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Floristic composition, diversity and structure of woody vegetation in the agrosystems of the Maradi Region along the North-South agroecological gradient

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Abstract

The objective of this study is to characterize the current status of woody species in agrosystems and to identify ecologically important woody species that favor agriculture-livestock integration in the context of strong anthropic pressures in the Maradi region. The ground forest inventory method was used to characterize woody vegetation in three sites in the departments of Dakoro (north), Guidan Roumdji (center) and Madarounfa (south). A total of 187 plots were installed, each with a surface area of 2500m². Data collected included species list, total height, diameter at 1.30m from the ground and both perpendicular diameters of the crown, and natural regeneration of woody species. The results show that the southern zone has more species (17) divided into 9 families, followed by the central zone with 16 species and 12 families and finally the northern zone with 9 species and 7 families. The diversity decreases from the south (3.01 bites), center (2.27) and north (1.76 bites). As for the dendrometric parameters, the difference is significant ($P < 0.000$) with greater values of average height, diameter at 1.30 m from the ground and basal area of the trees in the southern area. It is not significant between ecological zones the basal area of trees ($P = 0.9$). *Faidherbia albida* and *Piliostigma reticulatum* were the most ecologically important species distributed in all three zones. The overall diameter class and height structure imputed by the dominant species shows a negative skewed distribution of the disturbed stand in all three ecological zones. Regeneration is 747±65 (ft/ha), 2136±177 (ft/ha), and 1018±63 (ft/ha) in the north, center, and south, respectively, with a highly significant difference (P=0.000). This regeneration is an important source for re-greening the fields if maintained. This study provides important results that can be used to refine the management of agroforestry parks for various ecosystem services for the benefit of populations.

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Introduction

Woody plants are an indispensable component for agriculture and livestock production today. They provide litter to fertilize soils to increase agricultural yields and fodder for livestock feed (Baggnian *et al.*, 2012). In fact, in the Sahel, very remote fields or bush fields (Dramé *et al.*, 2008) are most often abandoned to the sole fertilization of trees, some of which are fodder trees that play a crucial role in the fodder balances of livestock systems, especially during the lean season (Bechir and Zoungrana, 2012; Gning *et al.*, 2013). In addition, woody plants provide many products and services to the population, including leaves, wood, fruits, gums, pods, seeds, etc. (Larwanou *et al.*, 2010). Also, César (2005) noted that in the Sahelian zone, most of the fodder consumed by animals is provided by natural ecosystems and agrosystems. However, in recent years, due to anthropogenic pressures, particularly to develop areas for agriculture, the mutilation of trees by transhumant herders, women and loggers and the roaming of animals (Baggnian *et al.*, 2012), combined with climate change, have led to a degradation of natural resources. As a result, forest formations are being degraded at alarming rates in favor of agriculture and livestock (Boubé, 2010). The Maradi region, despite its high population growth (Dan Lamso *et al.*, 2015), is one of the areas where millions of hectares have been regreened through the practice of assisted natural regeneration in recent years (Larwanou *et al.*, 2006). These species are widely and diversely distributed along the north-south agro-ecological gradient (Larwanou *et al.*, 2012; Moussa *et al.*, 2015; Felix *et al.* 2019).

Despite the socioeconomic and ecological interests that these species represent in agrosystems very little knowledge is capitalized in terms of dendrometric characterization and diversity. The knowledge of the state of these species according to the agroclimatic distribution could facilitate the choice of species to be conserved in terms of assisted natural regeneration in the producers' fields. Therefore, it is important to carry out this study to assess the status of woody vegetation along the agroclimatic gradient in order to identify the most distributed species that potentially offer more ecosystem services. The objective of this study is to characterize the woody vegetation in the agrosystems of the Maradi region along a North-Central-South climatic guard to serve for an adapted integration of agriculture-livestock and trees.

Materials and methods

Study site

The present study was conducted in three departments distributed along the north-south climatic gradient represented by the department of Dakoro, Guidan Roumdji and Madarounfa. In each department, two distinct villages were selected based on the management practices and use of trees in the farmers' fields. The pedoclimatic and biological characteristics and location of each zone are presented in Table 1 and Fig. 1 below. Annual rainfall in the study area ranges from 378 to 535mm with a 30-year average. The climate is Sahelian in the center and north and Sahelo-Sudanese in the south. In the fields, the soils are poor due to the absence of fallow land and are of the tropical iron type with vegetation dominated by fabaceae.

