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Local Communities Implications' in Managing Woody Species and Carbon Accumulation in Sahelian parts of Maradi Region, Niger Republic

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Abstract
In Sahel, climate change will intensify especially in West Africa in the future and seasons are observed to have a decrease in rainfall projected. This situation will affect future woody vegetation cover because Sahelian zone was characterized by significant vegetation response to rainfall. Notwithstanding climate change impacts on woody vegetation cover, some human practices can play positive role in Sahelian vegetation change. This study aimed to analyze local community implications' in managing woody species and carbon accumulation in Sahelian parts of Maradi Region, Niger Republic. Both quantitative and qualitative data were used in this study. Results showed that ecosystem services (provisioning, regulating and supporting) provided by woody trees species in the study area represent the main reasons for maintenance and protection of trees in farmlands. This clearly highlighted the roles of local communities in maintenance and protection of woody trees and consequently carbon accumulation by these woody species. This can allow farmers to be eligible to receive payments for the ''Carbon'' that those practices contribute to sequester under a ''Carbon'' trading arrangement in the Clean Development Mechanism (CDM) of the Kyoto Protocol of United Nations Framework Convention on Climate Change.

Keywords: Sahel, Vegetation, Carbon, Ecosystem services.

1. Introduction

Sahelian vegetation change have been at the center of many researches since the early 2000s. Woody vegetation change is the key factor that contributes to the greening observed in the Sahel (Martin et al., 2016). A spatial and temporal variation of vegetation was observed in Sahelian zones (Raphael et al., 2014; Martin et al., 2016; Louise et al., 2017). This change differs from an area to another or depending on time. In addition to this, a variation of Sahelian woody vegetation was observed in sparsely populated and densely populated zones (Martin et al., 2016), and this change influenced the woody species density and structure (Hendrik et al., 2016).

Previous studies showed that change in climate is expected to affect general patterns of vegetation such as decrease in tree density and diversity (Ali et al., 2007; Martin et al., 2014; Jordi & Francisco, 2016; Stefanos et al., 2017). In Sahel, climate change will intensify especially in West Africa in the future and seasons are observed to have a decrease in rainfall projected (Oluwaseun & Vincent, 2020). This situation will affect the future woody vegetation cover because Sahelian zone was characterized by a significant vegetation response to rainfall across all inter and intra annual time-scales (Zhou et al., 2021).

Notwithstanding climate change impacts on woody vegetation cover, some human practices can play positive role in Sahelian vegetation change. Vegetation growth under human practices play an important role in explaining the patterns of vegetation (Martin et al., 2017). Since the late 1980s, farmers from some Sahelian zones have been encouraged to reforest their fields through the natural regeneration project, which concentrates on protecting and managing the regeneration of trees and shrubs among cropped fields (Louise et al., 2017).

Trees on farms are also promoted by tolerance and protection of natural tree regeneration (Jenny et al., 2013; Miller et al., 2016). The interactions between trees and crops represents a key element determining the management options applied by farmers (Bayala et al., 2014). Natural regeneration of trees can contribute to maintain trees in Sahelian ecosystems and consequently increases the number of woody species. Planting trees and maintenance of trees in dryland could considerably contribute to carbon sequestration increase and buffer the effects of climate change (Bayala et al., 2014; Wafa et al., 2016; Asako et al., 2017).

Niger Republic is a Sahelian country and most populations live in the southern part of the country where natural resources like woody species are important. In the 1970's, Niger government and international Non-Government Organizations (NGOs) had made considerable efforts to address land degradation and desertification through tree planting and regeneration (Abasse et al., 2009). Despite climate change in Sahelian parts of Maradi region, the importance of studies which integrate information of tree species density and structure can contribute to complement the understanding of woody vegetation trends in Sahel at local scale.

Several studies have shown the roles of trees in carbon sequestration without clearly highlighting the roles of local communities in the maintenance and protection of these trees. This study aimed to analyze local community implications' in managing woody species and carbon accumulation in Sahelian parts of Maradi Region, Niger Republic.

2. Study Area

Maradi Region (Figure 1) is located in the south-central part of Niger Republic, between 13° and 15°26' North latitude and 6°16' and 8°36' East longitude. Maradi Region is located in arid climate with three (3) agroecological zones differentiated based on average annual precipitation (Sécretariat Exécutif du Commité Interministériel pour la Stratégie de Développement Rural, 2022): **(i) Saharo Sahelian zone**, precipitation varies from 200 to 300 mm. It concerns the northern part of Maradi Region including Northern part of Dakoro and Bermo departments. The woody vegetation cover is dominated by shrub tree with a dominance of thorns species. The farming system is mainly based on the cultivation of millet in association with cowpea. The pastoral zone covers the large northern part of these two departments. **(ii) Sahelian zone** receives total precipitations between 300 and 400 mm and is located in the central part of Maradi Region. The woody vegetation cover is dominated by trees and shrubs which are located in both agricultural farms and pastoral areas. The farming system is mainly based on the cultivation of millet in association with cowpeas and groundnuts. There are pastoral enclaves and passage corridors that allow animals to reach the southern part of the region after the harvest period and during the dry period. The two (2) agroecological zones of the study area (Mayahi and Korahane) are located respectively in the Southern and Northern parts of this Sahelian zone. **(iii) Sahelo Sudanian zone** (400 to 600 mm) which is located in a small southern part of of Maradi Region. The woody vegetation cover is dominated by trees with a low representation of shrubs. Crop cultivation such as millet in association with groundnuts and cowpeas represent the farming system of this area. The third agroecological zone (Hawandawaki) of the study area is located in this zone.

The relief is characterized by a slight inclination from south to north (550 to 400 m altitude), and does not present mountains, hills or pit. The large sets of relief in the Region are made up of valleys, sandy spreading glacis, dune and lateritic plateaus (Secrétariat Permanent Régional Code Rural, 2019).

The soil in Maradi region is classified into five (5) types (Secrétariat Permanent Régional du Code Rural, 2019): **(i) Tropical ferruginous soils** (70%) which are subdivided into two subclasses: moderately leached tropical ferruginous soils (''*Guéza*'' 5%) and leached tropical ferruginous soils (''*Jigawa*'' 65%). They are mainly found in the south and center of Maradi Region and the southern part of Dakoro Department. **(ii) Red-brown subarid soils** (17%) have on the surface a humus horizon at least 50 cm thick, brown in color, fairly structured and are sensitive to water and wind erosion. They are found in Northern part of Maradi and covers the pastoral zone. **(iii) Hydromorphic or Fadama soils** (12%) located in the valleys, they have a fairly good retention capacity and have a clay-silty texture. They are ideal for vegetable and cereal crops and are found in the Goulb N'Kabba, Goulbin Maradi (south and center) and Tarka valley (Northern part of the Region). **(iv) Lithosols** which are limited in depth by a coherent, hard and continuous rock at a depth of less than 10 cm, and mainly found in the south and southwest of the region which used to live crop production and some shrubs. **(v) Regosols** are represented in Maradi region by crumbled outcrops of clay and kaolinic sandstone and associated with ferruginous soils that are not or only slightly leached on sandy-clayey veneers. They are mainly found in the southeast and southwest of Maradi Region.

