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Farmers' preferences for woody plant species and their indicative biomass carbon stocks in silvopastoral systems of Benin (West Africa)

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Introduction: Agroforestry is increasingly promoted in cattle production systems in West Africa; however, empirical evidence linking farmers' woody plant species preferences with indicative biomass carbon stocks remains limited. Understanding these relationships is important for designing agroforestry interventions that respond to farmers' production needs while accounting for environmental co-benefits.

Methods: The study was conducted in Benin's dry tropical zone (DTZ) and sub-humid tropical zone (STZ). Data were collected through 18 focus group discussions, interviews with 338 cattle farmers, and inventories of woody plant species in 30 agroforestry plots of 1,000 m² each. Farmers assessed woody plant species using eight selection criteria, and species were ranked based on mean ordinal scores. Biomass carbon stocks were estimated at the tree level to provide indicative comparisons among preferred species.

Results and discussion: Across both zones, feed value was consistently ranked as the most important selection criterion. *Leucaena leucocephala* was the most preferred species in both DTZ and STZ, followed by *Khaya senegalensis*, reflecting farmers' emphasis on fodder provision and adaptability rather than environmental functions. Estimated biomass carbon stocks varied significantly ($p < 0.05$) among species, with comparable values for *Leucaena leucocephala* (46.4 ± 5.9 kg C tree⁻¹) and *Khaya senegalensis* (61.8 ± 10.4 kg C tree⁻¹), and substantially higher stocks for *Azizelia africana* (112.5 ± 18.9 kg C tree⁻¹). These findings suggest that agroforestry interventions in cattle production systems should prioritize farmer-preferred species to ensure adoption, while strategically incorporating complementary woody plant species with higher carbon storage potential to enhance environmental co-benefits without compromising livestock productivity.

KEYWORDS

agroforestry, carbon sequestration, cattle, climatic zone, preferences, woody plant species

1 Introduction

In Benin, livestock farming is a fundamental pillar of the economy and plays a vital role in people's livelihoods. It contributes significantly to the agricultural gross domestic product (GDP), ensures the supply of animal-source protein, and fulfills socio-economic and cultural needs of rural communities (MAEP, 2017). Being a major source of income for many households in rural areas, livestock farming plays a central role in resilience strategies against poverty and food insecurity (Idrissou et al., 2019). Cattle, in particular, are valuable for savings, traditional ceremonies, and trade (Adesogan et al., 2025). However, the livestock sector faces growing environmental challenges. Natural resource degradation, biodiversity loss, shrinking pasture areas, desertification processes, and the impacts of climate change are threatening the productivity and sustainability of livestock systems (Dossa et al., 2017). These environmental pressures are exacerbated by high population growth and agricultural expansion, which contribute to deforestation and the fragmentation of natural ecosystems (Lambin and Meyfroidt, 2011). In response to these challenges, agroforestry is increasingly considered as an integrated strategy to reconcile livestock production, land restoration, enhance biodiversity and contribute to carbon sequestration.

Agroforestry, and more specifically tree planting in livestock systems, is widely recognized for its potential to enhance land productivity, improve farmers' livelihoods and contribute to climate change adaptation and mitigation (Duguma et al., 2014; Mbow et al., 2014). Useful woody plant species may provide fodder, shade, timber or fuelwood, fruits, medicinal products and carbon storage in biomass and soils (Amare et al., 2019; Reppin et al., 2020; Ibrahim et al., 2022; Zomer et al., 2022). However, these benefits do not depend on tree planting alone. They are strongly shaped by the woody plant species selected, their ecological traits, their management, and the extent to which they respond to farmers' immediate production needs. In cattle production systems, this is particularly important because farmers are likely to prioritize species that support feeding and hence animal performance as well as easy management before considering less obvious environmental functions such as carbon sequestration (Franzel et al., 2014).

In Africa, several studies contributed to the understanding of the factors that influence farmers' adoption of tree planting on farmland, including socio-economic conditions, perceived benefits, access to extension services and institutional support (Jha et al., 2021; Ibrahim et al., 2022; Wakaba et al., 2025; Idrissou et al., 2025). These studies explain why farmers may accept or reject agroforestry. Yet, adoption studies often provide limited information on the species-level decisions that determine the actual composition and functions of agroforestry systems. This information is critical for livestock-based systems, where the choice of the woody plant species affects fodder availability, compatibility with crops, ease of management and potential environmental co-benefits (Barwani et al., 2023).

Several other studies analysed farmers' preferences for tree species in West African agroforestry systems, indicating that farmers generally value trees for functions that directly support livelihoods, such as food provision, medicine, income generation and soil improvement (Faye et al., 2011; Sèwadé et al., 2018). In Burkina Faso, Dimobe et al. (2018) further showed that some farmer-preferred species in parkland agroforests may also store substantial amounts of carbon. This suggests that farmers' tree preferences and their carbon-related ecosystem services can sometimes converge. However, in cattle-based silvopastoral systems, farmers are likely to select trees primarily for livestock-related

functions, especially fodder value, regrowth after cutting, drought tolerance and compatibility with crops (Montcho et al., 2025). Yet, species that are useful and preferred for livestock production are not necessarily those that provide the greatest carbon-related co-benefits (Cuni-Sanchez et al., 2018). Consequently, it remains unclear whether the woody plant species preferred by cattle farmers for production purposes also offer a substantial biomass carbon storage potential.

This specific knowledge gap is addressed in the present study, by integrating ethnobotanical surveys with biomass assessments in order to explore the synergies between the woody plant species preferred by cattle farmers and the climate services these species provide. The objectives of this study were (i) to identify the selection criteria that cattle farmers in Benin use to choose woody plant species, (ii) to determine the specific woody plant species that they prefer based on these criteria, and (iii) to estimate the biomass carbon stock potential of the preferred species. By linking farmer preferences to species traits and carbon outcomes, this research provides evidence to inform policy frameworks that promote agroforestry systems capable of enhancing food security, conserving biodiversity, and mitigating climate change in West Africa.