Table 1. Description of study sites.

Departments	Sites	Longitude	Latitude	Annual precipitation (mm)	Soils	Vegetation
Dakoro	Ajekorya	6°47'24"E	14°20'20,9"N	378 ± 90	Tropical ferruginous and hydromorphic	Combretaceae on lateritic plateaus, savannahs on southern sandy terraces and steppes on dunes and in dry valleys
	Baban Kori	6°58'36,4"E	13°55'47,7"N			
Guidan Roumdji	Karazomé	6°51'21,4"	13°39'31,2"	449 ± 104	Sandy soils poor in organic matter due to water and wind erosion, lack of fallow and over-clearing (PDC, 2013) and Hydromorphic soils	Herbaceous, shrubby and woody steppe on sandy soils dominated by combrétacées and Fabacées.
	Karo Sofoua	6°37'09,3"	13°37'48,1"			
Madarounfa	Safo	7°07'18,6"	13°24'28,4"	535 ± 93	Hydromorphic soils found in the Goulbi Maradi valley and ferruginous soils found in the rest of the area.	Shrubby and wooded savannahs and Combretaceae thickets (Mahamane *et al.*, 2007).
	Bargaja	7°05'48,8"	13°17'35,8"			

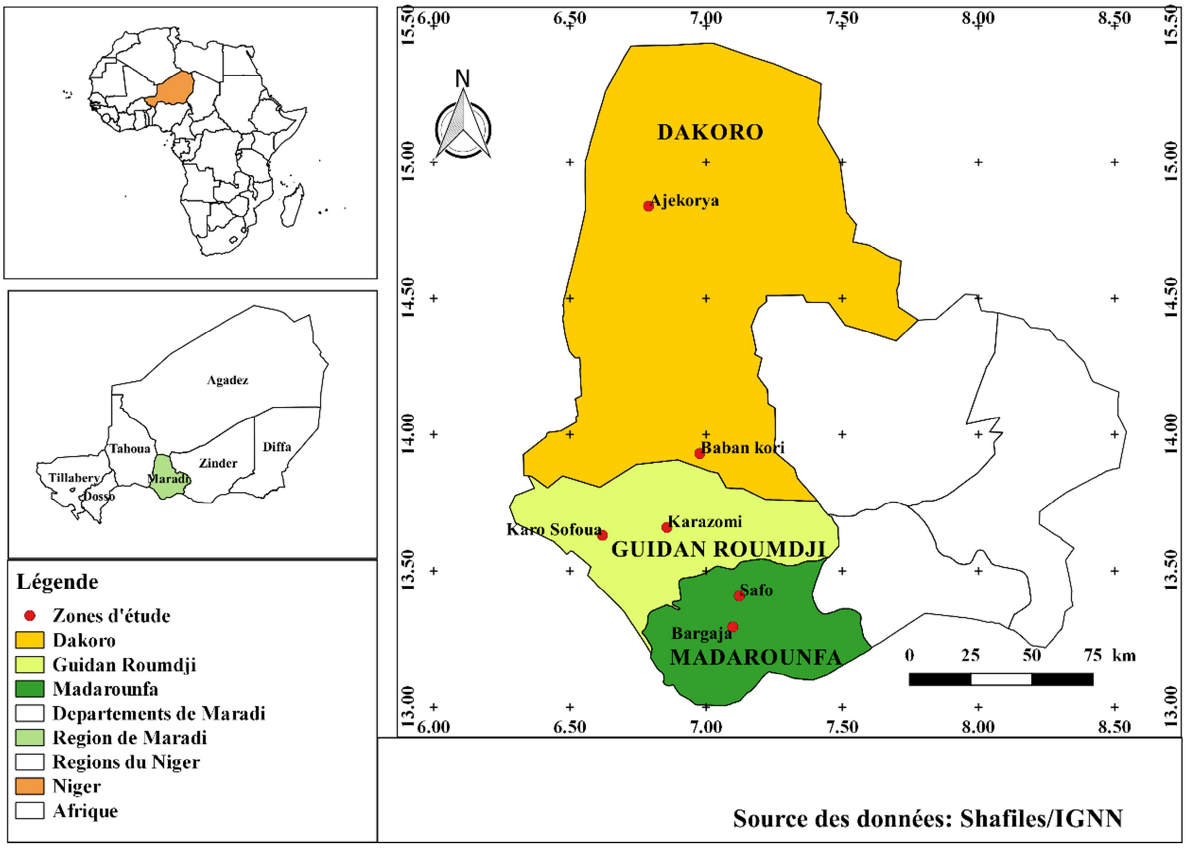

Fig. 1. Location of study sites.

Sample

In each of the six villages, four radial transects were run from the village that constitutes the center. The aim was to follow the four geographical directions in order to cross the heterogeneity of the area. This type of sampling is widely used in agrosystems in many publications (Moussa *et al.*, 2015; Larwanou *et al.*, Felix *et al.*, 2019; Abasse *et al.*, 2021). At 500 m from the village, the first plot is installed on each transect. Following each of these, 50 m x 50 m square plots were installed with an equidistance of 200 m each (Thombiano *et al.*, 2015). A total of 187 plots divided into seventy (70) plots in the North (Dakoro), sixty-six (66) in the center (Guidan Roumdji) and fifty-one (51) in the South (Madarounfa) were installed.

Data collection

Within each plot, an exhaustive count of all species encountered was made. For each adult individual, with a diameter at 1.30 m from the ground greater than 2cm, the following dendrometric parameters were measured: the total height of the trees using a graduated pole, the circumference of the trunk at 1.30 m from the ground and the two diameters of the crown in the two perpendicular directions. Individuals with a diameter less than or equal to 2cm were considered as rejects and their number per species was counted in each plot.

Data processing

The collected data were entered into the Excel spreadsheet. Floristic richness, specific diversity indices and diameter and height structure were determined as follows:

