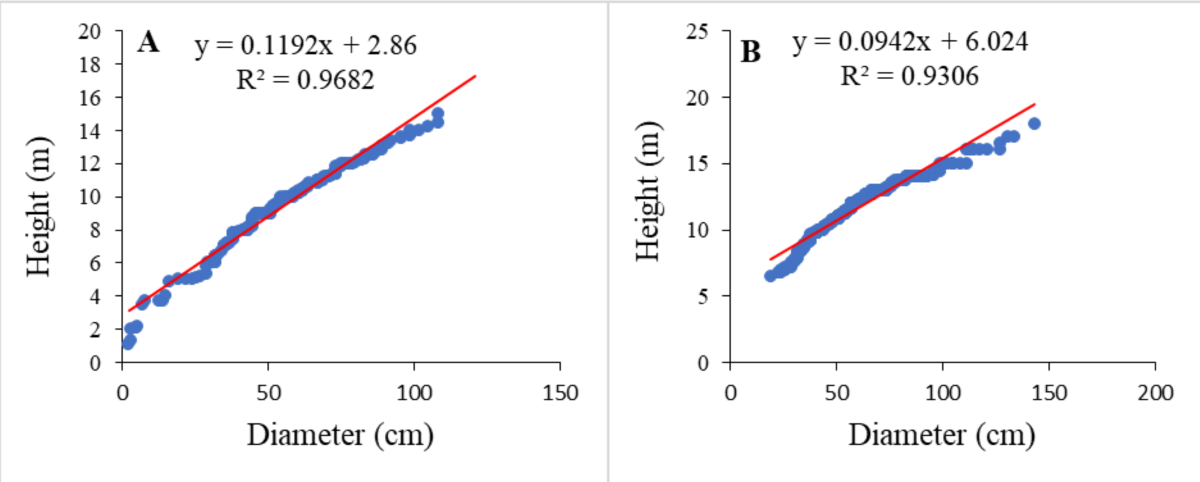

Fig. 4. Height-diameter relationship for *V. doniana* (A) and *V. paradoxa* (B)

4. Discussion

4.1 Discussion of Dendrometric Attributes

The dendrometric attributes of the *V. doniana* and *V. paradoxa* populations confirm a clear dependence on the rainfall gradient. The distribution and abundance of these species can be explained by the combined influence of ecological factors and anthropogenic pressures. The higher densities and basal areas observed in the Sudanian zone reflect more favourable edaphic and climatic conditions. This result corroborates the work of Zounon et al. (2019), who highlighted an improvement in the structural parameters of vegetation formations along the north-south rainfall gradient.

Density, which varied by sector and species, ranged from 7.68 to 25.36 plants/ha for *V. doniana* and from 9.42 to 27.94 plants/ha for *V. paradoxa*. This increased presence in agrosystems suggests selective protection favouring their development, a trend similar to that reported by Aleza et al. (2015) in Benin. However, these densities differ from the observations of Bondé et al. (2013), reflecting the cumulative impact of agricultural pressure and limited regeneration. This difficulty in regeneration is well documented: Mahamane (1997) highlighted the removal of juveniles to free up agricultural land, whilst Barmo (2008) pointed to over-harvesting and households' lack of resilience to climatic hazards.

The Sudanian zone appears to be a preferred habitat for these species, with optimal annual rainfall (800–1,500 mm), although *V. paradoxa* exhibits ecological plasticity that enables it to colonise the Sahelian region (550–800 mm), as documented by Dan Guimbo et al. (2016). Furthermore, the shea tree adapts to sandy-clay to lateritic soils (Atakpama et al., 2022).

4.2 Population Status and Structural Dynamics

Analysis of diameter (bell-shaped distribution) and height (left-skewed) structures reveals a concerning population dynamic. The Weibull shape parameter c (c ≈ 2.5 for diameters) indicates a positively skewed distribution, characteristic of populations with impaired recruitment. For heights, values of c > 3.6 (5.28 for *V. doniana*; 3.77 for *V. paradoxa*) confirm a predominance of older individuals, reflecting an ageing stand.

This structure, typically described as degraded or unstable (Adjonou et al., 2009; Thiombiano et al., 2016), can be explained by the convergence of two major factors. On the one hand, anthropogenic pressure, characterised by the systematic felling of large trees and the grazing of young trees, severely limits the recruitment of younger age classes. On the other hand, the species' low biological capacity, illustrated by a reduced germination rate (Houetchegnon, 2016) and the intrinsic vulnerability of seedlings to agricultural land clearance (Abdourhamane, 2016), constitutes an additional ecological constraint.

As Abdou (2021) pointed out, the future of natural stands depends crucially on the significant presence of young individuals. The near-total absence of such individuals in our study area therefore serves as a warning sign of genetic erosion and the threat of local extinction in the medium term, a finding echoed by Ouoba et al. (2023) in Burkina Faso.

5. Conclusion

This study assessed the current status of *Vitex doniana* and *Vitellaria paradoxa* populations along the rainfall gradient in the Dosso Partial Wildlife Reserve. The findings indicate that the Sudanian zone supports higher densities, basal areas and mean diameters than the Sahelian zone, suggesting that more favourable rainfall and environmental conditions are associated with stronger stand development. Nevertheless, the diameter and height structures show an imbalance, with populations dominated by adult and ageing individuals and limited evidence of successful regeneration. This pattern indicates that recruitment is constrained and that young plants are unlikely to reach maturity under existing pressures in the study area. The conservation of these species therefore requires practical and locally acceptable management measures that protect juveniles, encourage regeneration and reduce pressures on adult trees. Cost-effective approaches, including farmer-managed natural regeneration and community participation, may support the persistence and sustainable use of these species within agroforestry systems and natural stands.

6. Limitation

This study was limited to inventory data collected from selected municipalities and plots within the Dosso Partial Wildlife Reserve. It assessed population structure at one period and did not measure long-term changes in recruitment, mortality or land-use pressure. Seasonal variation, seedling survival and socio-economic drivers of exploitation were not examined in detail.

Declaration of AI Use

This manuscript was prepared through the combined contributions of all author(s), including contributions to the study design, data, content development, results, interpretation, and related scholarly work. The author(s) acknowledge the use of Grammarly and ChatGPT to assist with grammar checking, language refinement, reference formatting. These AI-assisted tools were not used as authors and did not replace the intellectual contributions or scholarly judgment of the author(s). All AI-assisted outputs, including content, references, and interpretations, were carefully reviewed, revised, verified, and approved by the author(s). The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that no competing interests exist.

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