2 Materials and methods

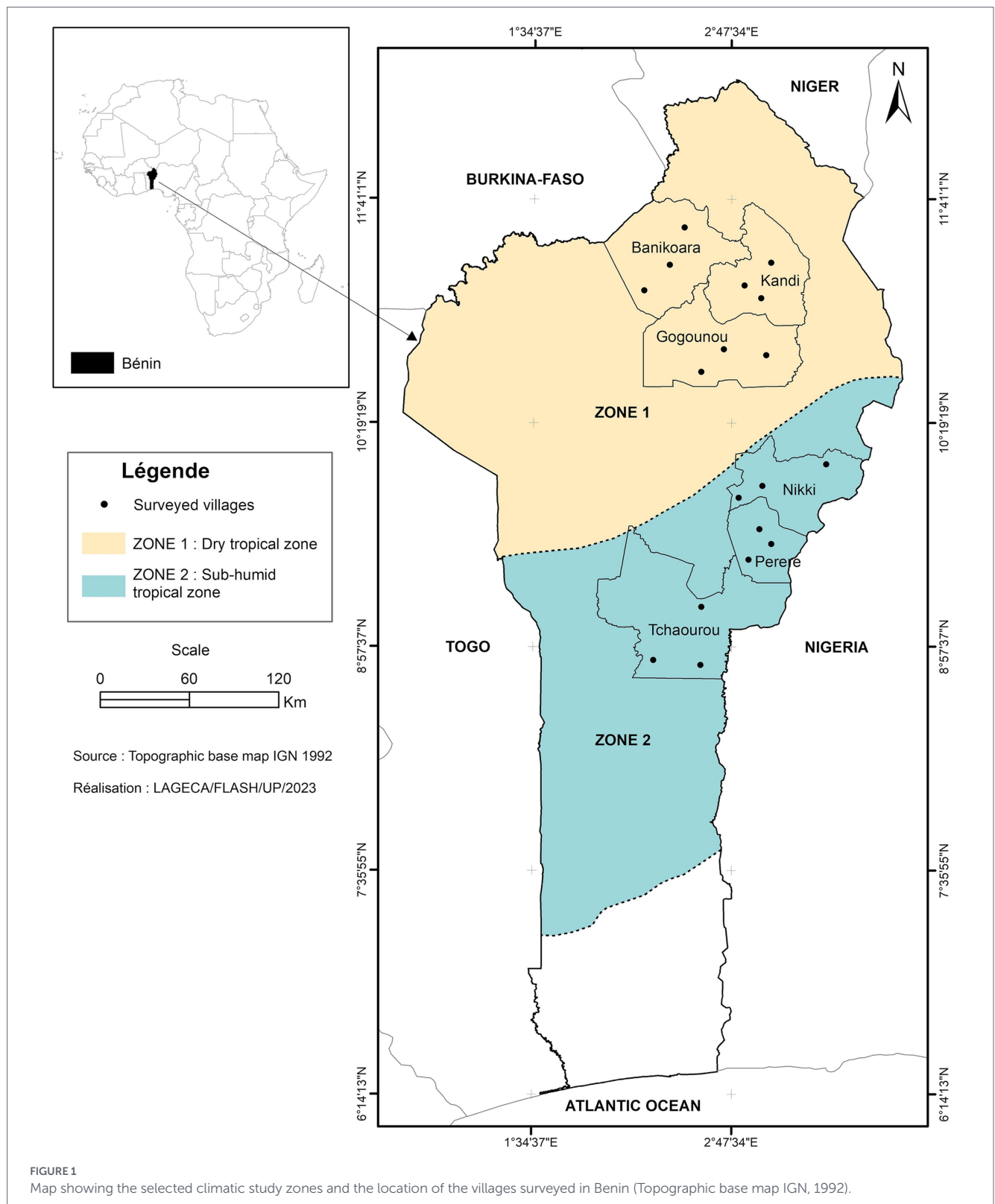
2.1 Study zones

The study was carried out in two climatic zones of Benin: the dry tropical zone (DTZ) located between 9° 45' and 12° 25'N and the sub-humid tropical zone (STZ) located between 7° 30' and 9° 45'N (Figure 1). These zones were selected based on climate projections, identifying them as the most vulnerable to rainfall deficits and intense sunlight (Gnanglè et al., 2011). Notably, they also host over 85% of the national cattle herd (Alkoiret et al., 2011), underscoring their strategic importance for livestock-related research and interventions. In each zone, three municipalities were chosen because they hosted a large number of cattle farmers and had been covered by preliminary interviews with technicians from the "Agences Territoriales pour le Développement Agricole" (ATDA). Specifically, the municipalities of Banikoara, Gogounou, and Kandi were selected in the DTZ, and Nikki, Pèrèrè, and Tchaourou were selected in the STZ. Within each municipality, three (3) villages were selected based on the importance of cattle farming and accessibility (Figure 1).

The DTZ has hydromorphic, well-drained lithosols. The vegetation of this zone is mainly composed of savannas with small trees (Assogbadjo et al., 2012). The mean annual rainfall is 953 mm (Idrissou et al., 2020a). Average annual temperature varies from 24 to 31 °C, and relative humidity from 18 to 99% (Assogbadjo et al., 2012). In the STZ, soils are ferruginous with variable fertility (Adomou et al., 2006). The vegetation is characterized by a mosaic of woodland, dry dense forests, tree and shrub savannas, and gallery forests (Assogbadjo et al., 2012). The mean annual rainfall is 1,155 mm (Idrissou et al., 2020a). Average annual temperature varies from 25 to 29 °C, and relative humidity ranges from 31 to 98% (Neuenschwander et al., 2011).

2.2 Sampling and data collection

Data were collected from September 2024 to May 2025 via focus group discussions (FGDs), a survey, and an inventory of



agroforestry plots. The study followed a multi-stage purposive sampling design to ensure that data collection focused on the main cattle-producing areas where tree integration into livestock systems is most relevant. This sampling approach was appropriate for capturing farmers' preferences, selection criteria, and existing tree-based practices in contrasting climatic zones. The sampling procedure involved four main stages: (1) selection of

climatic zones, (2) selection of municipalities and villages, (3) selection of cattle farmers for FGDs and individual interviews, and (4) selection of farms for biomass inventories. At each stage, selection was guided by the importance of cattle farming, climate vulnerability, farmers' willingness to participate, accessibility, and the presence or intention to integrate woody plant species into farming systems.

2.2.1 FGDs and individual interviews

Before the FGDs started, a pilot survey was carried out in each village. The aim of this survey was, on one hand, to explain to the village authorities the objective of the study and, on the other hand, to identify cattle farmers willing to partake in the study. To identify the cattle farmers' selection criteria for woody plant species, 18 FGDs were organized - nine per climatic zone and one per village, respectively. Each FGD was carried out with 15 cattle farmers. The number of participants per FGD was retained to ensure active participation while keeping the group manageable for discussion and consensus building. FGDs were moderated to allow all participants to express themselves in a comfortable environment. Participants were selected with the support of village authorities and local agricultural technicians to ensure that they were active cattle farmers familiar with the local farming context. The FGDs were conducted using a semi-structured discussion guide developed from the objectives of the study, the pilot survey, and previous studies on farmers' preferences for tree species and agroforestry adoption (Nkurikiye et al., 2024; Idrissou et al., 2025). The guide mainly included open-ended questions to encourage farmers to freely discuss their perceptions, experiences, and preferences regarding tree planting on farmland.