Diversity indices

Shannon's diversity indices (H) and Pielou's Equitability (E) were calculated to assess plant diversity, the way species are distributed. The following formulas are used:

Shannon-Weaver diversity index (H)

$H=-\sum_{i=1}^{S} pi \, log2 \, pi$ (1)

With S being the total number of species and pi being the relative frequency of species

Diversity is low when H is less than 3 bits; medium if H is between 3 and 4 bits; high when H is greater than or equal to 4 bits (Frontier and Piochod-Viale, 1995).

The Pielou fairness was calculated from the formula (E)

$E=\frac{H}{Hmax}$ (2)

with H: Shannon diversity index

If E [0 - 0.6] then the Pielou equitability is low (dominance phenomenon existing in the community).

If E [0.7 - 0.8] then Pielou's equitability is medium.

If E [0.8 - 1] then Pielou equitability is high (lack of dominance in the community) (Garba *et al*, 2017)

Maximum diversity index (Hmax)

$Hmax=\log_2 S$ with S Total number of species

Dendrometric parameters

Average Lorey height (HL)

The average Lorey height expressed in (m) is the average height of individuals weighted to their basal area. It is calculated by the following formula:

$HL=\frac{\sum_{i=1}^{n} gi*hi}{\sum_{i=1}^{n} gi}$ with $gi=\frac{\pi}{4}\, di^2$ (Rondeux, 1999) (3)

Basal area

The global basal area (G) expressed in (m^2/ha) and given by the formula:

$G=\frac{\pi}{40000xS}\sum_{i=1}^{n} di^2$ (Bonou *et al.*, 2009) (4)

S=Plot area in hectare and di=diameter of stem i (cm).

Density

Density (N/ha) is a simple index of the average competition in the stand. It is defined as the number of individuals considered in the inventory per unit area per hectare (Traoré and Toé, 2004). It is a biological index that provides information on the abundance of individuals of a species in a given site and is obtained by the formula:

$N=\frac{n}{S}x10000$ (5)

where S=Plot area (ha) and n is the number of trees in the plot

Cover

The cover corresponds to the surface of the ground that would be covered by the projection of the aerial parts of the individuals of the species (Gounot, 1969). It is expressed as a percentage (%) and is calculated by the formula:

$R=\frac{r}{s}$ avec $r=\frac{\pi}{4}\sum_{i=1}^{n} di^2$ (6)

With r=coverage of all individuals in the plot (m^2); di=mean crown diameter of individual i (m); s=plot area (m^2).