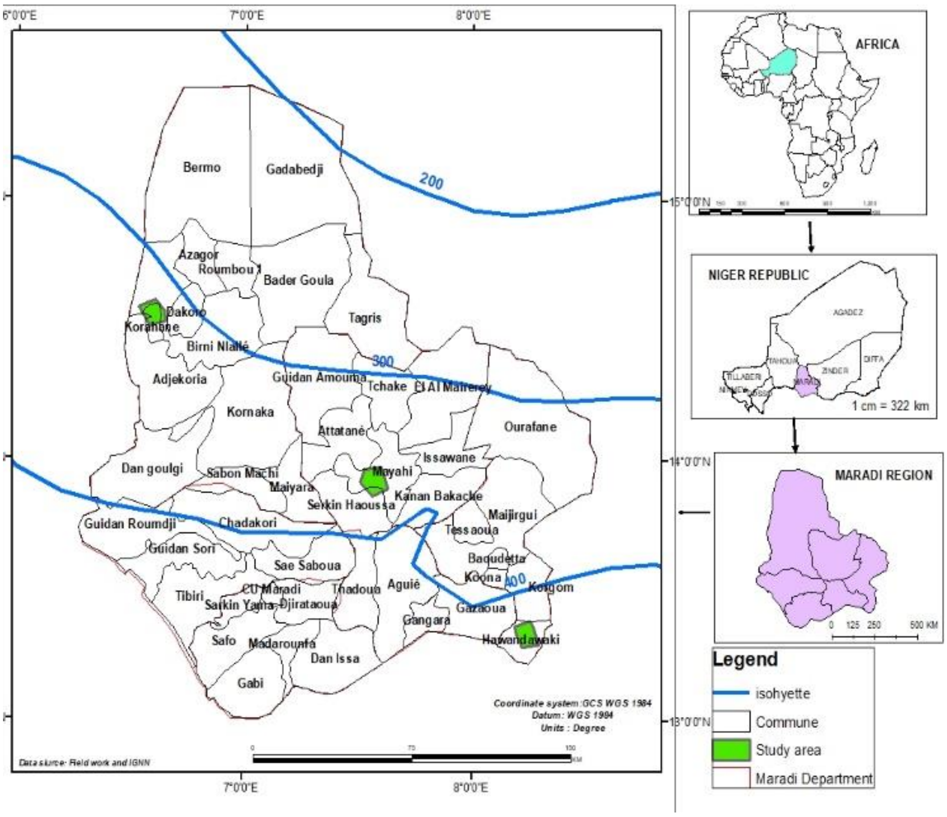


Figure 1: Maradi Region and the Study Area, Niger Republic

3. Methodology

Both quantitative and qualitative data were used in this study. Questionnaire were used to elicit information for the study. The Purposive sampling technique was used to select the respondents. The selected villages are located in the three communes (Hawandawaki, Mayahi and Korahane) and constitute a cluster of 5 villages located in an area of 5 km by 5 km in each agroecological zone. A total of three hundred and sixty (360) respondents were purposively selected in the study area (Table 1) based on the following criteria: (i) to have a farm in the area; (ii) to live in the area more than 10 years; (iii) to use or apply at least one climate smart agricultural practice (known during the reconnaissance survey); (iv) respondent should declare interest in participation.

Table 1: Selected villages of the Study Area

Commune (agroecological zone)	Main selected villages (with respondents)	Respondents
Hawandawaki Sahelo Sudanian Zone (SS-Z)	-Hawandawaki (24) - Dodori (24) - Toubourtou (25) - Angoual Guiyé (24) - Kissagaoua (23)	120
Mayahi Sahelian Zone South (SZ-South)	-Tsamiya Makada (25) - Guidan Bawa (24) - Sakatta (24) - Loda (23) - Dadin Kowa (24)	120
Korahane Sahelian Zone North (SZ-North)	-Korahane (22) - Kouran Mota (24) - Farin Baki (24) - Douloukou (25) - Zangon Tela (25)	120

For vegetation identification, the transect method with quadrats (plots) in each agroecological zone was used (Thiombiano et al., 2016, Issoufou et al., 2020). Four (4) transects were drawn to measure dendrometric parameters. From the central village, the transects followed the four geographical directions (East, West, North and South) with quadrats of 50 m x 50 m every 500 m interval were used in order to have maximum of the environmental heterogeneity. The quadrat size (2500 m^2) corresponds to the minimal area needed for study of woody vegetation in the Sahel. In each plot, all woody species were enumerated by direct counting and the local names of these trees are identified. The dendrometric parameters measured in each plot were diameter at breast height (1.30 meters), total height of tree and tree cover (tree crown diameter).

Data was analyzed with Excel software and woody vegetation data was analyzed first by determining the floristic composition of all woody species. The values were calculated using the following formulas:

(i) *Relative density* (*Dr*)

The relative density (Dr) or Tree density of each woody specie was calculated by the ratio between the total number of each woody specie (i) and the number of plots (quadrants) per hectare (a).

$$Dr = \frac{i}{a}$$

The average density of the three (3) agroecological zones was also calculated.

(ii) *Tree recovery* (R)

The Tree recovery (%) was calculated for each woody specie in different agroecological zones. This allowed to know the species with the most important recovery and those with weak recovery.

$$R = r \times r \times \pi$$

With **r** radius.

(iii) Relative Frequency (Fr)

The woody species relative frequency was calculated using the following formula:

$$Fr = \frac{ni}{N} \times 100$$

With **ni** number of woody specie **i** and **N** total number of woody species of the area.

(iv) Basal area (Ba)

The Basal area (m²/ha) of woody specie is the sum of the areas of the cross sections of the entire trunk measured at the level of the plot, and reduced to the hectare.

$$Ba = \frac{\sum(Dbh\ x\ \pi/4) \times 4}{Number\ of\ plots}$$

With ***Dbh*** Diameter at breast height

(v) *Important value index* (IVI)

The Important Value Index is a quantitative index for identifying ecologically important woody species in an area; it varies from 0 to 300 (Adomou et al., 2009; Thiombiano et al., 2016).

IVI = relative frequency (%) + basal dominance (%) + relative dominance (%)

The basal dominance is the basal area of the species, the relative dominance is the frequency of the recovery formed by the species and the relative frequency is the frequency of the species.

Here, the first ten (10) species with the highest Important Value Index (IVI) were picked as common species (Robert et al., 2018). The ten (10) common species structure and their stocks of carbon were assessed.

(vi) Height Classes Structure of the Ten Common Woody Species

The height classes structure of the ten (10) woody species with the highest Important Value Index (IVI) was done with 2 m amplitude and the smallest value of height considered is 2 m.

(vii) Regeneration

The woody species with diameter equal or less than 2 cm represent the regeneration. The regenerations are enumerated by direct counting and the average was calculated and compared.

(viii) Carbon sequestered in agroecological zone

The two main dendrometric parameters (diameter at breast height > 5 cm and total height) of woody species in the study area was used to estimate carbon sequestrated. The allometric equation of Chave et al. (2014) was used:

$$AGB = 0.0673 \times (\rho D^2 H)^{0.976}$$

AGB = Aboveground biomass (kg/tree), ρ = Wood density (g/ cm3) and D = Diameter at breast (cm), H= Height (m).

The used tree density values of identified tree species have been reported in previous studies (Robert & Björn, 2000; Zanne et al., 2009; Hamad, 2014; Weber et al., 2017 and Samaila, 2023).

The carbon stock and carbon sequestration were derived as representing 50% of the AGB. According to Chave et al. (2014), this model can be used to ''tropical woody vegetation sites'' such as tropical is defined between the 2 tropics. This improved allometric equation of Chave et al. (2014) was used respectively by Kapoury et al. (2016) in the in southern Mali and Musse & Mesele (2018) in the dryland ecosystem in Southern Ethiopia.