During each FGD, the following data were collected: importance of tree/shrub planting, criteria for choosing woody plant species, and a list of woody species that farmers wanted to plant. These data were obtained in three steps. Firstly, participants from each village-level FGD shared their perceptions of the importance of planting trees on farmland. Secondly, they discussed and jointly agreed upon eight key criteria for selecting woody plant species. These criteria were then scored according to their relative importance (1 = lowest priority to 8 = highest priority), allowing the calculation of a mean score for each criterion (Equation 1) following Nkurikiye et al. (2024). The resulting mean scores were subsequently used to rank the criteria, with higher values indicating greater perceived importance. Finally, participants generated a list of woody species that they considered important to plant on their farms.

$$S_c = \frac{1}{k} \sum_{j=1}^k S_{cj} \quad (1)$$

where S_c is the mean score of criterion c ; S_{cj} is score position (i.e., first = 8 pts, second = 7 pts, ..., last = 1 pt) in the j th FGD; k is the total number of FGDs.

Following the FGDs, individual interviews were conducted with 338 cattle farmers selected from a previous survey reported by Idrissou et al. (2025). In that earlier survey, 450 cattle farmers were interviewed regarding their intention to adopt agroforestry practices, of whom 75.1% ($n = 338$) reported a positive intention and were subsequently revisited for the present study. This sampling strategy was deliberately chosen to focus on potential adopters of tree-based systems. Therefore, interviewed households were not randomly selected from the entire cattle-farming population, but purposively selected from a previously identified group of farmers whose profiles were directly relevant to the study objective.

Individual interviews were carried out using a structured questionnaire. The questionnaire was developed based on the study objectives, information obtained during the pilot survey, and previous studies on farmers' tree species preferences and agroforestry

adoption (Nkurikiye et al., 2024; Idrissou et al., 2025). It included both closed-ended questions and ranking/scoring questions. Closed-ended questions were used to collect farmers' socio-economic characteristics, whereas ranking and scoring questions were used to assess farmers' preferred woody plant species and their evaluation of each species against the selection criteria identified during the FGDs.

During the individual interviews, data on farmers' socio-economic characteristics were first collected. Farmers were then asked to rank the woody plant species identified during the FGDs according to their perceived importance for integration into their farms, from the most to the least important. Subsequently, farmers evaluated each species against a set of selection criteria previously identified through FGDs in each climatic zone, using a four-level ordinal scale (1 = low relevance, 4 = high relevance). For each species, the average score was calculated across all criteria and respondents. These average scores were then grouped by magnitude and used to determine the species' relative priority ranking.

2.2.2 Biomass inventory

During the FGDs, cattle farmers who had introduced preferred woody plant species on their farms were asked whether they agreed to participate in farmland inventories to characterize the biomass carbon stock of planted trees. The stocks estimated from these inventories were used to compare the various woody species recorded on farmers' fields. The respective estimates represent indicative, tree-level carbon stocks for established woody individuals within the sampled plots, rather than comprehensive carbon stocks at the farm, stand, or landscape scale.

Farms were selected using a purposive sampling approach because the inventory required the presence of planted individuals of the preferred woody plant species identified during the FGDs. The target number of 30 farms was retained to ensure a balanced representation of the two climatic zones while remaining feasible for detailed field measurements of tree density, diameter, and height at the farm level. Accordingly, 15 farms were selected in each climatic zone, which allowed comparison between zones and reduced potential bias associated with unequal sampling. The selected farms contained key woody plant species such as *Leucaena leucocephala*, *Khaya senegalensis*, *Azelia africana*, *Pterocarpus erinaceus*, *Gliricidia sepium*, and *Gmelina arborea* (see Supplementary material).

To estimate biomass carbon stocks, a systematic sampling approach was employed. On each farm, a rectangular plot of 1,000 m² (50 m × 20 m) was established. This plot size was retained because planted woody species were not always uniformly distributed across farms and often occurred as scattered trees, boundary plantings, or small clusters within farmland. Therefore, the 1,000 m² plot provided a practical compromise between capturing a sufficient number of planted individuals and maintaining field measurement feasibility across the 30 farms. The plot was positioned in the part of the farm where the preferred planted woody species were present, but without selectively excluding other woody individuals occurring within the plot. Thus, the inventory intended to provide indicative biomass carbon stock estimates for planted woody components in silvopastoral farms, rather than a full-farm carbon assessment. A full inventory of all trees and shrubs within each plot was then carried out.

Dendrometric measurements included the diameter at breast height (DBH) and tree height. A minimum DBH threshold of 5 cm

was applied to exclude smaller trees and shrubs, as they contribute minimally to aboveground woody biomass. Trees with DBH ≤ 5 cm were classified as potential regeneration rather than mature biomass. Consequently, the biomass estimates represent current woody biomass of established trees above the measurement threshold and do not capture the contribution of seedlings, saplings or early regeneration stages to future carbon accumulation. This threshold also ensured that sampled trees were sufficiently resilient to fire and facilitated species identification (Dimobe et al., 2018). DBH was calculated from circumference measurements taken at 1.30 m above ground using a tape measure. Tree height was determined with a clinometer, recording the distance from the base to the highest point with an accuracy of 0.1 m. Aboveground biomass (AGB) was estimated using the allometric equation (Equation 2) proposed by Chave et al. (2014):

$$AGB = 0.0673 * \left(P * DBH^2 * h \right)^{0.976} \quad (2)$$

Where AGB is the aboveground biomass in kg per tree, DBH is the diameter at breast height in cm, P is wood density in $g\ cm^{-3}$, and h is the total height of the tree in meters.

We selected this equation because the inventory included several indigenous and introduced woody species with contrasting architecture and wood density. Furthermore, no species- and/or country-specific agroforestry equations were available. The utilized pan-tropical equation, therefore, provides a standardized approach for estimating and comparing biomass among species. However, because it was not locally calibrated, the resulting values should be interpreted as indicative estimates rather than direct measurements of biomass carbon stocks. The *getWoodDensity* function from the *BIOMASS* package (Réjou-Méchain et al., 2017) was employed to assign wood density values to each taxon, referencing the global wood density database (Chave et al., 2009). When available, the function uses at least one wood density measurement from the same genus to calculate a genus- or species-level average for the target taxon (Réjou-Méchain et al., 2017).

Belowground biomass (BGB) was estimated as 24% of AGB, based on the root:shoot ratio recommended by IPCC (2003). Total biomass (TB) for each tree was calculated as the sum of AGB and BGB ($TB = AGB + BGB$) following Handavu et al. (2021). Carbon stocks were subsequently estimated for each tree by multiplying TB by the IPCC default carbon fraction of 0.5 (IPCC, 2003).