Diameter and height structure

The theoretical three-parameter Weibull distribution (of position a, scale or size b and shape c) was used to characterize the structure of the diameter classes of the dominant species, because of its flexibility and the great variability in the shape of the distribution it produces. Its probability density function f(x) has the following formula:

$$f(x)=\frac{c}{b}\left(\frac{x-a}{b}\right)^{c-1} exp\left[-\left(\frac{x-a}{b}\right)^{c}\right] \quad (7)$$

x is the diameter or height of the trees and f(x) its probability density value; a is the smallest diameter value; b is related to the central value of the diameter class structure. Finally, the parameter c is related to the structure of the observed distribution and according to its central value leads the Weibull distribution to take several forms. A test of fit of the observed distribution to the theoretical Weibull distribution (Rondeux, 1999) was performed using Minitab 16 software. When $c<1$, the distribution is inverted "J"; when $c=1$ the distribution is an exponential function of increasing. For $c>1$ the distribution is a unimodal function. If $1<c<3.6$ the distribution is positive skewed, when $c=3.6$ the distribution is approximately normal, and when $c>3.6$ the distribution is negative skewed.

Results and discussion

Floristic composition

Table 2 presents the woody species recorded in the three zones of Dakoro, Guidan Roumdji and Madarounfa. A total of 26 woody species were recorded in 16 families. It appears from this study that among the species identified, Piliostigma reticulatum (73%) followed by *Faidherbia albida* and *Azadirachta indica* with each (4.69%) are the most dominant in Guidan Roumdji; *Faidherbia albida* (55.64%) followed by species such as *Balanites aegyptiaca* (15.04%) and *Piliostigma reticulatum* (6.77%) in Dakoro. As for the Madarounfa site, the species Hyphaene thebaica (28.57%) followed by *Piliostigma reticulatum* (27.82%) and *Faidherbia albida* (6.02%) are the most represented. The results of this study showed that the floristic richness is dominated by Fabaceae on all the study sites with a decrease in the number of species from north to south. These results are similar to those of many authors working on woody vegetation in the bioclimate of the same area (Garba *et al.,* 2017). Indeed, Baggnian (2014) working in the same area obtained similar results which is 26 species distributed in 15 families. Zounon *et al. (*2015) and Moussa *et al. (*2015) working in south-central Niger obtained respectively 24 species distributed in 14 families in the northern Sudanese zone and 16 species distributed in 9 families in the *F.albida* park in the north and 20 species in 17 families in the *Prosofice africana* park in the south.

Ali *et al.* (2017) also found in the same area but on the sites of Goulbi Maradi 51 species divided into 22 families of which the most representative are the Mimosaceae and on the site of Goulbi Kaba 42 species divided into 19 families dominated by the Mimosaceae. This difference in the number of species is due to the fact that the work of these researchers was carried out in a species-specific forest park, whereas our study was carried out in the agroforestry park. In addition, this increase in the number of species could be due to the specific climatic conditions favorable to the development of various species in the Goulbi Kaba and Goulbi Maradi valley.

Morou (2010) states that in natural formations, the floristic richness is higher in the Sudano-Sahelian zone and Mahamane (2009) states that in Niger the specific richness is higher in the bioclimates of the southern part of the country which are the most watered. From all these studies we note the dominance of Mimosaceae, Combretaceae and Caesalpiniaceae species and a decrease in species from north to south.

The dominance of these species may be due to their strong regeneration capacities (Akpo and Grouzi, 1996), the advantages they provide to farmers (Larwanou, 2005) and the fact that they are favorable to the pedoclimatic conditions of the zone (Ambouta *et al.*, 1998, Karoune, 2016). This is because the dominant species are among the preferred and highly palatable fodder trees (Bonkoungou *et al.*, 1993) that people use to feed their animals, especially during the difficult fodder seasons.