4. Results And Discussion

4.1. Roles of Local Communities in Maintenance and Protection of Woody Species

The protection and maintenance of woody tree in farmland is an old practice. However, increasingly farmers in the study area are particularly interested in natural regeneration which allows them to identify, protect and maintain trees in their farmlands. Several reasons encourage farmers to protect trees in their farmlands as presented in figure 2. This figure shows that firewood, wood for local construction, animal feed, traditional medicine, human food, water erosion control, wind erosion control, soil fertility increase, tree shading and possible return of bird are the main reasons of trees maintenance and protection in the agroecological zones. There is not major difference in terms of reasons for tree maintenance and protection in the three (3) agroecological zones of the study area.

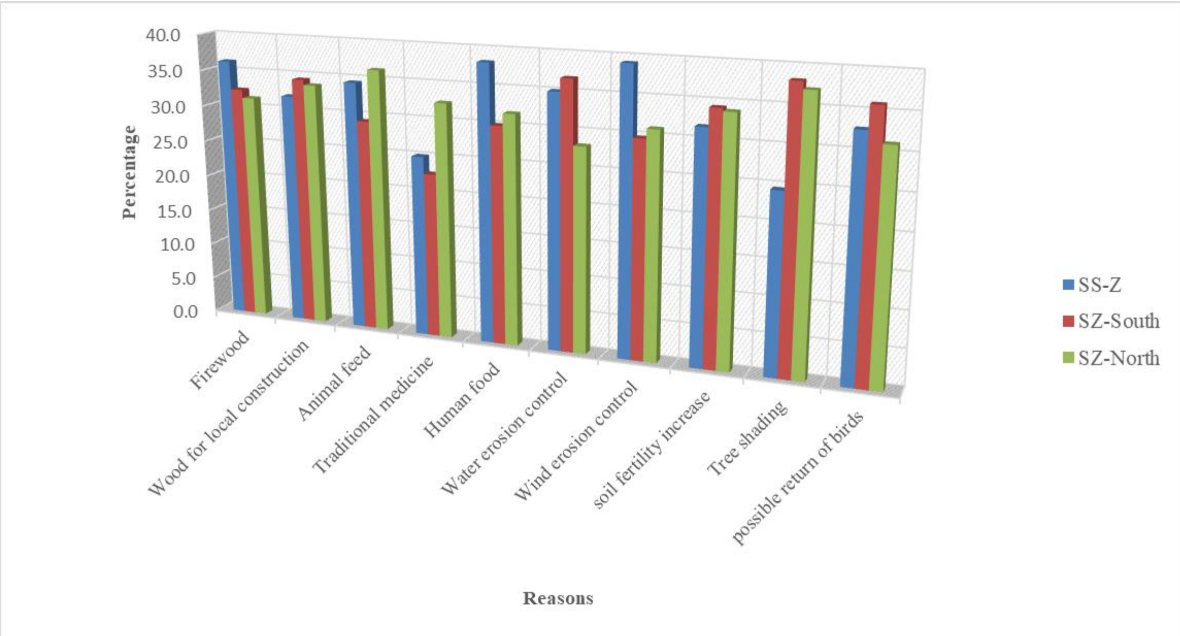


Figure 2: Reasons for Woody Tree Maintenance and Protection

According to the conceptual framework of Millennium Ecosystem Assessment (MEA) 2002, the ecosystem services can be in basical four (4) forms/types which can be related to farm trees:

- ✓ Provisioning (*products obtained from ecosystems*): food, water, etc.
- ✓ Regulating (*Benefits obtained from regulation of ecosystem processes*): climate, water decrease regulation;
- ✓ Cultural (*Nonmaterial benefits obtained from ecosystems*): spiritual, aesthetic;

- ✓ Supporting (*Services necessary for the production of all other ecosystem services*): primary production, soil formation

Based on this ecosystem services classification, the reasons of woody trees maintenance and protection in farmlands of the study area can be classified in three (3) ecosystem services:

- ✓ **Provisioning ecosystem services** (provision of energy wood, lumber, feed, human food and traditional medicine);
- ✓ **Regulating ecosystem services** (protection in terms of water erosion control, wind erosion control and tree shading);
- ✓ **Supporting ecosystem services** (increased soil fertility).

These basic ecosystem services were identified in the three (3) agroecological zones. Soil fertility increase, water and wind erosion control directly affects the farmlands as regulating and supporting services. The provisioning services like human food, animal feeds, firewood, wood for local construction, traditional medicine can be used by farmers or other persons in the village area. The uses of products/ecosystem services from woody species are at the center of the maintenance and protection of these trees. This demonstrates the importance of these trees in the daily lives of these farmers.

The ecosystem services (provisioning, regulating and supporting) provided by trees in the study area represent the main reasons for maintenance and protection of trees in farmlands. In addition to the ecosystem services provided by woody species in the study area, other benefits are derived from the sale of the wood. Thereby, the sale of wood contributes to improve livelihoods of households in different ways such as: transport payment; ceremony support; food; fertilizer; seed buying, etc.

In Maradi Region, the practice of natural regeneration of trees allows farmers to identify trees, protect and maintain them in their farmland and this contribute to increase the number of woody species. These results demonstrated that several reasons encourage farmers to protect woody trees of their choice in their farmlands.

This is in line with Hanna et al. (2022) who demonstrated in Burkina Faso, shrubs and trees on fields generate many ecosystem services that are key to rural livelihoods, while Mustapha (2021) enumerated some benefits of natural regeneration of trees in Madarounfa village of Niger Republic such as control of erosion, pollination, increase water retention on farms. In southern Mali, Kapoury et al. (2016) reported that farmlands without tree are more vulnerable to soil erosion and runoff. In addition to this, trees in agroforestry systems contribute to provide supporting ecosystem services like reduction of carbon dioxide in the atmosphere according to Kapoury et al. (2020). Similar results were reported by Tougiani & Toudou (2020) who concluded that, tree species were selected by farmers for soil fertility enhancement, fodder species, human food and firewood in Niger Republic. Trees in farmland became a fundamental element which contribute to diversify food production and to mitigate climate risks (Breman et al., 1995; Larwanou et al., 2006). However, Muhammad (2018) reported that, the increase in tree densities around Kano (Nigeria) is attributed to continued reliance on wood as the main energy source, by a still rapidly growing population.

4.2. Woody Species Density

The density was calculated for each woody specie and for all woody species in Sahelo Sudanian Zone (SS-Z), Sahelian Zone South (SZ-S) and Sahelian Zone North (SZ-N). The density of each woody specie by zone is represented in table 2.