2.3 Statistical analysis

All data were entered into Microsoft Excel 2016 and analyzed using R software version 3.5.1 (R Core Team Development, 2018). Descriptive statistics were first used to summarize the socio-economic characteristics of cattle farmers. Associations between categorical variables and climatic zones were examined using Chi-square tests.

Scores generated from focus group discussions and individual interviews were based on ordinal rating scales (1–8 and 1–4). For each criterion and woody plant species, mean scores were computed to derive synthetic indicators of relative importance and prioritization, following the approach proposed by Mekoya et al. (2008). Although these indicators are expressed as means for ease of interpretation, statistical inference explicitly accounted for the ordinal nature of the underlying data. Consequently, non-parametric methods were applied, as no assumptions of normality or homoscedasticity were

imposed. Comparisons of score distributions between the two climatic zones were conducted using the Mann–Whitney U test, which is appropriate for independent samples with ordinal responses (McDonald, 2009). Results are reported as mean scores followed by p -values.

AGB, BGB, TB, and tree carbon stock data were analyzed using Linear Mixed-Effects Models (LMMs). The models were specified to evaluate the fixed effects of tree species and climatic zone, as well as their interaction, while controlling for differences in tree size by including DBH as a covariate. DBH was used as a proxy for tree age and growth stage, enabling species-level comparisons of carbon stocks under equivalent-size conditions. DBH was retained as the main covariate because tree diameter is a robust field-based indicator of tree size and biomass accumulation. Other variables, such as height and wood density, were not included as additional covariates because they were components of the biomass estimation procedure (Equation 2) and could have introduced over-adjustment or collinearity with species identity. To account for the hierarchical structure and non-independence of the data, plot identity was included as a random effect, with individual trees nested within plots. Potential collinearity was considered during model specification, particularly because wood density is closely linked to species identity and tree height, which were already included in the biomass estimation (Equation 2). Models were fitted using the *lme4* package (Bates et al., 2015), which is well suited for ecological datasets with unbalanced sampling designs and nested observations (Harrison et al., 2018). The significance of fixed effects was assessed using the *lmerTest* package (Kuznetsova et al., 2017). Model assumptions were verified using residual diagnostics, including residual-versus-fitted plots, normal Q-Q plots, and inspection of random effects for normality and homoscedasticity. When significant effects were detected, post-hoc pairwise comparisons were performed on estimated marginal means using Tukey-adjusted tests implemented in the *emmeans* package (Lenth, 2021).

3 Results

3.1 Socio-economic characteristics of cattle farmers

The socio-economic characteristics of the surveyed cattle farmers are summarized in Table 1. The respondents were predominantly male (92%) and belonged to three socio-cultural groups: Gando (37.6%), Fulani (34.3%), and Bariba (28.1%). Farmers in the DTZ had a significantly higher schooling rate (primary and secondary education, 21.1%) compared to those in the STZ (16.3%). Most cattle farmers were sedentary (79%), members of a herders' organization (92.6%), and in contact with agricultural extension services (65.4%). Land access modes differed between the zones ($p < 0.001$). In the DTZ, inheritance (49.4%) and purchase (40.6%) were the primary means, followed by gifting (10%). In contrast, inheritance (61.9%) dominated in the STZ, with gifting (21.4%) and purchase (16.7%) being less common. The farmers had an average age of 55 years and a household size of 9 people, with no significant differences ($p > 0.05$) between both zones. However, farmers in the DTZ had significantly larger cattle herds (42 vs. 30 heads; $p < 0.001$), while those in the STZ owned more land (6 vs. 4 ha; $p < 0.001$). Overall, the two climatic zones differed mainly in production orientation, land access patterns,

TABLE 1 Socio-economic characteristics of cattle farmers surveyed in the dry (DTZ) and subhumid (STZ) tropical zones of Benin.

Characteristics	Climatic zone		Total	χ^2	<i>p</i> -value
	DTZ (<i>n</i> = 170)	STZ (<i>n</i> = 168)			
Gender (%)					
Male	94.7 ^a	89.3 ^a	92	3.377	0.066
Female	5.3 ^a	10.7 ^a	8		
Ethnic group (%)					
Fulani	40 ^a	28.6 ^b	34.3	16.672	<0.001
Gando	41.8 ^a	33.3 ^a	37.6		
Bariba	18.2 ^b	38.1 ^a	28.1		
Education level (%)					
Unschooling	78.8 ^b	88.7 ^a	83.7	6.044	0.048
Primary	17.6 ^a	9.5 ^b	13.6		
Secondary	3.5 ^a	1.8 ^a	2.7		
Membership in a herders' organization (%)					
Member	91.2 ^a	94 ^a	92.6	1.017	0.313
No member	8.8 ^a	6 ^a	7.4		
Contact with extension services (%)					
Contact	64.7 ^a	66.1 ^a	65.4	0.069	0.791
No contact	35.3 ^a	33.9 ^a	34.6		
Production mode (%)					
Sedentary	66.5 ^b	91.7 ^a	79	32.327	<0.001
Semi-transhumant	33.5 ^a	8.3 ^b	21		
Land access mode (%)					
Inheritance	49.4 ^b	61.9 ^a	55.6	26.250	<0.001
Gifting	10 ^b	21.4 ^a	15.7		
Purchase	40.6 ^a	16.7 ^b	28.7		
Means ± SE					
Age (years)	56 ^a ± 0.3	55 ^a ± 0.4	55 ± 0.2	–	0.076
Household size (persons)	8 ^a ± 0.1	9 ^a ± 0.1	9 ± 0.1	–	0.306
Cattle size (heads)	42 ^a ± 1.2	30 ^b ± 0.9	36 ± 0.8	–	<0.001
Land holding size (ha)	4 ^b ± 0.2	6 ^a ± 0.1	5 ± 0.1	–	<0.001

Values in rows with different superscripts differ significantly ($p < 0.05$). SE, Standard error.

herd size and landholding size, whereas most social characteristics were similar between zones.

3.2 Cattle farmers' criteria for choosing woody plant species

Table 2 summarizes farmers' prioritization of selection criteria for woody plant species in the DTZ and the STZ, based on ordinal scores derived from FGDs. Overall, the results reveal a high degree of convergence between zones, with only a limited number of criteria showing statistically significant differences.

Feed value was unanimously identified as the most important criterion in both zones, receiving the maximum mean score (8.0 ± 0.0) and ranking first in DTZ and STZ. For most other criteria, mean scores ranged between 5.0 and 6.9 in DTZ and between 5.2 and 6.7 in STZ, with no statistically significant differences between zones

($p > 0.05$). Criteria such as biomass yield (DTZ: 5.0 ± 0.2 ; STZ: 5.2 ± 0.8), growth and regrowth capacity (6.1 ± 0.3 in both zones), and life span (DTZ: 5.4 ± 0.2 ; STZ: 5.9 ± 0.3) showed comparable mean scores ($p > 0.05$). Apart from feed value, the remaining criteria showed relatively moderate score variation, indicating broadly similar prioritization patterns between zones.