Table 2. Distribution of woody species by agroecological zone.

Spicies	Famillies	Dakoro	Guidan Roumdji	Madarounfa	Global
Piliostigma reticulatum	Fabaceae	6,77	73,44	27,82	35,53
Faidherbia albida	Fabaceae	55,64	4,69	6,02	22,34
Hyphaene thebaica	Arecaceae	0,75	1,56	28,57	10,41
Balanites aegyptiaca	Zygophyllaceae	15,04	-	3,76	6,35
Azadirachta indica	Meliaceae	-	4,69	9,02	4,57
Adansonia digitata	Malvaceae	-	0,78	9,02	3,30
Combretum glutinosum	Combretaceae	4,51	1,56	-	2,03
Sclerocarya birrea	Anacardiaceae	2,26	1,56	2,26	2,03
Acacia nilotica	Fabaceae	4,51	-	0,75	1,78
Diospyros mespiliformis	Ebenaceae	-	2,34	2,26	1,52
Lannea fruticosa	Anacardiaceae	-	3,91	0,75	1,52
Ziziphus mauritiana	Rhamnaceae	4,51	-	-	1,52
Albizia chevalieri	Fabaceae	-	0,78	3,01	1,27
Acacia laeta	Fabaceae	3,01	-	-	1,02
Annona senegalensis	Fabaceae	-	0,78	1,50	0,76
Guiera senegalensis	Combretaceae	1,50	0,78	-	0,76
Bombax castatum	Malvaceae	-	-	1,50	0,51
Maerua crassifolia	Capparaceae	0,75	0,78	-	0,51

Spicies	Famillies	Dakoro	Guidan Roumdji	Madarounfa	Global
Tamarindus indica	Fabaceae	-	-	1,50	0,51
Bauhinia rufescens	Fabaceae	0,75	-	-	0,25
Detarium microcapum	Fabaceae	-	0,78	-	0,25
Entada africana	Fabaceae	-	-	0,75	0,25
Ficus thonningii	Moraceae	-	0,78	-	0,25
Prosopis africaina	Fabaceae	-	0,78	-	0,25
Stereospernum kunthianum	Bignoniaceae	-	-	0,75	0,25
Vitex doniana	Lamiaceae	-	-	0,75	0,25
Total		100	100	100	100

Species diversity

The diversity indices for all the sites are presented in Table 3. The Shannon diversity index is average at Madarounfa with 3.01 bites, but low at Dakoro and Guidan Roumdji with values of 2.27 bites and 1.76 bites respectively. The Pielou equitability index is average in all sites and varies from 0.44 to 0.73. The highest value is obtained at Madarounfa (0.73) and the lowest at Guidan Roumdji (0.44). As for the maximum diversity index, it is highest in Madarounfa (4.08) followed by Guidan Roumdji (4) but is low in Dakoro (3.58). It is noted that the Madarounfa zone has the highest specific diversity indices of all the zones studied. These results are similar to those of Larwanou *et al.* (2012) and Zounon *et al.* (2019). Indeed, Larwanou *et al.* (2012) found a diversity of 2.801bites in the pastoral zone and 3.809bites in the agropastoral and agricultural zone following a rainfall gradient pastoral-agricultural zone. Zounon *et al.* (2019) found an average plant diversity of 3.4 bits in the Sahelo-Sudanian zone and 2.61 bits in the strict Sahelian zone and 2.55 bits in the North Sudanian zone. This difference in plant diversity between zones is also dependent on the population density and edapho-climatic conditions of the region (Larwanou *et al.*, 2012, Moussa *et al.*, 2015). The low diversity values in the north are due on the one hand to the decrease in rainfall in this locality (Moussa *et al.*, 2015) and on the other hand by anthropic activities notably the abusive cutting of old individuals in these areas for their needs in service wood, timber and service wood (MME, 2006). On the other hand, the high value of the Shannon diversity index in the Madarounfa zone is due to the practice of assisted natural regeneration advocated by the Projects and NGOs whose protection and monitoring is ensured by the village monitoring committees in (Baggnian, 2014). Pielou's equitability index is average at all study sites. These values range from 0.44 to 0.73. This would be explained by the fact of average dominance between species. These results corroborate those of Moussa *et al.* (2015) who found a Pielou equitability index of 0.57 in the *F. albida* park and 0.56 in the P. africana park. The low values of this index can be explained by the fact that a minority of species, notably *F. albida*, *P. africana*, *C. glutinosum* and *P. reticulatum*, tend to dominate the two woody stands in the parks to the detriment of the other species.