Table 2: Woody Species Density in the Agroecological Zones

Species	Density SS-Z (tree ha^{-1})	Density SZ-South (tree ha^{-1})	Density SZ-North (tree ha^{-1})
Acacia nilotica (L) WILLD. Ex Del.	1.8	0.3	0.4
Acacia senegal (L) Willd.	0.3	0.7	2.1
Acacia tortilis subsp raddiana (Savi) Brenan	-	2	8.4
Adansonia digitata L,	0.2	-	-
Albizzia chevalieri Harms	0.6	-	-

Annona senegalensis Pers.	-	0.2	-
Azadirachta indica A. Juss.	2.3	0.2	-
Balanites aegyptiaca (L.) Del.	1.4	2.7	5.7
Bauhinia rufescens Lam.	0.3	0.1	0.2
Boscia salicifolia (Pers.) Lam. ex Poir.	0.1	-	-
Cassia sieberiana DC.	0.2	-	-
Combretum glutinosum Perr. Ex DC.	0.3	5.3	0.3
Commiphora africana (A. Rich.) Engl.	-	0.1	-
Combretum micranthum g. Don.	0.3	-	-
Diospyros mespiliformis hochst. Ex A. DC.	0.5	-	-
Faidherbia albida Del	3.8	8.5	3.6
Guiera senegalensis J.F. Gmel.	0.2	3.4	1.2
Hyphaene thebaica (L.) Mart.	1.4	1.4	-
Lannea microcarpa Engl.Et K. Krause	0.7	-	-
Maerua crasssifolia Forsk.	0.1	0.4	1.5
Parkia africana r. Br.	0.6	-	-
*Piliostigma reticulatum (*dC.) Hochst.	10.4	6	-
Prosopis africana (Guill. et Perr.) Taub.	1.8	-	-
Sclerocarya birrea	0.7	0.3	0.3
Strychnos spinosa Lam.	-	0.1	-
Vitex doniana sweet.	0.2	-	-
Ziziphus mauritiana Lam.	0.1	-	0.3
*Ziziphus spina-christi (*L.) Desf.	0.2	0.8	-

The results show in the SS-Z, the density of *Piliostigma reticulatum (*10.4 tree ha^{-1}) is higher following by *Faidherbia albida (*3.8 tree ha^{-1}) and *Azadirachta indica* (2.3 tree ha^{-1}). In SZ-South, *Faidherbia albida (*8.5 tree ha^{-1}) has the highest density following by *Piliostigma reticulatum (*6 tree ha^{-1}) and *Combretum glutinosum* (5.3 tree ha^{-1}). The highest density of these species can be explained by their importance in the farmland of local communities. *Acacia tortilis subsp raddiana (8.4* tree ha^{-1}), *Balanites aegyptiaca (*5.7 tree ha^{-1}) and *Faidherbia albida* (3.6 tree ha^{-1}) are the 3 most important woody species in terms of density per hectare in SZ-North. These thorny species are drought resistant and resistant to water stress. This can mainly be the reason for their dominance in northern part of Maradi Region.

The average density of each zone was calculated and presented in the table 3.

Table 3: Average Density of Study Area

SS-Z		SZ-South		SZ-North	
Average density (tree ha^{-1})	**Coefficient of variation CV**	**Average density (tree ha^{-1})**	**Coefficient of variation CV**	**Average density (tree ha^{-1})**	**Coefficient of variation CV**
17.2 ± 11.25	65.40	33.2 ± 12	37.43	24.7 ± 11.88	48.08

The normality test was done for the three agroecological zones, and consequently the non-parametric test between the average densities. The average density of SZ-South (33.2 tree ha^{-1}) is different and most important (P=0.000) than SS-Z (17.2 tree ha^{-1}) and SZ-North (P= 0.001) with 24.7 tree ha^{-1}.

The comparison test demonstrated that the average density at SZ-South which is most important than SS-Z, was dominated by *Piliostigma reticulatum* and *Faidherbia albida.* However. The density in Sahelian Zone North (24.7 tree ha^{-1}) is dominated by the thorny woody species (*Acacia tortilis subsp raddiana* and *Balanites aegyptiaca*). Many studies in tree density were conducted in farmlands of Niger such as Dan Guimbo (2010), Massaoudou et al. (2015) and Amadou et al. (2017) who respectively found 45 tree ha^{-1}, 33.02 tree ha^{-1} and 23.6 tree ha^{-1}. In Sahelo Sudanian Zone, woody vegetation cover is dominated by big trees in the farmland and few young shrubs. To sum up, the effort of farmers which allows to protect and maintain many young trees in the farmland is the major reason of the difference of woody density in the agroecological zones.

These results are different from the general trend which considers a decrease in trees density from south to north due to the decrease in rainfall. However, natural regeneration of trees provides information that, agroecological zone with high natural regeneration practices may have higher tree density more than another agroecological zone despite the quantity of received rainfall and the demographic pressure. This is consistent with the findings of Adam et al. (2021) and Robert et al. (2021) who reported that human management has been a more important determining factor as it allowed protecting and regenerating of tree density in agricultural landscapes. In addition to this, Abasse et al. (2023) reported an increase of woody species in south central Niger due to natural regeneration of trees promoted by farmers. These results can corroborate the process of "*more people more trees*", while the common perception is '*'population increase can be synonymous with ecosystem degradation in Sahel*''.

4.3. Importance Value Index (IVI)

The Importance Value Index (IVI) allowed to identify the ecologically significant species in the study area. Table 4 presents the IVI of woody species in Sahelo Sudanian Zone and the three most important species are *Piliostigma reticulatum* (81.64), *Faidherbia albida* (65.86) and *Prosopis africana* (34.38).

Table 4: Importance Value Index of Woody Species in Sahelo Sudanian Zone

Specie	Frequency (%)	Ba/specie/ ha (%)	Tree recovery/ specie ha^{-1} (%)	IVI
*Piliostigma reticulatum (*dC.) Hochst.	35.74	18.93	26.98	81.64
Faidherbia albida Del	13.06	29.08	23.72	65.86
Prosopis africana (Guill. et Perr.) Taub.	6.19	16.94	11.26	34.38
Azadirachta indica A. Juss.	7.90	5.60	4.85	18.35
Acacia nilotica (L) WILLD. Ex Del.	6.19	2.01	5.73	13.92
Balanites aegyptiaca (L.) Del.	4.81	3.97	4.38	13.15
Hyphaene thebaica (L.) Mart.	4.81	4.03	1.97	10.81
Parkia africana r. Br.	2.06	4.83	3.60	10.49
Diospyros mespiliformis hochst. Ex A. DC.	1.72	3.51	3.95	9.18
Sclerocarya birrea	2.41	1.64	3.02	7.07
Lannea microcarpa Engl.Et K. Krause	2.41	1.30	2.45	6.16
Albizzia chevalieri Harms	2.06	1.64	1.58	5.28
Adansonia digitata L.	0.69	3.24	0.36	4.29
Annona senegalensis Pers.	2.06	0.63	0.89	3.59
Acacia senegal (L) Willd.	1.03	0.50	1.39	2.93
Combretum glutinosum Perr. Ex DC.	1.03	0.49	0.86	2.38
Vitex doniana sweet.	0.69	0.64	1.02	2.35
Bauhinia rufescens Lam.	1.03	0.15	0.46	1.64
*Ziziphus spina-christi (*L.) Desf.	0.69	0.33	0.43	1.45
Combretum micranthum g. Don.	1.03	0.11	0.29	1.43
Cassia sieberiana DC.	0.69	0.09	0.50	1.28
Guiera senegalensis J.F. Gmel.	0.69	0.05	0.06	0.79
Maerua crasssifolia Forsk.	0.34	0.12	0.10	0.56
Boscia salicifolia (Pers.) Lam. ex Poir.	0.34	0.13	0.06	0.53
Ziziphus mauritiana Lam.	0.34	0.04	0.11	0.49
Total general	**100**	**100**	**100**	**300**

In the Sahelian Zone South *Faidherbia albida* (158.23), *Piliostigma reticulatum* (39.18) *and Combretum glutinosum* (33.51) are the ecological important woody species (Table 5).