Significant differences ($p < 0.05$) between zones were detected for only three criteria: adaptability, ease of propagation, and compatibility with crops. Adaptability was scored higher ($p < 0.001$) in the STZ (5.2 ± 0.1) than in the DTZ (4.1 ± 0.1), while ease of propagation also received higher scores ($p = 0.032$) in the STZ (5.1 ± 0.2) compared to the DTZ (4.4 ± 0.2). Compatibility with crops exhibited the largest relative difference, increasing from 5.0 ± 0.3 in the DTZ to 6.7 ± 0.2 in the STZ ($p = 0.003$), which was reflected in rank positions (DTZ: 6th; STZ: 2nd). Although statistically significant, these differences were small in magnitude (generally ≤ 1.7 points on an 8-point scale) and

TABLE 2 Criteria used by cattle farmers in the dry (DTZ) and subhumid (STZ) tropical zones of Benin for choosing woody species to plant on their farmland (mean $\pm$ standard error).

Selection criteria	Criteria' details	Mean score		<i>p</i> -value	Rank	
		DTZ	STZ		DTZ	STZ
Feed value	Palatability, enhanced milk yield and animal growth, improved straw intake, better animal health.	8.0 ^a $\pm$ 0.0	8.0 ^a $\pm$ 0.0	1.0	1	1
Biomass yield	Quantity of leaves.	5.0 ^a $\pm$ 0.2	5.2 ^a $\pm$ 0.8	0.537	5	6
Multi-functionality	Timber, fencing, fuelwood, construction, medicine, soil fertility, erosion control, shade.	6.9 ^a $\pm$ 0.1	6.4 ^a $\pm$ 0.3	0.248	2	3
Adaptability	Adaptable to soils and drought-resistant.	4.1 ^b $\pm$ 0.1	5.2 ^a $\pm$ 0.1	<0.001	8	7
Growth and regrowth capacity	Fast-growing and regrowing after cutting.	6.1 ^a $\pm$ 0.3	6.1 ^a $\pm$ 0.3	0.886	3	4
Life span	Long-lived under frequent cutting.	5.4 ^a $\pm$ 0.2	5.9 ^a $\pm$ 0.3	0.334	4	5
Ease of propagation	Easily propagated: seeds, seedlings, and cuttings.	4.4 ^b $\pm$ 0.2	5.1 ^a $\pm$ 0.2	0.032	7	8
Compatibility with crops	Non-competitive woody species; enhanced soil fertility and understory crop growth.	5.0 ^b $\pm$ 0.3	6.7 ^a $\pm$ 0.2	0.003	6	2

Values in rows with different superscripts differ significantly ($p < 0.05$).

indicate limited variation in the relative importance assigned to the criteria between zones. Overall, these results show that only a subset of selection criteria varied significantly between climatic zones, whereas the general ranking pattern remained broadly similar.

3.3 Cattle farmers' preferences for woody plant species

The woody plant species preferred by cattle farmers are listed in Table 3. In the DTZ, farmers preferred six species: *Leucaena leucocephala* (*L. leucocephala*), *Khaya senegalensis* (*K. senegalensis*), *Azizelia africana* (*A. africana*), *Pterocarpus erinaceus* (*P. erinaceus*), *Daniellia oliveri* (*D. oliveri*), and *Annona senegalensis* (*A. senegalensis*). In the STZ, the same species were preferred, along with three additional ones: *Gmelina arborea* (*G. arborea*), *Cajanus cajan* (*C. cajan*), and *Gliricidia sepium* (*G. sepium*).

Figure 2 presents the ranking of woody plant species based on mean ordinal scores assigned to eight selection criteria by cattle farmers in the DTZ and the STZ. The results highlight both convergence in farmers' preferences and context-specific differentiation in species evaluation.

In both zones, *L. leucocephala* consistently achieved the highest overall mean score (DTZ: 3.2; STZ: 3.4), reflecting high scores across key criteria, particularly feed value, growth potential, and compatibility with crops. The consistently high scores of *L. leucocephala* across several criteria resulted in its first-rank position in both climatic zones. *K. senegalensis* ranked second in both zones (mean score = 3.1), indicating stable appreciation across contrasting agroecological

conditions. Together, *L. leucocephala* and *K. senegalensis* formed the core group of highly preferred species shared across zones. Beyond these two top-ranked species, the preferred species and their order diverged between zones, whereby the zone-specific differentiation was mainly observed among intermediate- and lower-ranked species. In the DTZ, species such as *A. africana* and *P. erinaceus* occupied intermediate ranks (mean scores: 3.0 and 2.8, respectively), whereas in the STZ, *G. sepium* emerged among the high-ranked species (mean score = 3.0), driven by higher scores for growth potential. Conversely, *D. oliveri* and *A. senegalensis* ranked lowest in the STZ (mean score = 2.5), reflecting comparatively lower scores across several criteria. Overall, the rankings revealed both cross-zone consistency for key species and climatic-zone-specific variation in the relative importance of secondary species.

3.4 Carbon stock of woody plant species preferred by cattle farmers

After adjustment for DBH as a covariate, the woody plant species significantly affected AGB, BGB, TB and individual-tree carbon stocks (Table 4). Interspecific differences therefore remained significant even when trees were compared within corresponding diameter classes. When expressed on a per-tree basis, *A. africana* exhibited the highest mean carbon stock (112.5 ± 18.9 kg C tree⁻¹), followed by *G. arborea* (67.5 ± 7.0 kg C tree⁻¹) and *K. senegalensis* (61.8 ± 10.4 kg C tree⁻¹). *L. leucocephala* showed intermediate carbon stocks (46.4 ± 5.9 kg C tree⁻¹), whereas *P. erinaceus* (27.5 ± 3.9 kg C tree⁻¹) and *G. sepium* (9.1 ± 1.4 kg C tree⁻¹)

TABLE 3 List of woody plant species preferred by cattle farmers in the dry (DTZ) and subhumid (STZ) tropical zones of Benin.