Table 3. Species diversity at the three sites.

Areas	S	H	Hmax	E
Dakoro	12	2,27	3,58	0,63
Guidan Roumdji	16	1,76	4	0,44
Madarounfa	17	3,01	4,08	0,73
Probability		0,198	0,00	0,125

S: species richness; H: Shannon diversity index; Hmax: maximum diversity; E: Pielou equitability

Dendrometric parameters

The following Table 4 presents the means of the dendrometric parameters evaluated by zone. Mean diameter, mean regeneration density, mean height and mean basal area are significantly different between the three zones (P ≤ 0.05). However, this difference was not significant between Dakoro and Guidan Roumdji for diameter and basal area and between Dakoro and Madarounfa for mean height and regeneration density. Lorey density per foot and mean height were not significantly different between zones (P ≥ 0.05). Nevertheless, Madarounfa and Guidan Roumdji areas had the highest values for mean density (10.43 ± 2 ind/ha) and mean Lorey height (7.76 ± 3.59 m), respectively. Analysis of the dendrometric parameters of the dominant species shows a significant difference between all sites for the species *Faidherbia albida*. Thus, the highest values are obtained in the Madarounfa zone. However, for the species *Piliostigma reticulatum*, only the average height and the density of regeneration are significantly different between the zones. This could be due to the favorable soil and climatic conditions for the development of woody species. Also, Traoré (2012) reported that variations in juvenile density could be related to the complex interaction between factors involving species characteristics, soil types, as well as the ability of the species to dispose of stumpy offspring.

Table 4. Dendrometric parameters by area.

Dendrometric parameters	Dakoro	Guidan Roumdji	Madarounfa	Probability
Density (ind/ha)	7,6±1,6a	7,7±1,7a	10,43±2a	0,9
Diameter (cm)	29,1±14,2b	26±14,4b	40,5±32a	0,0000
Regeneration density (rejects/ha)	747,3±64,8b	2135,8±177,5a	1017,6±63,8b	0,0000
Average height (m)	6,3±1,8a	5,6±3b	6,3±2,4a	0,03
Average height of Lorey	5,65±1,39 a	7,76±3,59 a	6,31±2,33 a	0,106
Basal area (m^2/Ha)	0,23b	0,19b	0,59a	0,0000
Faidherbia albida				
Density tree/ha	4,23±4a	0,36±0,34a	0,63±0,66a	0,09
Average diameter incm	30,52±16,08b	28,98±10,51b	80,61±39,8a	0,0001
Average height	6,16±1,85b	9,3±2,96a	11,03±1,69a	0,0001
Height of Lorey	8,36±1,85b	9,68±2,96a	11,72±1,69a	0,0001
Density of regeneration (Feet/ha)	23±9,5b	39,3±11,1b	70,6±31,5a	0,0001
Piliostigma reticulatum				
Density tree/ha	0,51±0,28a	5,7±0,12a	2,9±1,6a	0,07
Average diameter incm	20,84±9,1a	23,27±10,81a	25,77±12,19a	0,367
Average height	6,61±2,27a	4,81±1,67b	4,71±1,32	0,006
Height of Lorey	5,35±1,06a	5,88±1,67a	5,46±1,32a	0,944
Density of regeneration (Feet/ha)	19,5±36,9c	555,8a±138,7	181,3b±79,7	0,001

Diameter class structure of dominant species by zone

Analysis of the diameter class structures shows that the majority of the diameter class structures of *Piliostigma reticulatum* and *Faidherbia albida* have a "bell-shaped" appearance at all three sites with shape parameter c values greater than 3.6 (Fig. 2).

This diameter structure of the stand shows an asymmetrical left-hand distribution, characteristic of monospecific stands with a predominance of old individuals. Thus, in Guidan Roumdji, we note the absence of individuals in the 20 to 25cm diameter class for *F. albida* and between 30 and 35cm for *P. reticulatum* in Dakoro.