Table 5: Importance Value Index of Woody Species in Sahelian Zone South

Specie	Frequency (%)	Ba/specie/ ha (%)	Tree recovery/ specie ha^{-1} (%)	IVI
Faidherbia albida Del	26.15	53.83	78.25	158.23
*Piliostigma reticulatum (*dC.) Hochst.	18.46	13.66	7.06	39.18
Combretum glutinosum Perr. Ex DC.	16.31	12.63	4.57	33.51
Balanites aegyptiaca (L.) Del.	8.31	7.08	2.92	18.30
Acacia tortilis subsp raddiana (Savi) Brenan	6.15	2.58	2.68	11.41
Guiera senegalensis J.F. Gmel.	10.46	0.49	0.38	11.33
Hyphaene thebaica (L.) Mart.	4.31	4.64	0.60	9.55
*Ziziphus spina-christi (*L.) Desf.	2.46	1.76	1.31	5.52
Acacia senegal (L) Willd.	2.15	0.62	0.70	3.47
Sclerocarya birrea	0.92	1.07	0.54	2.53
Acacia nilotica (L) WILLD. Ex Del.	0.92	0.50	0.47	1.89
Maerua crasssifolia Forsk.	1.23	0.31	0.18	1.72
Azadirachta indica A. Juss.	0.62	0.25	0.13	1.01
Bauhinia rufescens Lam.	0.31	0.26	0.10	0.67
Annona senegalensis Pers.	0.62	0.03	0.01	0.66
Strychnos spinosa Lam.	0.31	0.20	0.07	0.58
Commiphora africana (A. Rich.) Engl.	0.31	0.09	0.03	0.43
Total general	**100**	**100**	**100**	**300**

In Sahelian Zone North, table 6 presents the IVI of woody species and the three most important species are *Acacia tortilis subsp raddiana* (110.14), *Balanites aegyptiaca* (93.17) and *Faidherbia albida* (31.24).

Table 6: Importance Value Index of Woody Species in Sahelian Zone North

Specie	Frequency (%)	Ba/specie /ha (%)	Tree recovery specie ha^{-1} (%)	IVI
Acacia tortilis subsp raddiana (Savi) Brenan	35	30.26	44.88	110.14
Balanites aegyptiaca (L.) Del.	23.75	42.67	26.76	93.17
Faidherbia albida Del	15	9.85	6.39	31.24
Acacia senegal (L) Willd.	8.75	5.70	7.29	21.74
Maerua crasssifolia Forsk.	6.25	5.19	9.74	21.18
Guiera senegalensis J.F. Gmel.	5	1.32	1.26	7.59
Acacia nilotica (L) WILLD. Ex Del.	1.67	1.14	1.01	3.82
Combretum glutinosum Perr. Ex DC.	1.25	1.22	0.83	3.30
Sclerocarya birrea	1.25	1.27	0.76	3.28
Bauhinia rufescens Lam.	0.83	0.90	0.60	2.34
Ziziphus mauritiana Lam.	1.25	0.48	0.48	2.21
Total general	**100**	**100**	**100**	**300**

The Importance Value Index (IVI) of woody species in Sahelo Sudanian Zone showed that *Piliostigma reticulatum* and *Faidherbia albida* are the dominants species as well as in Sahelian Zone South. The results indicated the importance of these trees in the agroforestry system and their ecological capacity to be maintained. However, in Sahelian Zone North, thorny species (*Acacia tortilis subsp raddiana* and *Balanites aegyptiaca*) are most prevalent due to the resistant to water stress.

The results of woody vegetation characterization identified the dominant species in the study area. Therefore, among the most common species regenerating naturally and protected by farmers in Maradi Region as reported by many researchers (Chris et al., 2009; Muhammad et al., 2016. Issoufou et al., 2020), the most cherished woody species are *Faidherbia albida, Piliostigma reticulatum* and *Combretum glutinosum.* However, Zida et al. (2020) reported the dominance of Combretaceae species and thorny species of the genera Acacia and Balanites in Burkina Fasso Sahel because of their tolerance of drought and resistant to water stress.

4.4. Height Structure of Woody Vegetation

The height class structure is used to understand tree dynamics and can be used to assess the impact of anthropogenic pressure on the woody species density. The classes of height]4 - 6] and]6 - 8] are the most dominants in Sahelo Sudanian Zone following by class of]2 - 4]. *Faidherbia albida*, *Parkia africana* and *Prosopis africana* have the greatest heights (Figure 3). In Sahelian Zone South (Figure 4), the woody species with height classes]2 - 4] and]6 - 8] are the most dominants following by]4 - 6]. *Faidherbia albida*, *Hyphaene thebaica* and *Ziziphus spina-christi*, *Piliostigma reticulatum* have dominant height classes. From figure 5 (Sahelian Zone North), the dominant height classes are]4 - 6] and]2 - 4] represented by *Acacia Senegal*, *Acacia tortilis subsp raddiana*, *Faidherbia albida* and *Maerua crassifolia*.