Family	Species	Woody category	Origin	DTZ	STZ
Fabaceae	<i>Leucaena leucocephala</i> (Lam.) de Wit	Shrub	Exotic	+	+
Meliaceae	<i>Khaya senegalensis</i> (Desr.) A. Juss.	Tree	Native	+	+
Fabaceae	<i>Afzelia africana</i> Sm. ex Pers.	Tree	Native	+	+
Fabaceae	<i>Pterocarpus erinaceus</i> Poir.	Tree	Native	+	+
Verbenaceae	<i>Gmelina arborea</i> Roxb.	Tree	Exotic	–	+
Fabaceae	<i>Cajanus cajan</i> (L.) Millsp.	Shrub	Exotic	–	+
Fabaceae	<i>Daniellia oliveri</i> (Rolfe) Hutch. & Dalziel	Tree	Native	+	+
Fabaceae	<i>Gliricidia sepium</i> (Jacq.) Kunth	Shrub	Exotic	–	+
Annonaceae	<i>Annona senegalensis</i> Pers.	Shrub	Native	+	+

+: preferred; -: not preferred; Taxonomic authority follow the world flora online (<https://wfpantlist.org/>).

exhibited significantly ($p < 0.05$) lower values. Similar interspecific patterns were observed for AGB, BGB, and TB, confirming consistent differences in biomass accumulation capacity among species. The consistency of species ranking across biomass components indicates that species identity was a major source of variation in biomass accumulation.

Within the DTZ, the highest individual-tree carbon stocks were recorded for *A. africana* (103.0 ± 24.6 kg C tree⁻¹), followed by *K. senegalensis* (71.5 ± 13.1 kg C tree⁻¹). *L. leucocephala* displayed intermediate values, while *P. erinaceus* showed lower carbon stocks per tree. In the STZ, *A. africana* again exhibited the highest mean carbon stock (132.7 ± 28.2 kg C tree⁻¹). *G. arborea* showed intermediate values (67.5 ± 7.0 kg C tree⁻¹), whereas *G. sepium* recorded the lowest carbon stock per tree. Overall, the LMM results indicate that tree-level carbon stocks were primarily determined by species identity after accounting for DBH variation.

4 Discussion

4.1 Cattle farmers' criteria for choosing woody plant species

The eight selection criteria identified in this study reveal that cattle farmers use a comprehensive and multifactorial approach for choosing woody plant species to be integrated into their farms. This multiplicity of criteria is in line with the logic of agrosilvopastoral systems, where trees are not selected for a single function, but for their ability to simultaneously meet several needs of farmers and their livestock (Lemage and Legesse, 2018). In both study zones, feed value appeared to be the priority criterion (average score = 8), highlighting its central importance in livestock systems, and the key role of woody plants in providing quality feed to livestock, particularly in the dry season when herbaceous fodder is scarce (Du et al., 2023). Indeed, woody plant species are rich in crude protein and minerals such as calcium and magnesium, thus contributing to covering the nutritional needs of livestock (Coulibaly et al., 2025). The observed differences in the ranking of other criteria between the two study zones appear to reflect specific ecological and socio-economic contexts. An enlightening example is the criterion of compatibility with crops, which ranked second in the STZ, compared to sixth in the DTZ. This difference suggests a stronger integration of crop cultivation and livestock rearing in the STZ, aligning with observations by Traoré et al. (2011), who reported that in the more humid regions of West Africa, integrated agrosilvopastoral systems, requiring greater compatibility between woody plant species and crops, are more prevalent. In contrast, farmers in the DTZ, where livestock production dominates (Idrissou et al., 2020b), place less emphasis on this compatibility. Because the selection criteria were initially gathered through focus group discussions, they should be interpreted as collectively expressed priorities. Such criteria may partly reflect group dynamics and consensus-building processes, although the subsequent individual interviews helped refine species-level preferences.

4.2 Cattle farmers' preferences for woody plant species

The results of this study reveal a remarkable similarity between cattle farmers in both zones regarding their preferences for certain woody plant species. Indeed, *L. leucocephala* and *K. senegalensis* consistently occupied the top two positions in the rankings of farmers in both zones, demonstrating their high relevance, which is explained by their characteristics. *L. leucocephala*, with high protein content and high digestibility of its leaves, represents a prime forage resource, particularly during the feed-scarce dry season (De Angelis et al., 2021). *K. senegalensis* combines an appreciable fodder value with multiple uses, such as for timber and traditional medicine, which reinforces its value for agropastoral systems (Gaoue and Ticktin, 2009). These observations are consistent with previous findings showing that farmers in various West African contexts favor woody plant species combining high nutritional value and multifunctionality (Faye et al., 2011).

The preferences of farmers in the DTZ indicate a selection of species suitable for arid conditions. *A. africana* and *P. erinaceus*, ranked third and fourth, respectively, exemplify this trend. Their deep root systems, drought resistance, and further physiological characteristics make them particularly resilient to water stress and degraded soils (Atanasso et al., 2021; Asigbaase et al., 2024); they are thus able to

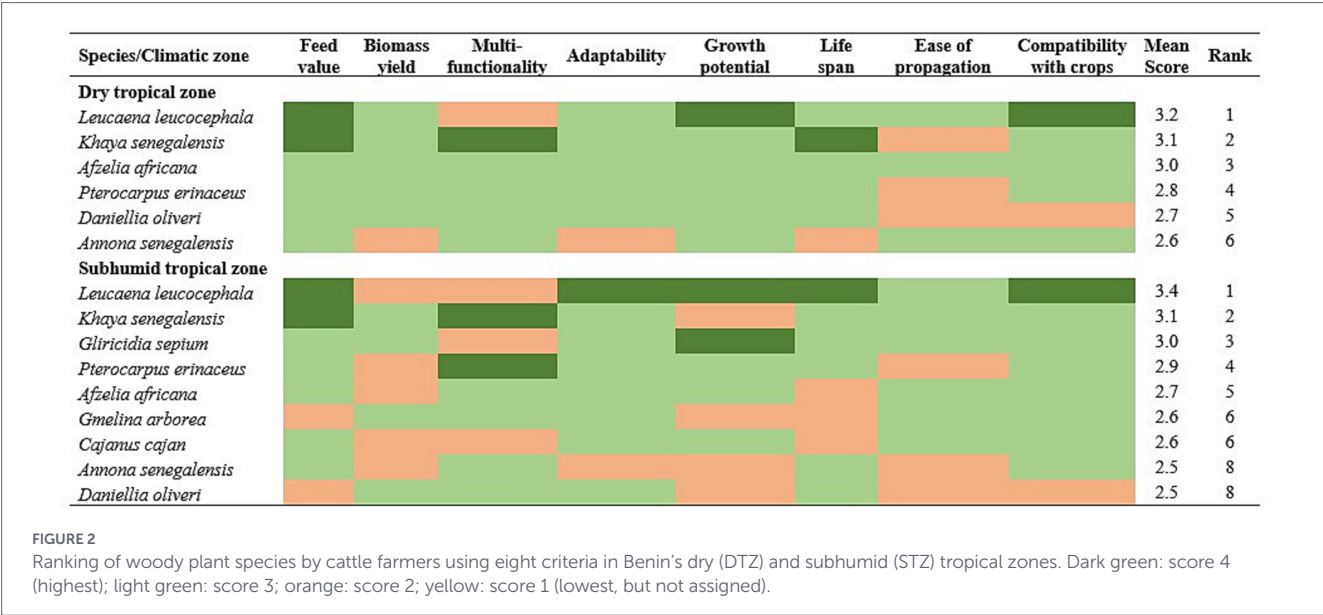


TABLE 4 Tree-level biomass and carbon stock (mean $\pm$ standard error) of woody plant species preferred by cattle farmers in Benin's dry (DTZ) and subhumid (STZ) tropical zones.