These results could be due, on the one hand, to the strong anthropic pressure exerted on adult woody species and, on the other hand, to the dominance of young individuals resulting from assisted natural regeneration in these zones. Several authors have reported that the regreening of the study area is due to the contribution of the population through the practice of assisted regeneration (Larwanou and Saadou, 2011; Baggnian, 2014; Moussa *et al.*, 2015). The number of individuals per hectare is low almost in all sites and progressively decreases from Madarounfa to Dakoro. This decrease in densities is linked according to several authors to anthropogenic action, the impact of overgrazing by animals and episodes of climate change (Larwanou *et al.*, 2005, Gonzalez *et al.*, 2012; Bakhoum *et al.*, 2012; Ouango *et al.*, 2015).

Height class structure of the two dominant species by area

The structure in height classes for the stands of *P. reticulatum* and *F. albida* shows a bell shape in the majority of the sites; the shape parameters c between 1 and 3.6 is synonymous with a straight asymmetrical distribution, characteristic of monospecific stands with a predominance of young individuals (Fig. 3). In the Guidan Roumdji area, we note the absence of individuals in the height class between 8 and 10 m for the two dominant species.

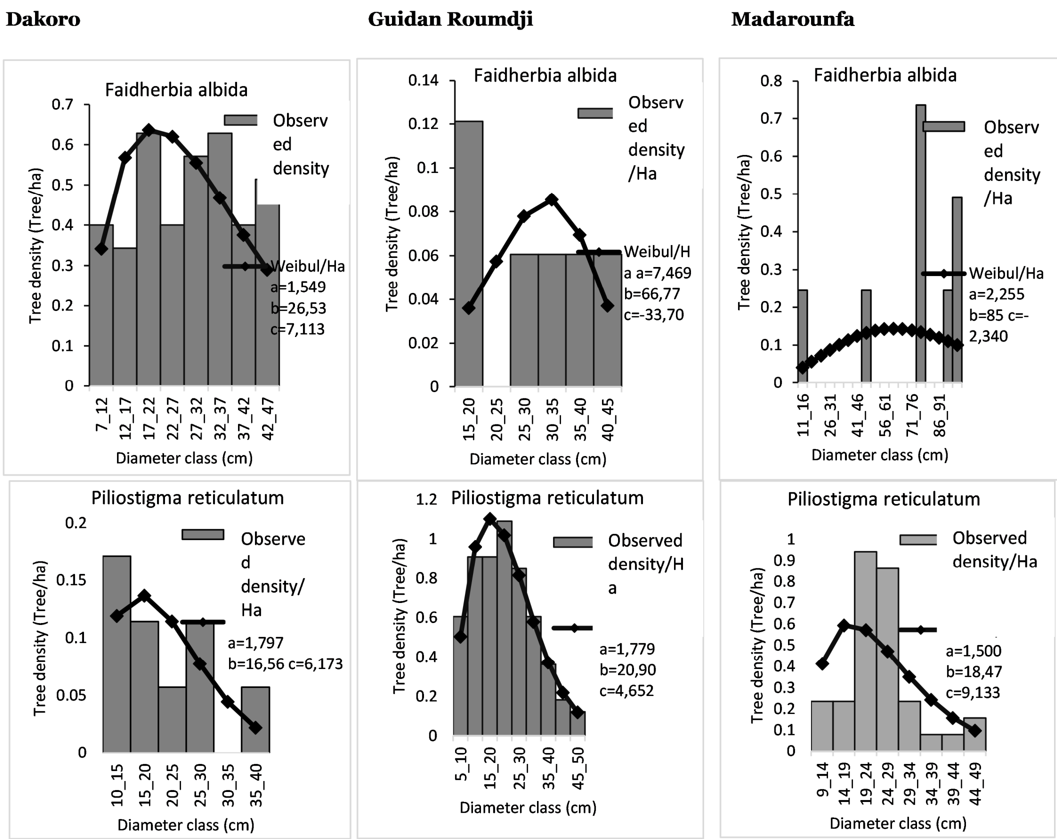

Fig 2. Diameter class structure of the two dominant species by area.