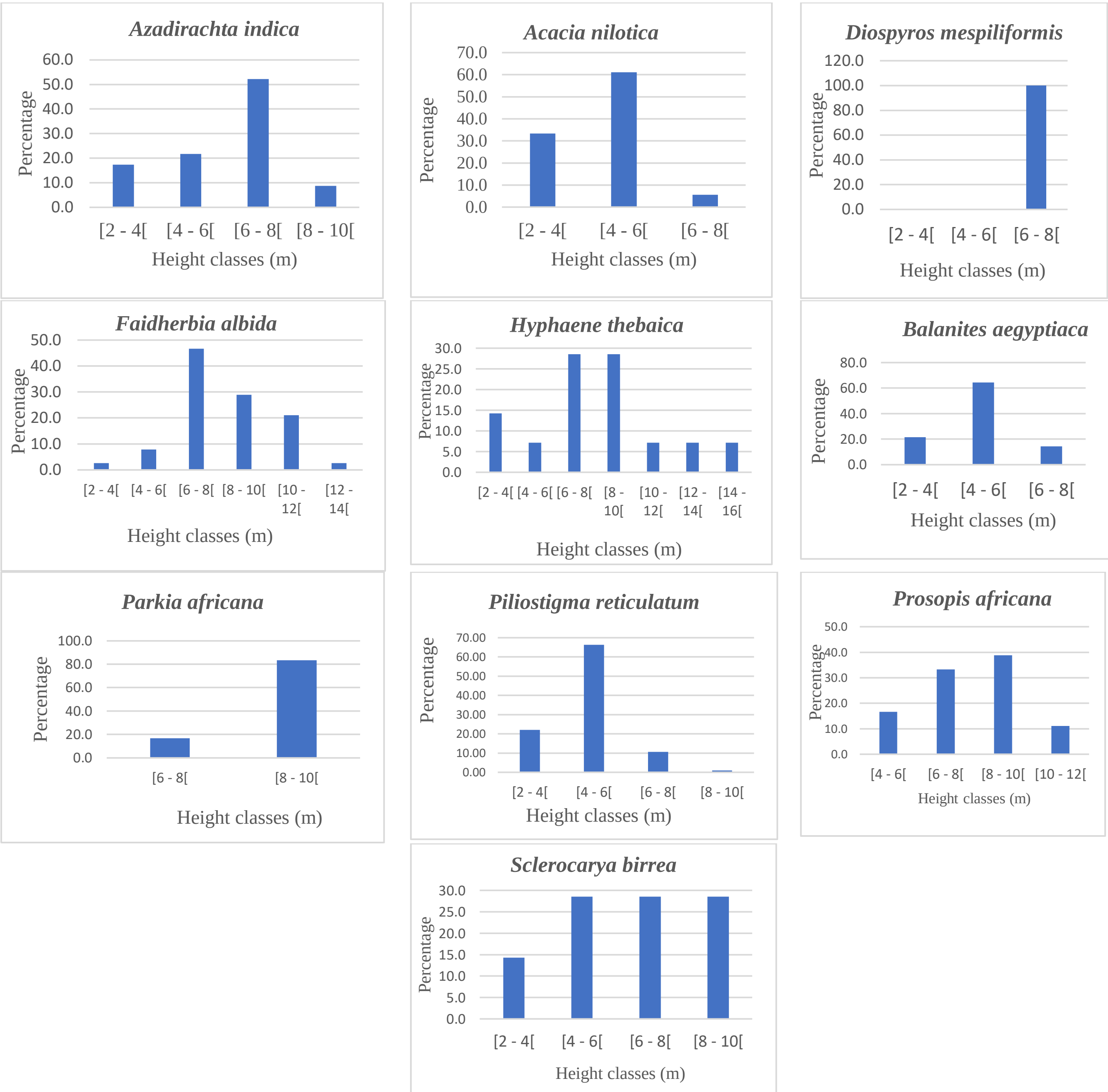


Figure 3: Height Classes Structure of Woody Species in Sahelo Sudanian Zone

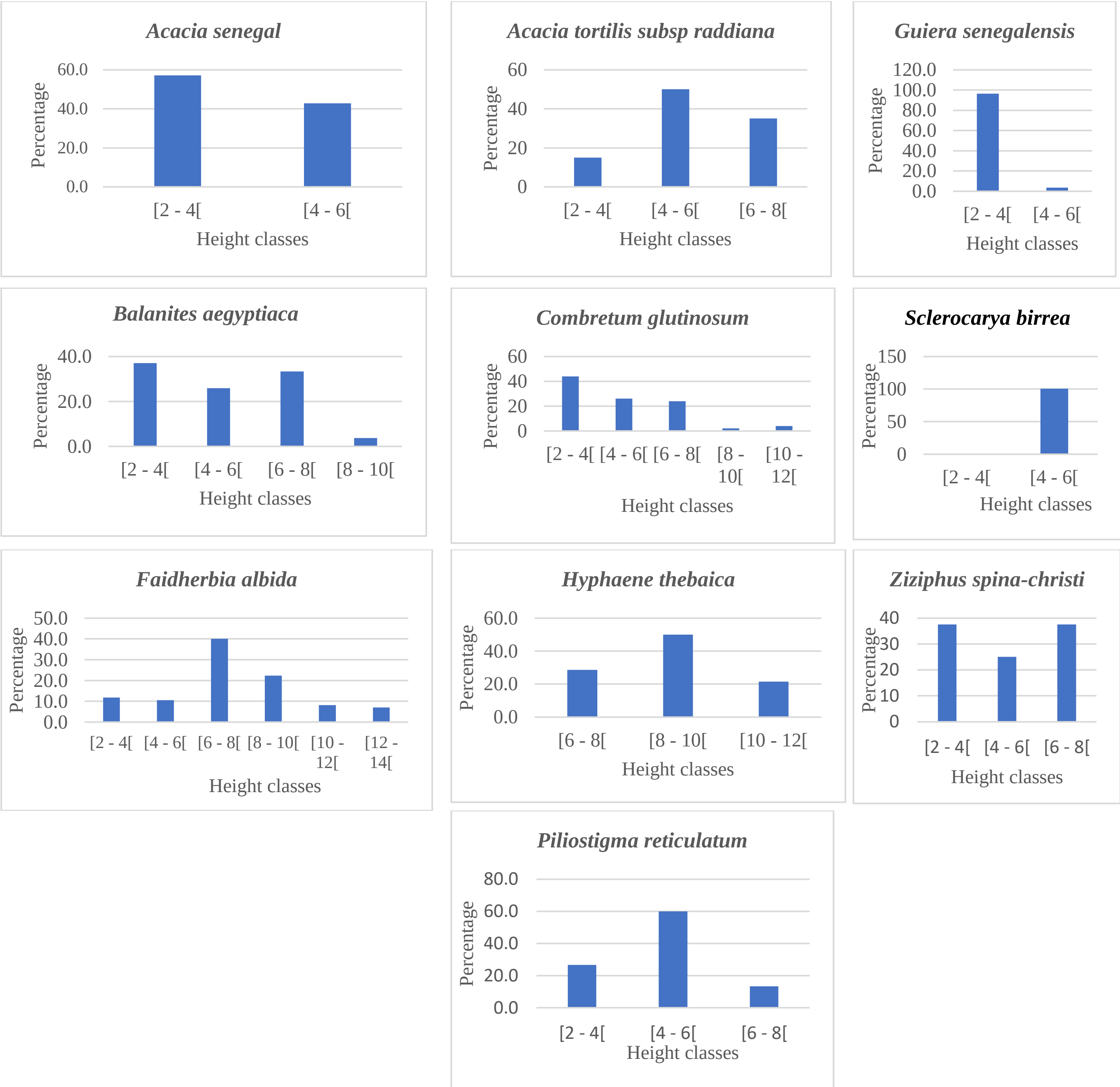
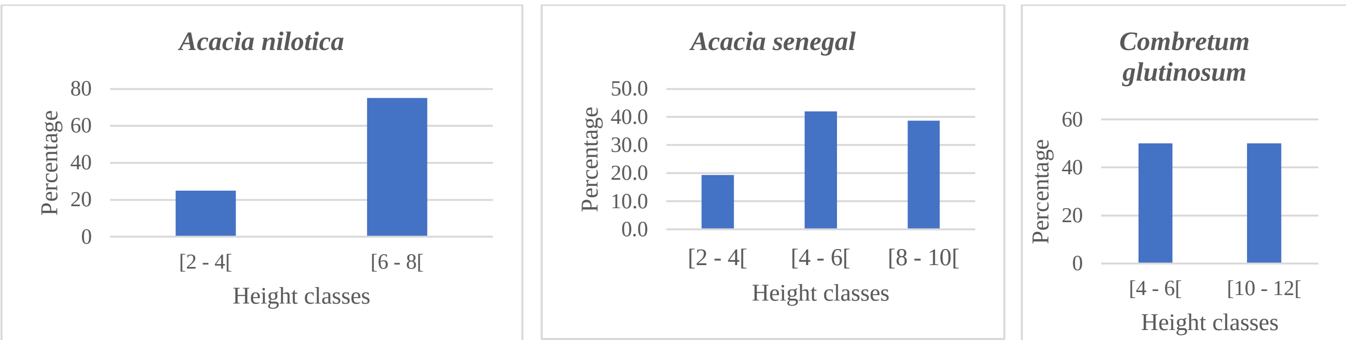