Parameters	Number of trees measured	AGB (kg tree ⁻¹)	BGB (kg tree ⁻¹)	TB (kg tree ⁻¹)	Carbon stock (kg C tree ⁻¹)
Species					
<i>Leucaena leucocephala</i>	164	74.8 ^{bc} $\pm$ 9.62	17.9 ^{bc} $\pm$ 2.3	92.8 ^{bc} $\pm$ 11.9	46.4 ^{bc} $\pm$ 5.9
<i>Khaya senegalensis</i>	49	99.8 ^b $\pm$ 16.7	23.9 ^b $\pm$ 4.0	123.7 ^b $\pm$ 20.7	61.8 ^b $\pm$ 10.4
<i>Azalia africana</i>	22	181.4 ^a $\pm$ 30.5	43.5 ^a $\pm$ 7.3	224.9 ^a $\pm$ 37.8	112.5 ^a $\pm$ 18.9
<i>Pterocarpus erinaceus</i>	17	44.3 ^{cd} $\pm$ 6.3	10.6 ^{cd} $\pm$ 1.5	54.9 ^{cd} $\pm$ 7.8	27.5 ^{cd} $\pm$ 3.9
<i>Gliricidia sepium</i>	61	14.7 ^d $\pm$ 2.3	3.5 ^d $\pm$ 0.6	18.3 ^d $\pm$ 2.8	9.1 ^d $\pm$ 1.4
<i>Gmelina arborea</i>	36	108.8 ^{ab} $\pm$ 11.4	26.1 ^{ab} $\pm$ 2.7	134.9 ^{ab} $\pm$ 14.1	67.5 ^{ab} $\pm$ 7
Preferred species in DTZ					
<i>Leucaena leucocephala</i>	106	73.9 ^{cd} $\pm$ 12.8	17.7 ^{cd} $\pm$ 3.1	91.7 ^{cd} $\pm$ 15.8	45.8 ^{cd} $\pm$ 7.9
<i>Khaya senegalensis</i>	37	115.4 ^{bc} $\pm$ 21.1	27.7 ^{bc} $\pm$ 5.1	143.1 ^{bc} $\pm$ 26.2	71.5 ^{bc} $\pm$ 13.1
<i>Azalia africana</i>	15	166.2 ^{ab} $\pm$ 39.7	39.9 ^{ab} $\pm$ 9.5	206.0 ^{ab} $\pm$ 49.2	103.0 ^{ab} $\pm$ 24.6
<i>Pterocarpus erinaceus</i>	11	36.9 ^{de} $\pm$ 6.2	8.9 ^{de} $\pm$ 1.5	45.7 ^{de} $\pm$ 7.7	22.9 ^{de} $\pm$ 3.9
Preferred species in STZ					
<i>Leucaena leucocephala</i>	58	76.4 ^{cd} $\pm$ 13.9	18.3 ^{cd} $\pm$ 3.5	94.8 ^{cd} $\pm$ 17.3	47.4 ^{cd} $\pm$ 8.7
<i>Khaya senegalensis</i>	12	51.6 ^d $\pm$ 13.4	12.4 ^d $\pm$ 3.2	63.9 ^d $\pm$ 16.7	31.9 ^d $\pm$ 8.3
<i>Azalia africana</i>	7	214.1 ^a $\pm$ 45.5	51.4 ^a $\pm$ 10.9	265.4 ^a $\pm$ 56.5	132.7 ^a $\pm$ 28.2
<i>Pterocarpus erinaceus</i>	6	57.9 ^d $\pm$ 12.5	13.9 ^d $\pm$ 2.9	71.8 ^d $\pm$ 15.5	35.9 ^d $\pm$ 7.7
<i>Gliricidia sepium</i>	61	14.7 ^c $\pm$ 2.3	3.5 ^c $\pm$ 0.6	18.3 ^c $\pm$ 2.8	9.1 ^c $\pm$ 1.4
<i>Gmelina arborea</i>	36	108.8 ^{bc} $\pm$ 11.4	26.1 ^{bc} $\pm$ 2.7	134.9 ^{bc} $\pm$ 14.1	67.5 ^{bc} $\pm$ 7.0

Values in the same columns with different superscripts differ significantly ($p < 0.05$); AGB, Aboveground biomass; BGB, Belowground biomass; TB, Total biomass.

maintain forage production under difficult environmental conditions (Shaibu et al., 2024). Their long lifespan is a major asset in areas where natural regeneration processes are slow and uncertain. The work of Ouédraogo et al. (2017) in Burkina Faso has confirmed farmers' preference in arid zones for perennial and resistant species.

Cattle farmers in the STZ mentioned a larger number of preferred woody plant species than those in the DTZ. The ranking of *G. sepium*, *G. arborea*, and *C. cajan* among the preferred species reflects their adaptation to the ecological specificities of the zone. Water availability

and higher soil fertility are favoring the introduction of fast-growing woody plant species with short regrowth cycles after coppicing. *G. sepium*, third in the ranking, perfectly embodies this aspect due to its ability to quickly generate abundant and renewable forage biomass (Bayala et al., 2022). As for *C. cajan*, it represents an interesting example of a dual-purpose species, providing quality fodder while enriching the soil by fixing atmospheric nitrogen (Adjéi-Nsiah, 2012; Mekonen et al., 2022). Our findings are consistent with previous evidence showing that farmers in West Africa tend to integrate woody

plant species that enhance the overall productivity of agropastoral systems (Félix et al., 2018). In the STZ, the diversity of selected species reflects a deliberate strategy of resource optimization, supported by a more favorable ecological environment. However, favorable ecological or fodder traits do not necessarily lead to high farmer preference. Some species may remain less preferred when they are less known to farmers, less available in terms of planting material, more difficult to manage, or less compatible with existing farm priorities (Meijer et al., 2015).