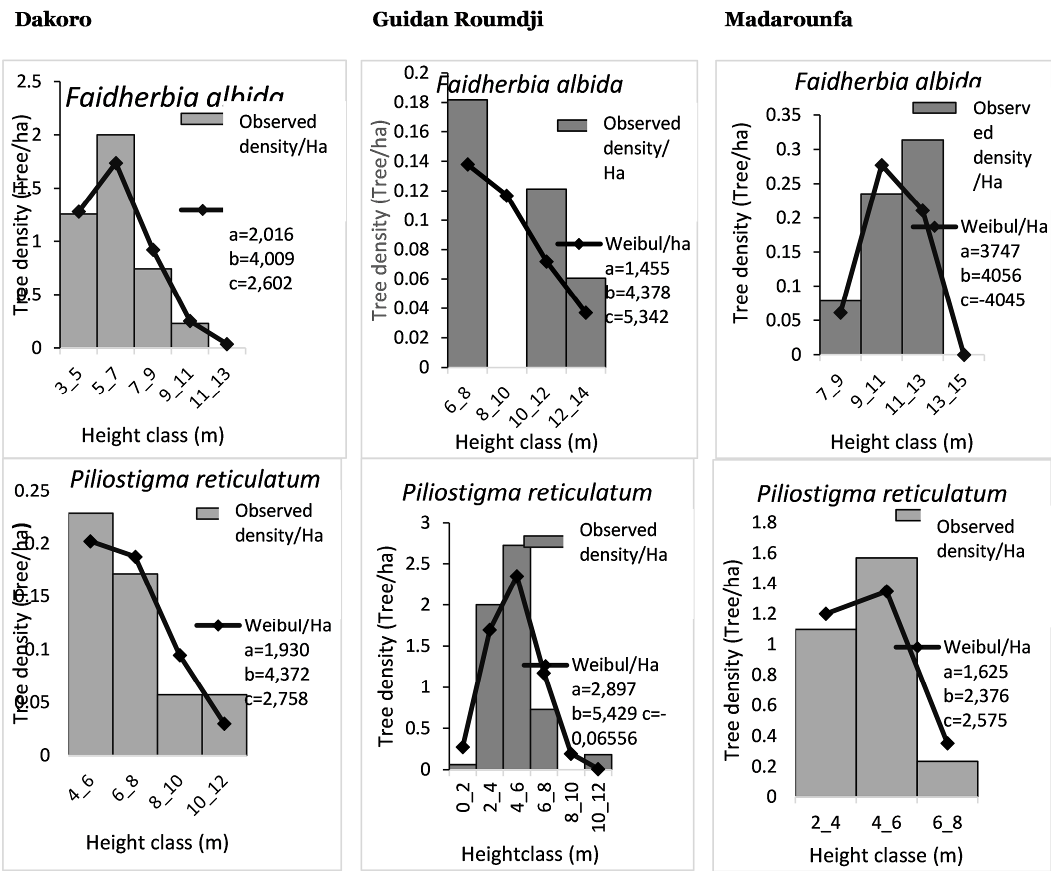

Fig. 3. Height class structure of the two dominant species by area.

Conclusion

This study revealed that floristic composition and species diversity decrease along the north-south agroecological gradient in the Maradi region. Thus, the Madarounfa and Guidan Roumdji zones are more abundant in woody species than the Dakoro zone. The most represented families are Fabaceae at all three sites. The most dominant woody species were Piliostigma reticulatum and Faidherbia albida. These woody species are sources of fodder for animals in this zone, especially during the lean season. It appears from this study that the highest dendrometric parameters are in the Madarounfa zone followed by Guidan Roumdji and Dakoro. The diameter and height structures show a "bell-shaped" structure of the woody stand in each agroecological zone. This structure is characterized by signs of disturbance due to the effect of anthropogenic pressure on natural resources. Although this vegetation is threatened, we note an effort of the farmers in the reconstitution of this vegetation through the practice of the assisted natural regeneration in the fields. The maintenance of the young shoots could allow an improvement of the fertility of the agricultural soils and an increase in the fodder potential of the ligneous plants of this zone.

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