Figure 4: Height Classes Structure of Woody Species in Sahelian Zone South



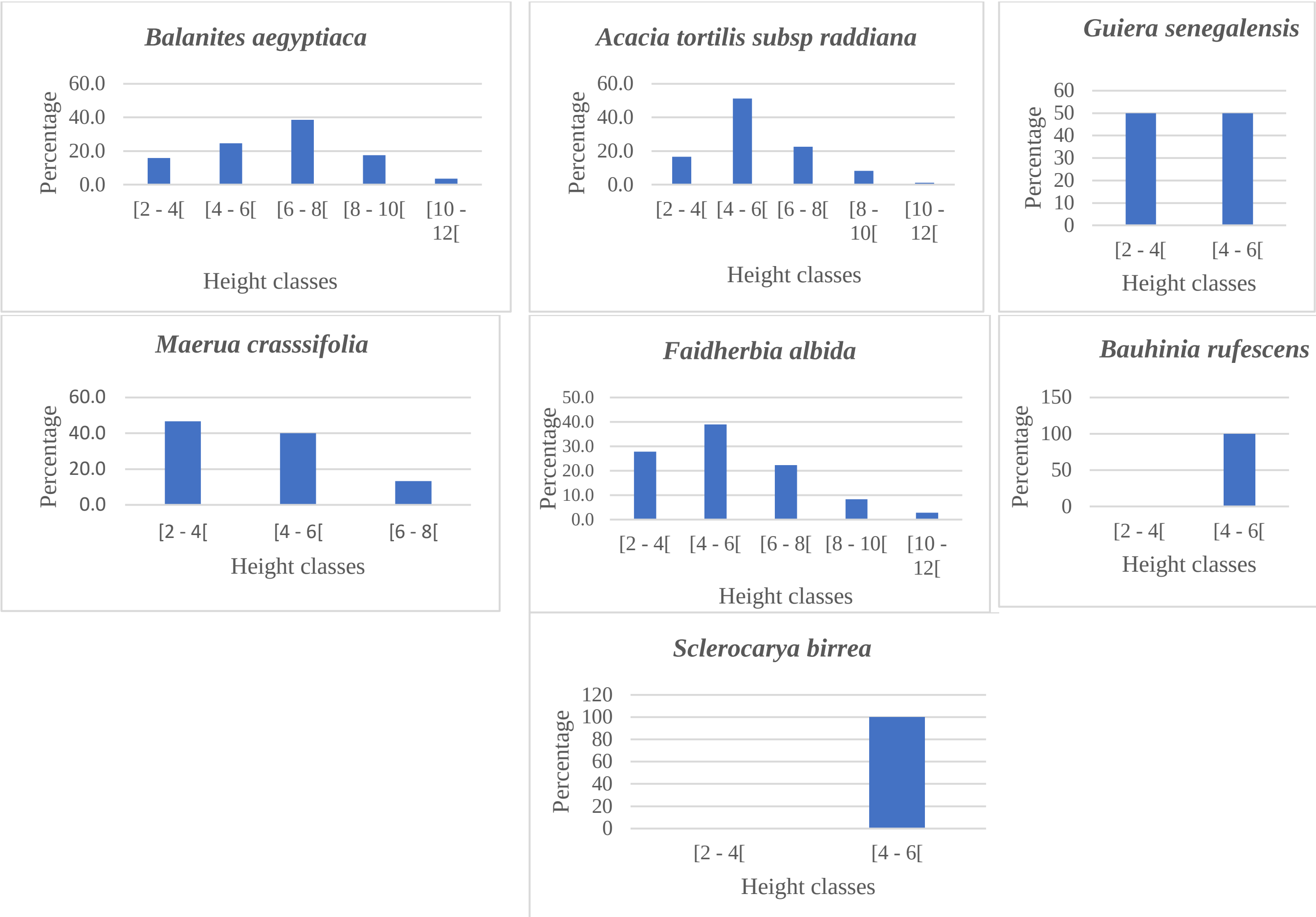


Figure 5: Height Classes Structure of Woody Species in Sahelian Zone North

The structure of the woody vegetation in the three (3) agroecological zones described groups of trees with small to medium height. The height classes structure of the study area demonstrated also the impact of anthropogenic pressure on the woody species which are located in farmlands. This is consistent with the results of Soumana (2015) and Laouali (2008) respectively on *Faidherbia albida* and *Prosopis africana* parklands where they reported height classes structure dominated by individuals of lower classes in the agrosystems of Aguié (Niger). In addition to this, Rabiou (2016) reported in Sudanian zone North of Niger, the height classes structure is dominated by woody species of height classes between 6 and 10 m. The presence and dominance of *Faidherbia albida*, *Balanites aegyptiaca* and *Sclerocarya birrea* can be explained by their ecological importance for local communities and capacity to be maintained in these agroecological zones. The dominance of thorny species in Sahelian Zone North explains the drought resistance and adaptation of these species.

4.5. Regeneration

Tree regeneration was estimated for each agroecological zone (Table 7). *Combretum micranthum* (172 tree ha^{-1}), *Guiera senegalensis* (132 tree ha^{-1}) and *Cassia singueana* (76 tree ha^{-1}) are the most dominants trees regeneration while *Balanites aegyptiaca* (8 tree ha^{-1}), *Faidherbia albida* (8 tree ha^{-1}) and *Bauhinia rufescens* (4 tree ha^{-1}) are the least represented regeneration in Sahelo Sudanian Zone.

In Sahelian Zone South, the regeneration is dominated by *Annona senegalensis* (260 tree ha^{-1}), *Guiera senegalensis* (148 tree ha^{-1}), *Balanites aegyptiaca* (124 tree ha^{-1}) and *Combretum glutinosum (*120 tree ha^{-1}). The weakly represented tree regenerations are *Bauhinia rufescens* (8 tree ha^{-1}), *Lannea microcarpa* (8 tree ha^{-1}) and *Acacia nilotica* (4 tree ha^{-1}).

Sahelian Zone North presented a regeneration dominated by *Balanites aegyptiaca* (92 tree ha^{-1}), *Ziziphus mauritiana* (48 tree ha^{-1}), *Guiera senegalensis (*44 tree ha^{-1}) and *Boscia senegalensis* (44 tree ha^{-1}).

Table 7: Tree Regeneration Density in the Agroecological Zones

Specie	Trees regeneration density (tree ha^{-1})		
	SS-Z	**SZ-South**	**SZ-North**
Acacia nilotica (L) WILLD. Ex Del.	60	4	8
Acacia senegal (L) Willd.	16	12	4
Acacia tortilis subsp raddiana (Savi) Brenan	-	52	28
Albizzia chevalieri Harms	40	-	4
Annona senegalensis Pers.	56	260	-
Azadirachta indica A. Juss.	32	-	-
Balanites aegyptiaca (L.) Del.	8	124	92
Bauhinia rufescens Lam.	4	8	4
Boscia salicifolia Oliv.	-	8	-
Boscia senegalensis (Pers.) Lam. ex Poir.	-	-	44
Borassus aethiopium Mart	32	-	-
Cassia sieberiana DC.	40	-	-
Cassia singueana Del.	76	4	-
Combretum glutinosum Perr. Ex DC.	8	120	4
Combretum micranthum g. Don.	172	-	-
Diospyros mespiliformis hochst. Ex A. DC.	-	8	-
Faidherbia albida Del	8	32	24
Grewia flavescens Juss.	-	4	-
Guiera senegalensis J.F. Gmel.	132	148	44
Hyphaene thebaica (L.) Mart.	8	-	-
Lannea microcarpa Engl. Et K. Krause	4	8	-
Maerua crasssifolia Forsk.	-	28	24
Piliostigma reticulatum (dC.) Hochst.	48	76	-
Prosopis africana (Guill. et Perr.) Taub.	4	-	-
Sclerocarya birrea	-	4	-
Vitex doniana sweet.	20	-	-
Ziziphus mauritiana Lam.	12	112	48

From table 7, 29.63% of tree regeneration is located in the three agroecological zones and 22.22% in two zones. This indicated that these woody species can be considered as indigenous trees and have the adapting capacity in the ecological and climatic conditions of these zones. Local communities play great roles by protecting and maintaining woody species in their farmlands. The diversity of tree regeneration is most important in Sahelo Sudanian Zone because seven (7) species (*Azadirachta indica, Borassus aethiopium, Cassia sieberiana, Combretum micranthum, Hyphaene thebaica, Prosopis Africana* and *Vitex doniana*) are identified only in this area while four (4) species (*Boscia salicifolia, Diospyros mespiliformis, Grewia flavescens* and *Sclerocarya birrea*) only in Sahelian Zone South. The low diversity is observed in Sahelian Zone North with *Boscia senegalensis* solely identified in this agroecological zone. The presence of Combretaceae (particularly *Guiera senegalensis* and *Combretum micranthum*) may be linked to the fairly frequent use of these trees as firewood.