4.3 Carbon stock in woody plant species preferred by cattle farmers

Marked interspecific differences were observed in the indicative biomass carbon stocks of woody plant species preferred by cattle farmers. In the DTZ, *A. africana* exhibited the highest carbon stock, followed by *K. senegalensis*, whereas in the STZ, *G. arborea* showed the highest values, followed by *A. africana*. In contrast, species such as *L. leucocephala* and *G. sepium* displayed comparatively modest carbon stocks, which is consistent with their classification as fast-growing, short-cycle species. These patterns are in line with previous studies showing that biomass carbon storage is strongly influenced by species-specific traits, including wood density, growth form, and longevity, as well as by local environmental conditions such as soil properties and climate (Nair et al., 2021). Direct comparison with regional or global carbon benchmarks remains limited because such benchmarks are generally expressed at stand, hectare or landscape scale, whereas the present estimates are expressed at tree level.

However, farmers' rankings reflected a different set of priorities and did not closely correspond to the carbon storage capacity of the species. While *K. senegalensis*, ranked second in both zones, combined relatively high carbon stocks with strong farmer preference, *L. leucocephala*, the most preferred species, showed only moderate carbon storage potential. Conversely, *G. arborea*, which exhibited substantial carbon stocks in the STZ, ranked relatively low in farmers' preferences. This divergence is not unexpected, as carbon sequestration was neither included among the eight selection criteria nor emphasized during focus group discussions or individual interviews. As noted by Murgueitio et al. (2011), farmers' decisions regarding tree integration are primarily shaped by immediate production needs, risk management, and livelihood considerations, rather than by longer-term environmental or climate-related objectives. The observed mismatch therefore reflects different selection logics: farmers primarily value woody plant species for immediate production and management goals, whereas carbon storage represents a less visible environmental co-benefit (Benebere et al., 2024).

Given the tree-level nature of the present estimates, these results alone are insufficient to assess the overall climate change mitigation potential of tree integration in cattle production systems. Rather, carbon storage should be viewed as a variable and species-dependent co-benefit of silvopastoral interventions. This finding reinforces the need for caution when framing smallholder agroforestry systems as climate solutions without considering the scale and magnitude of their carbon outcomes.

Although multi-species agroforestry systems have been shown to enhance productivity and ecosystem services under certain conditions (Liu et al., 2018), this study did not explicitly assess such effects. The results do therefore not provide empirical evidence that multi-species agroforestry systems outperform single-species

systems in terms of carbon sequestration or livestock productivity. Instead, the results highlight a conceptual implication arising from the mismatch between farmers' preferred species and those with the greatest carbon storage potential, which suggests combining highly preferred fodder species, such as *L. leucocephala*, with larger, longer-lived species, such as *K. senegalensis* or *A. africana*, to achieve significant carbon sequestration.

From a practical perspective, these findings emphasize the importance of basing agroforestry interventions on farmers' preferences in order to promote adoption and long-term management. Where they occur, carbon storage outcomes should be viewed as secondary benefits that depend on species composition and local ecological conditions, rather than as primary objectives guiding species selection. Adopting this farmer-centered approach is essential for designing agroforestry systems that are socially acceptable and operationally feasible in cattle production contexts.

Finally, the interpretation of these findings should consider two main methodological limitations: the uncertainty associated with biomass carbon stock estimation and the limited statistical representativeness resulting from the purposive sampling design. First, the biomass carbon stock estimates were based on generalized allometric equations, standard wood density values, and the assumption that carbon constitutes 50% of total biomass. These assumptions introduce uncertainty into the estimates, meaning that the carbon values presented here should be considered indicative rather than absolute. In addition, the exclusion of individuals with DBH ≤ 5 cm means that seedlings, saplings and early regeneration stages were not included in the biomass estimates. As a result, the reported carbon stocks reflect current tree-level stocks of established woody individuals, but not the future carbon accumulation potential at farm level. The limited and unbalanced number of preferred species across the two studied zones also restricts the robustness of any formal correlation or trade-off analysis between preference ranking and carbon stock. Future research should prioritize the development of species-specific allometric models, local measurements of wood density and carbon concentration, and the explicit consideration of spatial variability in soils, climate, and land-use patterns. These methodological refinements would enable more robust assessments of the environmental co-benefits of woody plant species preferred by cattle farmers.

Second, the study used a purposive sampling design. Climatic zones, municipalities, villages, interviewed farmers and biomass inventory farms were selected based on climate vulnerability, the importance of cattle farming, willingness to participate, accessibility, and the presence or intention to integrate woody plant species. Therefore, the findings should not be interpreted as statistically representative of all cattle farmers in Benin. Rather, they provide context-specific evidence on farmers' preferences and indicative biomass carbon stocks in cattle farming areas where tree integration is relevant or emerging. In addition, farmers' preferences were analysed mainly through selection criteria and species rankings, and not through a detailed model of household decision-making. As a result, factors such as market access, cultural values, availability of planting material, land-use constraints and perceived management risks were not considered in this study, even though they may also shape farmers' choices of woody species (Jerneck and Olsson, 2014). Future studies should combine purposive site selection with probability-based sampling of households and farms within selected zones, while also integrating these

socio-economic and cultural dimensions, to improve representativeness and allow broader statistical inference. Such an approach would help validate the patterns observed in this study while maintaining a focus on areas where tree integration in cattle farming systems is most relevant.

5 Conclusion

This study shows that cattle farmers' selection of woody plant species in Benin is primarily guided by production-oriented criteria, especially feed value, growth potential and multifunctionality. Relating farmers' choice to indicative tree-level carbon stocks shows that preferred species are not necessarily those with a high carbon storage potential. Carbon storage should therefore be considered as an environmental co-benefit rather than a major driver of farmers' woody species selection.

The findings have practical implications for silvopastoral interventions in West Africa. Extension agents and development practitioners should prioritize farmer-preferred species to ensure adoption and long-term management, while also promoting locally acceptable complementary species with higher carbon storage potential that are compatible with farm practices. Policymakers should support agroforestry strategies that integrate livestock productivity, farmer preferences and environmental co-benefits, rather than promoting carbon-oriented tree planting that overlooks farmers' production needs.

Further research based on larger and more representative inventories is needed to assess carbon stocks at farm or landscape scale and to better quantify the contribution of tree density and species composition to climate-related benefits.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The research protocol complied with ethical principles for social science research involving human participants. Cattle farmers participating in focus group discussions and individual interviews were informed in advance about the purpose of the study, data use, and confidentiality measures. Participation was entirely voluntary, and informed verbal consent was obtained from all respondents prior to data collection. Anonymity and confidentiality of participants were strictly ensured throughout the study.

Author contributions

YI: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Software, Visualization, Writing – original draft, Writing – review & editing. ES: Validation, Writing – review & editing. RR: Writing – review & editing.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declared that Generative AI was used in the creation of this manuscript. In the preparation of this work, the authors used the DeepL application in order to improve language and readability. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/ffgc.2026.1701472/full#supplementary-material>

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