4.6. Carbon Stock in the agroecological zones

The ten (10) common woody species with the highest IVI in each agroecological zone accumulated different quantity of carbon which is presented in figure 6.

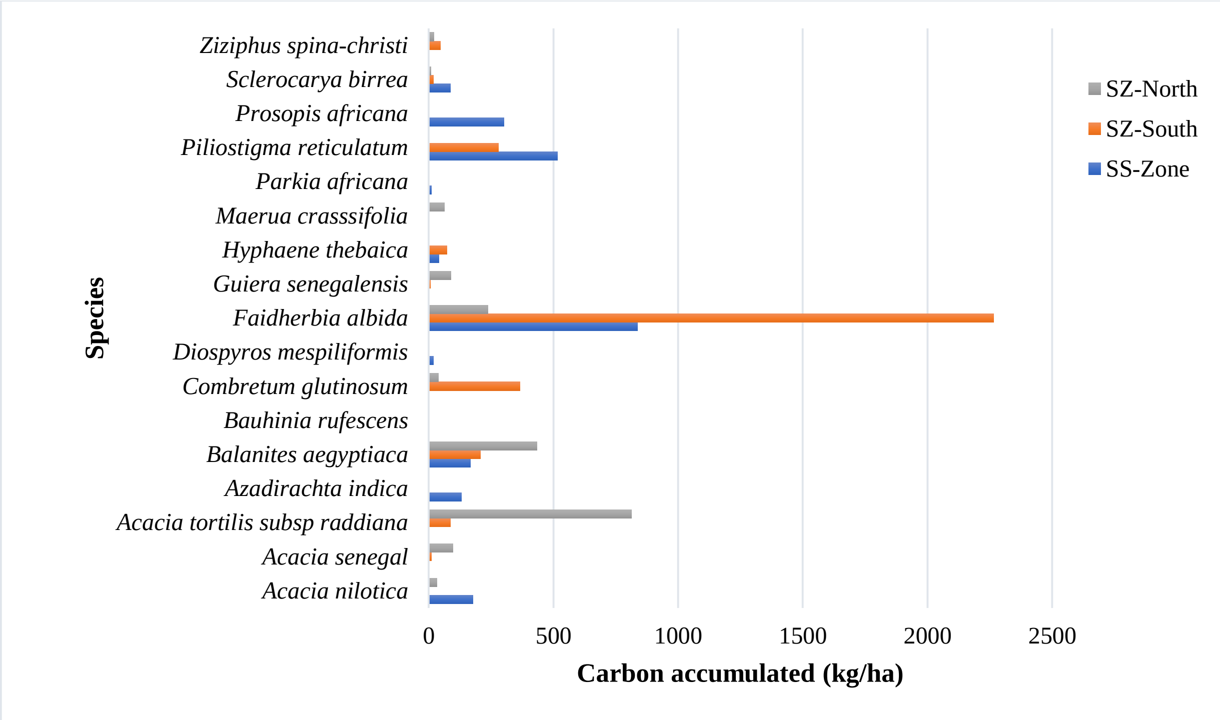


Figure 6: Carbon Accumulated by Woody Species in the Agroecological Zones

The species which contribute to accumulate maximum quantity of carbon are identified in Sahelian Zone South (SZ-South) and Sahelo Sudanian Zone (SS-Zone) with *Faidherbia albida* and Piliostigma reticulatum. In Sahelian Zone North (SZ-North), *Acacia tortilis sbsp raddiana* and *Balanites aegyptiaca* have accumulated the most important quantity of carbon.

The total quantity of carbon accumulated in the agroecological zones is presented in table 8.

Table 8: Sum of Carbon Sequestered by Woody Species in the Agroecological Zones

Agroecological Zones	**SS-Zone**	**SZ-South**	**SZ-North**
Carbon accumulated (kg/ha)	2287.87	3361.28	1835.01

From table 8, Sahelian Zone South (SZ-Zone) has the higher amount of accumulated carbon (3,361.28 kg/ha) than the Sahelo Sudanian Zone (SS-Zone) which is 2,287.87 kg/ha. The Northern part of Maradi Region (SZ-North) has the smallest quantity of carbon (1,835.01 kg/ha). The dominance of these woody species in carbon accumulation can be explained by their relative density per hectare and their diameters. More the diameter of a woody species is important, more this specie can sequester maximum carbon. This is consistent with the findings of Siriki et al. (2022) who concluded that the amount of carbon sequestered in agroforestry systems is linked to the circumference of trees which is linked to the diameter. This is in line with Victor et al. (2019) who reported that more a tree has a large circumference, more he occupies an important basal area and receive a large quantity of carbon. In addition to this, Wafa et al. (2016) showed that trees in drylands can increase biomass carbon stocks.

The tree species are promoted and protected by local communities through natural regeneration in the agroecological zones in Maradi Region. These results corroborate those found by Siriki et al. (2022) who reported that, the rate of carbon sequestered by agroforestry systems depends on the maintenance techniques of these systems in Dioïla Région (Mali Republic).

Thereby, good practices represent a potential increase in carbon sequestration and fight against climate change through carbon storage (Victor et al., 2019; Mensah et al., 2020; Elvire et al., 2023) through the presence of trees in agricultural system. These systems with good practices play an important role through carbon removal by photosynthetic activity of tree (Tiga et al., 2020), and retain much higher quantities of carbon in aboveground biomass (Farhat et al., 2017).

5. Conclusion

In Maradi Region the practice of natural regeneration of trees allows farmers to identify, protect and maintain trees in their farmlands. The ecosystem services (provisioning, regulating and supporting) provided by woody trees species in the agroecological zones represent the main reasons for maintenance and protection of trees in farmlands. Thereby, good practices of natural regeneration represent a potential to increase carbon sequestration and carbon stocks. Important amount of carbon is accumulated by woody species under this natural regeneration. The dominance of woody tree species promoted by local communities is related to their tolerance, ecological adaptation and resistant to water stress. This can allow farmers to be eligible to receive payments for the ‘’Carbon’’ that those practices contribute to sequester under a ‘’Carbon’’ trading arrangement in the Clean Development Mechanism (CDM) of the Kyoto Protocol of the United Nations Framework Convention on Climate Change.

Recommendations:

Based on results of this study, the following recommendations are formulated:

- ✓ Encourage and assist local communities in natural regeneration of trees and shrubs in their parklands and other land use/land cover in order to benefit the maximum of ecosystem services.
- ✓ The government and/or Non-governmental Organizations can help local communities by getting the ‘’carbon credit’’ and conduct sustainable activities for local development.

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